U.S. Department
of Transportation
**National Highway
Traffic Safety
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DOT HS 808 513

May 1996

interim Report

IVHS Countermeasures for Rear-End Collisions

Task 2-Functional Goals

Technical Report Documentation Page

1. Report No. DOT HS 808 513	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Task 2 Interim Report: Functional Goals		5. Report Dote May 20, 1996
		6. Performing Organization Code
7. Author's) Terry Wilson		8. Performing Organization Report No
9. Performing Organization Name and Address Frontier Engineering Inc., Advanced Programs Division 7655 E. Redfield Rd., Suite 10 Scottsdale, AZ 85260		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTNH22-93-C-07326
12. Sponsoring Agency Name and Address National &g&way Traffic Safety Administration Office of Crash Avoidance Research 400 Seventh St., S.W. Washington, DC 20590		13. Type of Report and Period Covered Interim Report 2/25/94 - 5/20/96
		14. Sponsoring Agency Code
15. Supplementary Notes Not applicable		
16. Abstract See attached		
17. Key Words Crash Avoidance, Rear-End Collision, Radar, Headway Maintenance, Crash Analysis, Performance Specifications	18. Distribution Statement	

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 43	22. Price

Form DOT F 1700.7 (8-72)

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ABSTRACT FOR THE TASK 2 REPORT

The attached report is from the NHTSA sponsored program, "IVHS Countermeasures for Rear-End Collisions," contract #DTNH22-93-C-07326. This program's primary objective is the development of practical performance guidelines or specifications for rear-end collision avoidance systems. The program consists of three Phases: Phase one: "Laying the Foundation" (Tasks 1-4), 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 vehicles only and emphasizes autonomous in-vehicle-based equipment (as opposed to cooperative infrastructure-based equipment.)

The results and conclusion presented in this interim report are preliminary in nature. The Task 2 report "Functional Goals" presents the functional goals developed for three basic types of rear-end collision avoidance and related systems (Driver Warning System (DWS), Intelligent Cruise Control (ICC) System, Automatic Control System (ACS)). In addition, the report presents the dynamic situations relevant to the rear-end crash problem. These dynamic situations allow the events leading to accidents, and accidents themselves, to be subdivided into smaller groups that can be addressed individually. To establish the functional goals, a taxonomy of collision subsets and crash-related events that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash was developed. The functional goals established for each of the system types is based on this taxonomy. The report also established the terms and definitions as they relate to this program. This is done to provide background into the rear-end collision avoidance problem and to standardize on definitions and terminology.

The results presented in this report are based on a limited mount of work carried out with limited interaction with the academic, research, and industry communities. Any conclusions drawn from the results presented must bear this in mind.

Phase two 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(s) . Phase two will finish in mid June 1996.

Phase three goals include the building and use 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 three will finish in early 1998.

Work continues through Phase two and three to add to, and to refine, the preliminary performance guidelines or specifications presented in the Task 4 report.

Arthur Carter, COTR

EXECUTIVE SUMMARY / ABSTRACT

Task 2

The overall purpose of this project is to develop practicable performance specifications or guidelines for rear-end collision avoidance systems.

The first phase 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 the first three tasks were to develop the background needed to write the preliminary performance guidelines.

In Task 2 Functional goals were developed. A functional goal is defined as any changes to the pre-crash and crash situation that would help to eliminate or mitigate the severity of collisions and, specifically for this report, modifications or changes to the driver's vehicle that enhance the driver's performance. To establish the functional goals, a taxonomy of collision subsets and crash-related events that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash was developed for each of the three basic types of rear-end collision avoidance and related systems (Driver Warning System (DWS), Intelligent Cruise Control (ICC) System, Automatic Control System (ACS)). The functional goals established for each of the system types is based on this taxonomy. In addition, the dynamic situations relevant to the rear-end crash problem were developed. These dynamic situations allow the events leading to accidents, and accidents themselves, to be subdivided into smaller groups that can be addressed individually. In addition terms and definitions were established as they relate to this program. This is done to provide background into the rear-end collision avoidance problem and to standardize on definitions and terminology.

The report findings:

1. Further development and definition of the Dynamic Situations, i.e. the motion of the two vehicles with respect ot each other prior to either driver recognizing a potentially dangerous situation, that relate to rear-end collisions.
2. Development of a Taxonomy: Dynamic Situations, Environmental Conditions, Roadway

Characteristics, Vehicle Characteristics, Driver Characteristics, and System Characteristics.

3. Listing of the Rear-end Collision avoidance countermeasure systems Functional Goals, broken out in three areas:

A. Headway Maintenance Systems - both Manual and Automatic Intelligent Cruise Control (AICC) Systems

B. Driver Warning Systems

C. Automatic Control Systems

These functional goals fall into three basic categories: 1) Modifications or changes to the roadway or infrastructure that enhance driver performance, 2) Modifications to other vehicles located on the roadway that enhance driver performance, and 3) Modifications or changes to the driver's vehicle that enhance th driver's performance.

4. Terms and definitions that relate to the above were formulated.

In summary the functional goals for the Driver Warning System (one of three that appear in the report) are as follows:

> A Driver Warning System must operate on stopped vehicles, detect the presence of vehicle ahead of the subject vehicle, process the sensor measurements regarding the situation, warn the driver when dangerous situation exists and possible suggest avoidance maneuvers.

This report (all volumes) forms the foundation for the work in the later stages of the contract.

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

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SECTION 1
INTRODUCTION

This document contains the functional goals and the Task 2 Interim Report deliverable item 8, for IVHS Countermeasures for Rear-End Collisions, Contract DTNH22-93-C-07326. 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. As part of meeting this objective, functional goals were established as they relate to rear-end collision avoidance systems. In order to develop functional goals, the terms and definitions in Section 1.1 were established as they relate to this program. This is done to provide background into the rear-end collision avoidance problem and to standardize on definitions and 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 types 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 from the vehicle in front. The driver maintains full longitudinal control of the vehicle until a dangerous condition, such as a stationary vehicle on the roadway ahead, is detected. Then the driver is warned. 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 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 Warning 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 (AICC) system.
- A Cooperative Intelligent Cruise Control (CICC) system.

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 and automatically maintains a 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 AICC sensing plus vehicle-to-vehicle communication and on-board computer processing. CICC concepts may also include receiving information from the infrastructure such as roadway speed limits in order to maintain a lawful vehicle speed.

Driver warning 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 drivers of a dangerous situation, while another type would tell the drivers what actions to take.

Automatic control systems are an extension of driver warning 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 should 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 detecting or 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.

1.1.1 Forward Looking Collision Warning

There has been some amount of confusion regarding the "rear-end" terminology. In some instances this term has been associated with collisions that occur when a vehicle is in the process of backing up. The use of "rear-end" throughout this document is used to mean collisions that occur when the front of the vehicle in question impacts the rear end of another vehicle in its forward path. Another common term for the types of systems that perform this collision warning task is Forward Looking Collision Warning (FLCW) This term may be more suited to uniquely describe systems that combat this type of accident problem.

1.1.2 False / Nuisance Alarms

False alarms are denoted as an occurrence of a false positive indication from the system in question due to system noise. Nuisance alarms are generally denoted as an occurrence of a false positive indication from the system in question when little or no crash threat exists. While false alarms are caused by internally generated spurious system noise, nuisance alarms are generated by the system misinterpreting reflected energy from objects that do not constitute a crash threat. Both false and nuisance alarms should be considered objectionable to the user. System misses are denoted as the occurrence of a false negative from the system when a crash threat exists.

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 collisions aids in identifying valid crash countermeasures for each crash situation and system type. Quantifying the different causes aids in tradeoffs of cost and benefit. Analysis of the rear-end collision problem will provide a framework to develop functional goals to be used in evaluate existing systems and the design and evaluation of new systems and, finally, to the establishment of a performance specification for rear-end collision countermeasures systems.

Section 2 defines the dynamic situations of interest. These dynamic situations allow the events leading to accidents as well as accidents themselves to be subdivided into smaller groups which can be addressed on an individual basis.

In order to establish the functional goals, a taxonomy of collision subsets and crash-related events that provide a basis for identifying opportunities for intervention in the sequence of events leading to a crash was developed. The development of the taxonomy is described in Section 3.

Based on the taxonomy, functional goals were established for each of the system types and each of the dynamic situations. Development of the functional goals is described in Section 4.

Section 5 of this report summarizes the Task 2 effort and describes how the results will be used in subsequent tasks of the IVHS Countermeasures for Rear-End Collisions program.

SECTION 2
DYNAMIC SITUATIONS

A dynamic situation refers to the motion of the two vehicles with respect to each other prior to either driver recognizing a potentially dangerous situation. The following paragraphs provide an overview of the dynamic situations to be considered in the development of functional goals. Previous study of the available accident data shows that some dynamic situations occur with such infrequency that they can be ignored, but all known dynamic situations are presented here for completeness. Table 2-l shows a matrix of vehicle velocities and references the accompanying figure that graphically illustrates the dynamic situation.

Table 2-1 Dynamic Situations

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

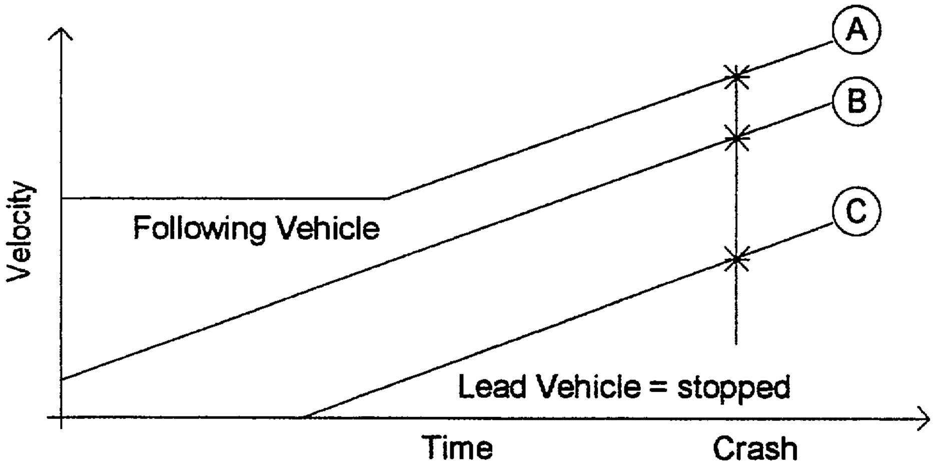

Figure 2-1 Lead Vehicle Stopped, Following Vehicle Accelerating

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

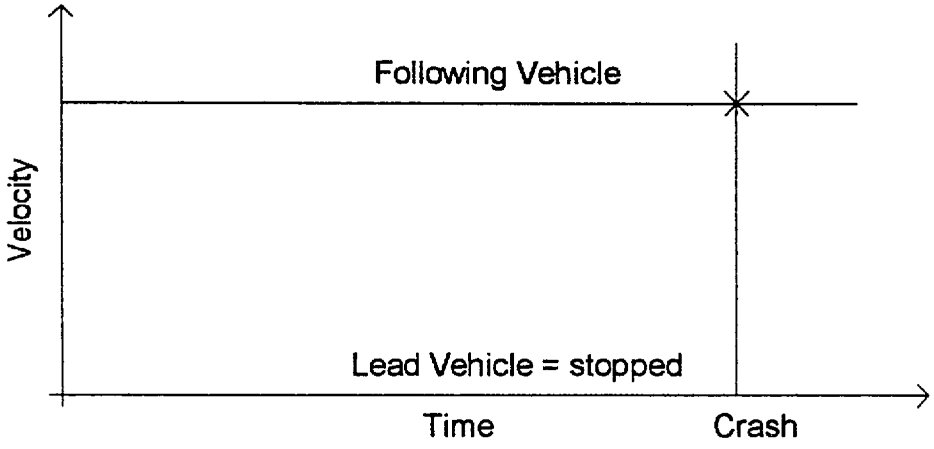

Figure 2-2 Lead Vehicle Stopped, Following Vehicle Constant Velocity

Figure 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. Panic decelerations were included because they could not be separated from normal decelerations in the mass database files.

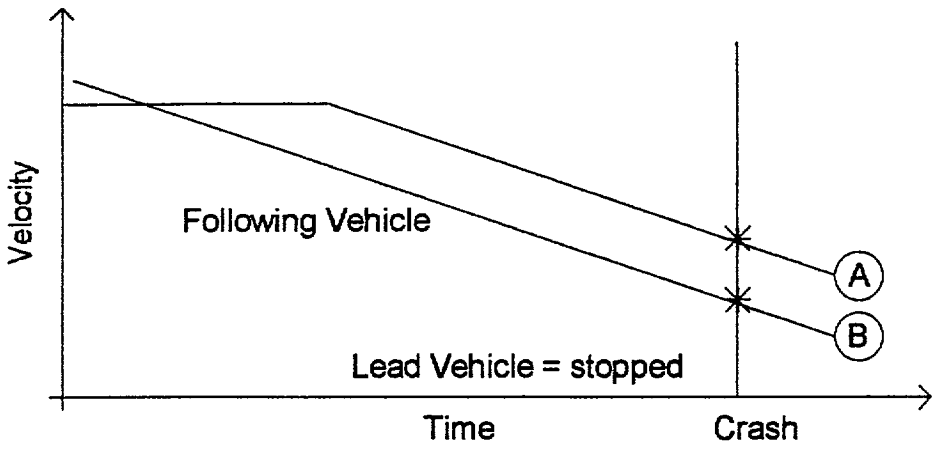

Figure 2-3 Lead Vehicle Stopped, Following Vehicle Decelerating

Figure 2-4 shows the situation when 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.

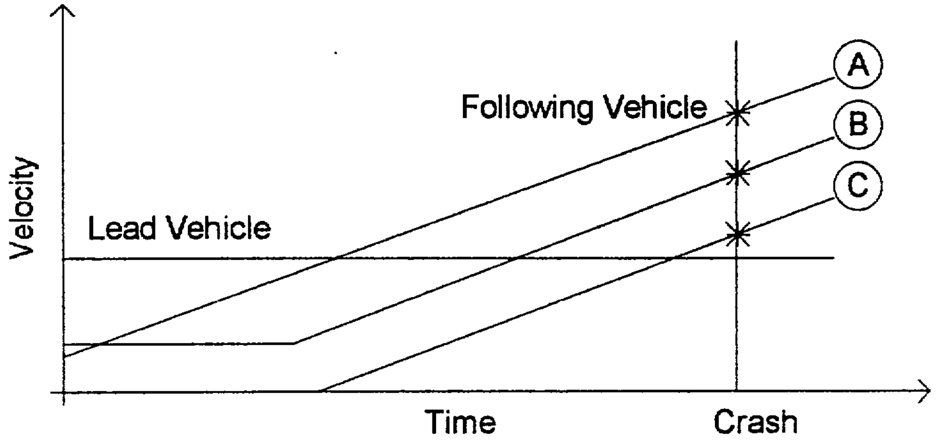

Figure 2-4 Lead Vehicle Constant Velocity, Following Vehicle Accelerating

Figure 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.

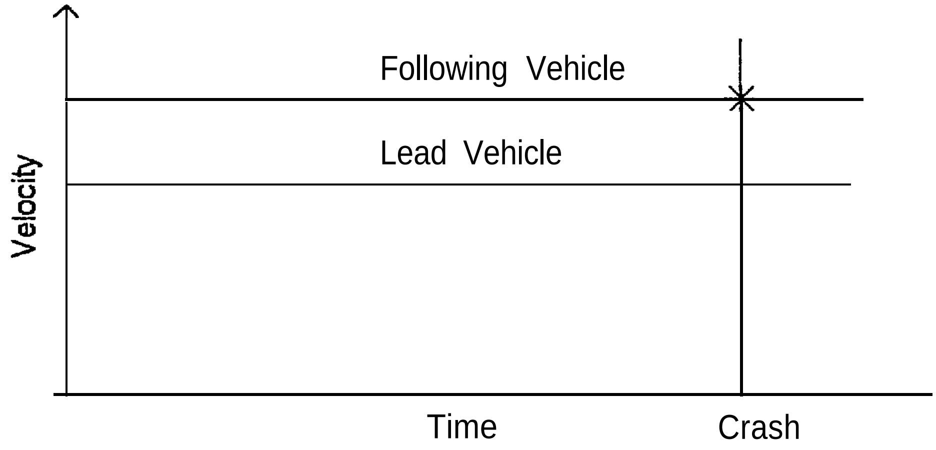

Figure 2-5 Lead Vehicle Constant Velocity, Following Vehicle Constant Velocity

Figure 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. Also included in this dynamic situation are panic decelerations where the striking vehicle's driver becomes aware of a problem and brakes too late to avoid a collision.

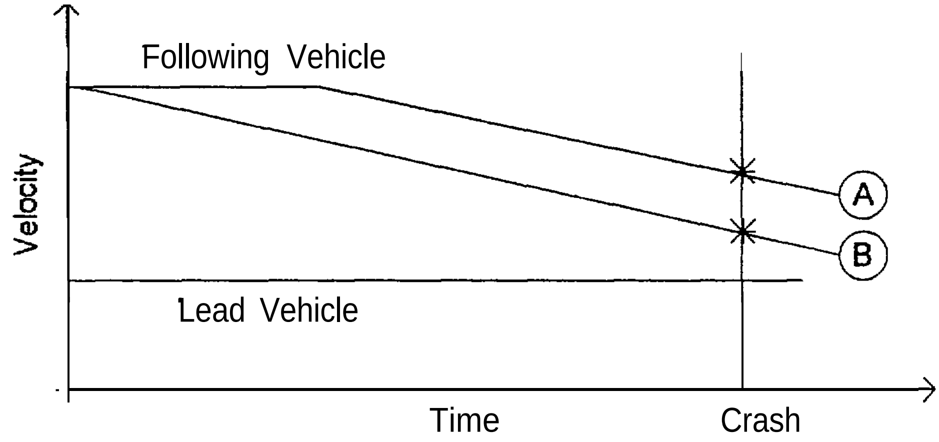

Figure 2-6 Lead Vehicle Constant Velocity, Following Vehicle Decelerating

Figure 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.

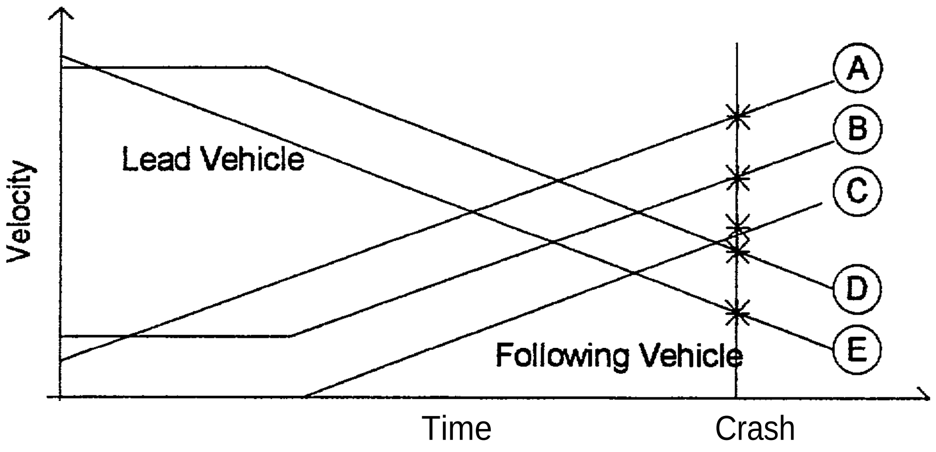

Figure 2-7 Lead Vehicle Decelerating, Following Vehicle Accelerating

Figure 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.

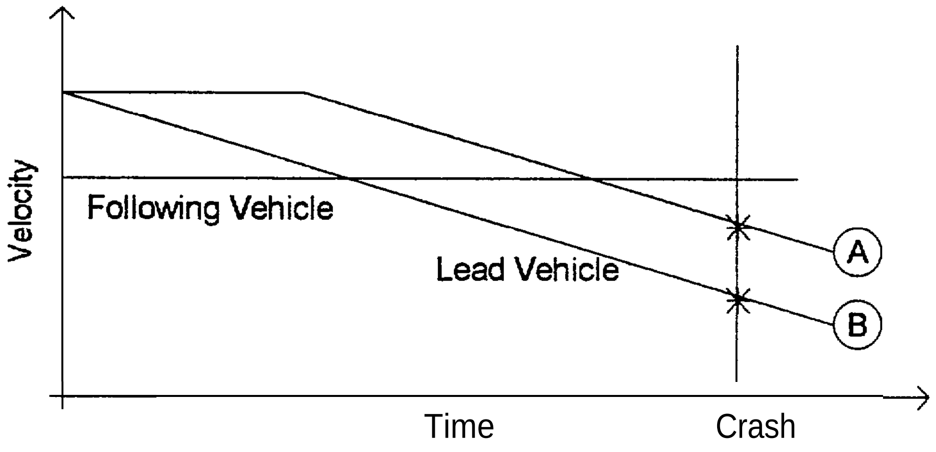

Figure 2-8 Lead Vehicle Decelerating, Following Vehicle Constant Velocity

Figure 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.

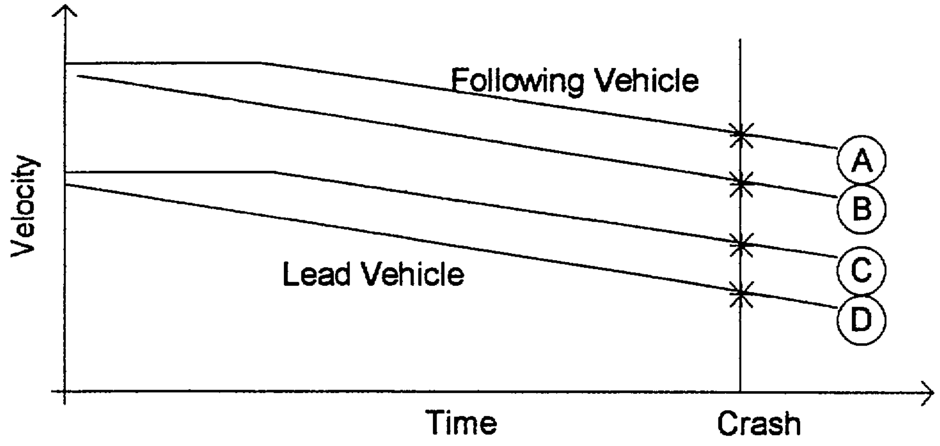

Figure 2-9 Lead Vehicle Decelerating, Following Vehicle Decelerating

Figure 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.

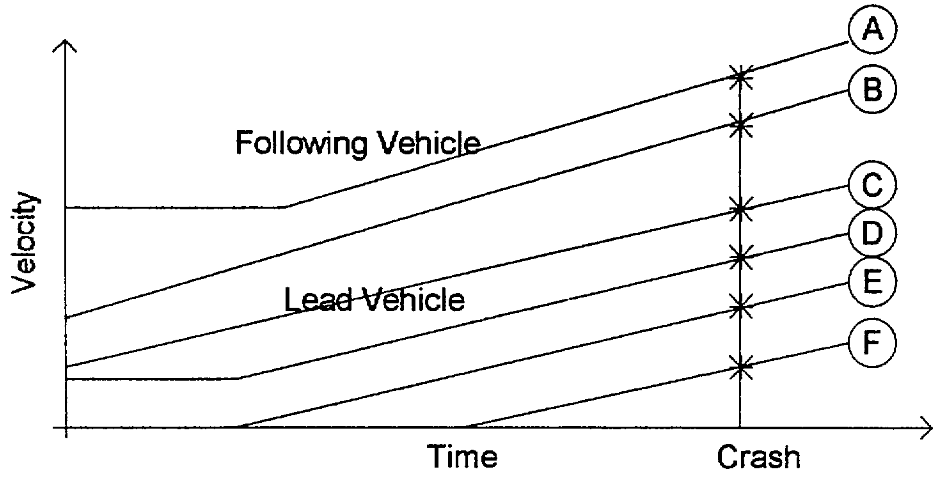

Figure 2-10 Lead Vehicle Accelerating, Following Vehicle Accelerating

Figure 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.

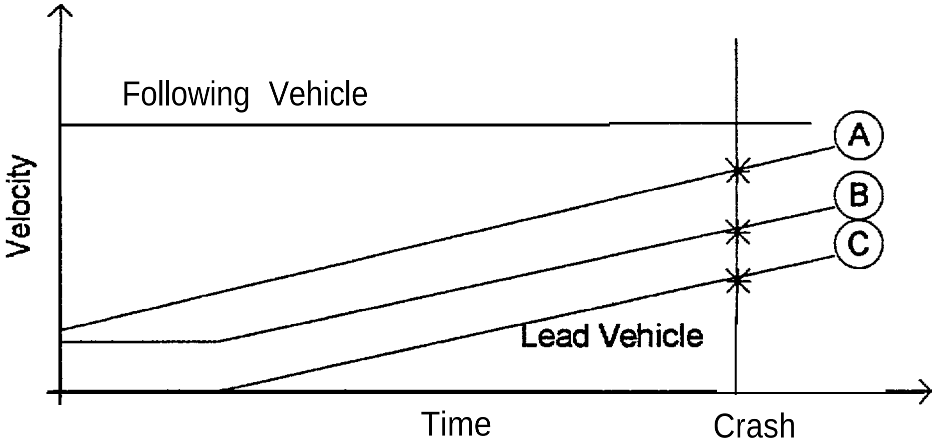

Figure 2-l 1 Lead Vehicle Accelerating, Following Vehicle Constant Velocity

Figure 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.

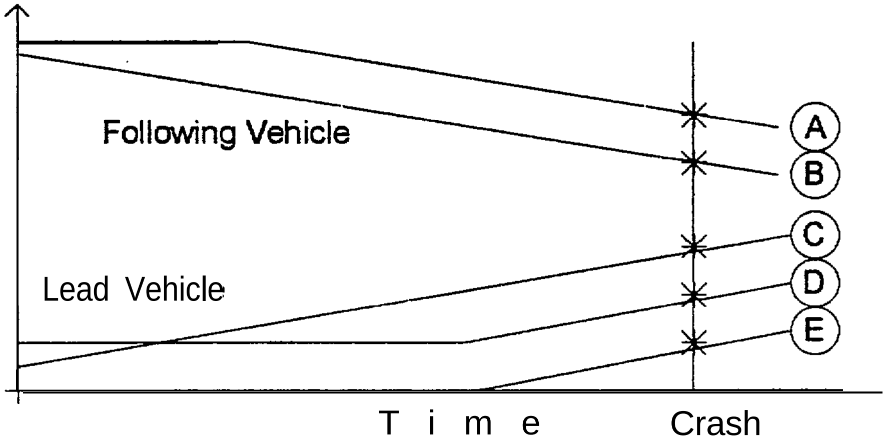

Figure 2- 12 Lead Vehicle Accelerating, Following Vehicle Decelerating

Figure 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.

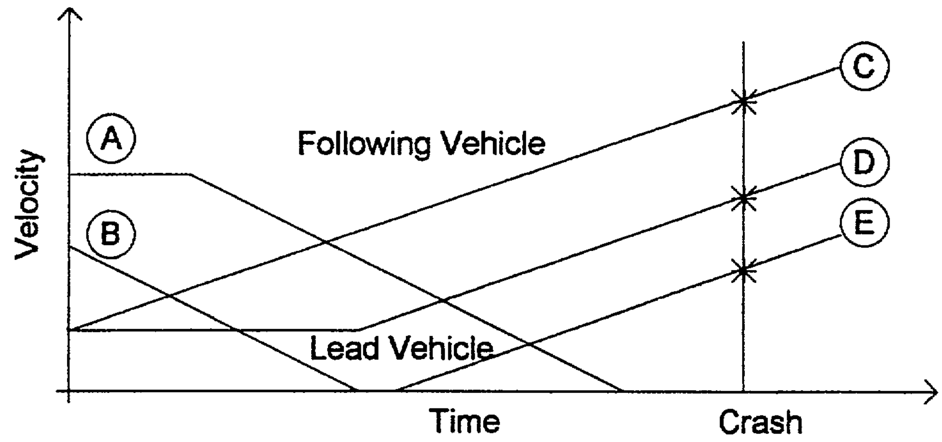

Figure 2-13 Lead Vehicle Decelerating & Stopped, Following Vehicle Accelerating

Figure 2-14 shows the situation when the lead vehicle is decelerating to a stop and the following vehicle is at a constant velocity.

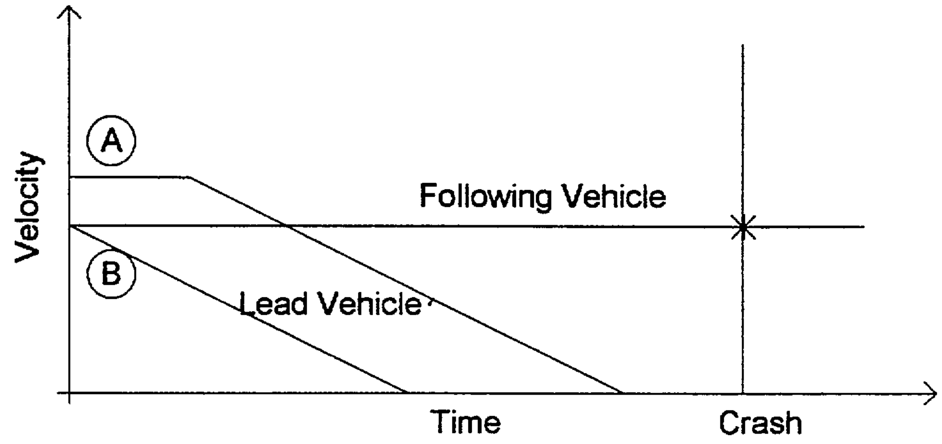

Figure 2-14 Lead Vehicle Decelerating & Stopped, Following Vehicle Constant Velocity

Figure 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.

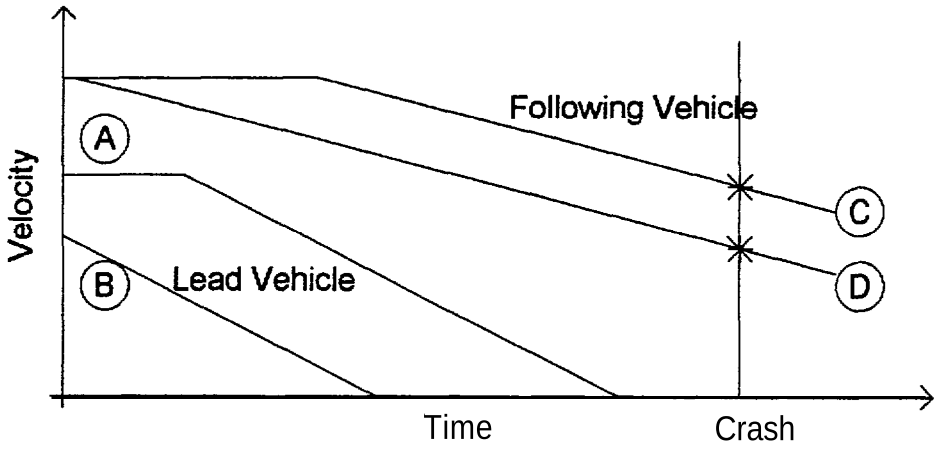

Figure 2-l 5 Lead Vehicle Decelerating & Stopped, Following Vehicle Decelerating

Table 2-2 shows the distribution of rear-end collisions versus dynamic situation for 135 clinical accident case files that were analyzed in the 1992 National Accident Sampling System (NASS) Crashworthiness Data System (CDS). In order to determine the dynamic situation from an accident, the following guidelines were established. A dynamic situation refers to the motion of the two vehicles prior to either driver recognizing a potentially dangerous situation. Consequently, those collisions that involved striking driver that “panic braked” were included in the constant velocity category instead of the decelerating category. A distinction had to be made between lead vehicle stopped and lead vehicle decelerating and stopped. There are no variables in either the NASS CDS or the NASS General Estimates System (GES) that allow an accurate determination between lead vehicle stopped and lead vehicle decelerating and stopped; this needed to be estimated as part of the clinical accident case review. 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 listed as lead vehicle decelerating and stopped. This is because it is believed that a forward looking sensor would have the lead vehicle within view. On the other hand, if the same conditions occurred on a curved roadway it was estimated as lead vehicle stopped because it is believed that a forward looking sensor would not have the lead vehicle in view until the lead vehicle came to a complete stop. Unfortunately it is not possible to make a better estimate of the dynamic situations using the NASS GES because no indication exists that allow separation of lead vehicle decelerating and stopped from lead vehicle stopped. The NASS CDS represents accidents in which one or more vehicles was towed from the scene. As a result the statistics presented in Table 2-2 may not adequately reflect the group of minor rear-end collisions.

Table 2-2 Percent of Rear-End Collisions vs. Dynamic Situation

Lead Vehicle	**Following Vehicle**		
	Accelerating	**Constant Velocity**	**Decelerating**
Stopped	0.54%	23.72%	0.69%
Constant Velocity	0.74%	2.80%	0.0%
Decelerating	0.0%	14.71%	0.0%
Accelerating	0.0%	2.07%	0.0%
Decel & Stopped	0.11%	50.05%	4.57%

In order to make a determination of the dynamic situation the five pre-crash variables were used. These five variables, that are new for the 1992 NASS, give additional insight into the events leading up to the rear-end collision. The pre-crash variables for the 1992 NASS are listed in Table 2-3.

Table 2-3 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

Figure 2-16 shows the breakdown of the five pre-crash variables for striking (following) vehicles from the 1992 NASS CDS. The data shown in Figure 2-I 6 was also verified on an analysis of 59 cases from the 1991 NASS CDS. An analysis of the five pre-crash variables from the 1992 NASS GES was unable to verify the data presented in Figure 2-16 due to inconsistencies in coding the five pre-crash variables between the NASS CDS and GES.

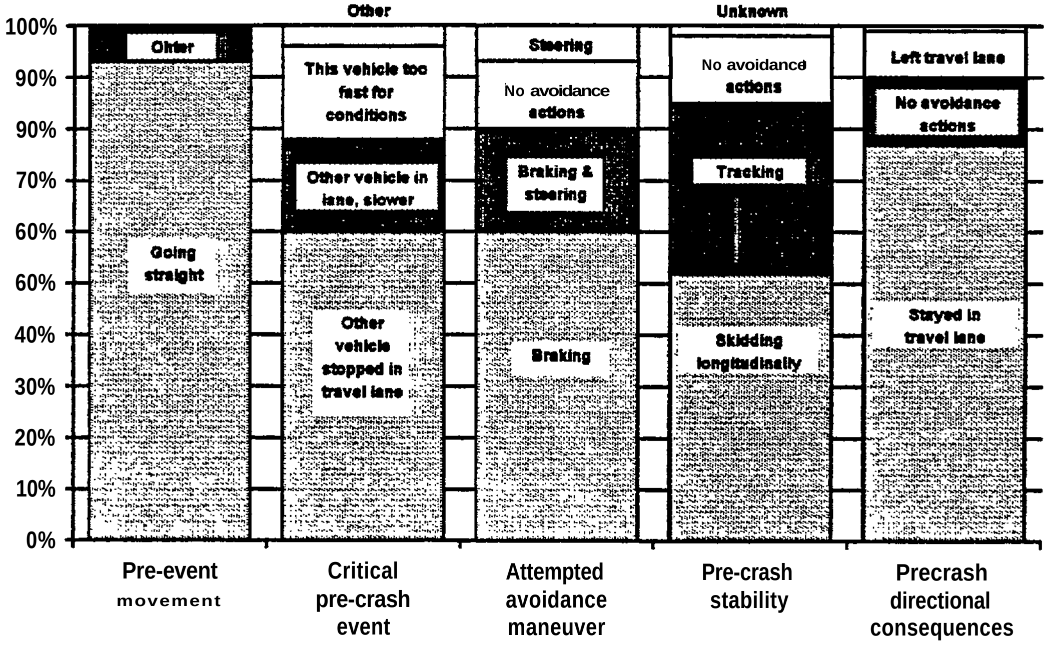

Figure 2-16 Breakdown of the Five Pre-Crash Variables for the Striking Vehicle

Figure 2-17 shows the relationship between the pre-crash variables, dynamic situation, and system type.

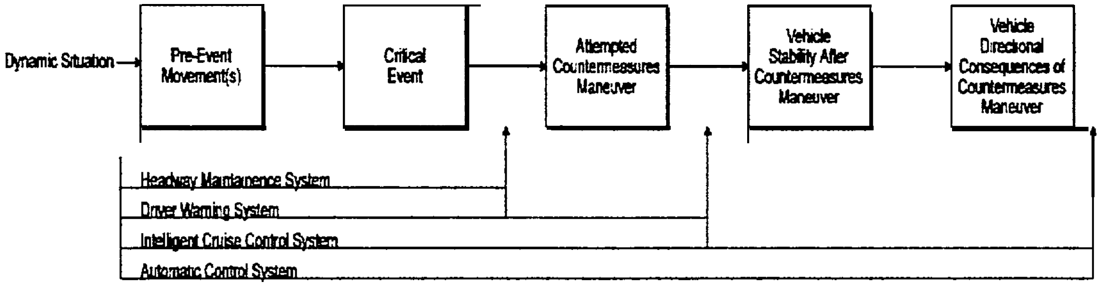

Figure 2- 17 Relationship between System Type, Dynamic Situation and Pre-Crash Variables

SECTION 3
DEVELOPMENT OF THE TAXONOMY

A taxonomy is defined as a system for arranging items into natural, related groups based on some factor common to each. This report has presented five different system types and for each system type fifteen dynamic situations have been identified. Additional information necessary to develop a performance specification was broken down into six primary categories as identified below:

1. Dynamic Situations - These relate the motion of the vehicles prior to the accident.
2. Environmental Conditions - Describe the surrounding environment, excluding roadway characteristics.
3. Roadway Characteristics - Describe attributes specifically associated with roadway features.
4. Vehicle Characteristics - Describe characteristics of both the lead and following vehicles.
5. Driver Characteristics - Describe particular characteristics of the drivers.
6. System Characteristics - Describe particular characteristics of the rear-end collision avoidance system.

These six primary categories are essentially situation modifiers for the different system types and dynamic situations. Additional information on the primary categories is contained in Appendix A. Using dynamic situations as the final division describing the movements of both the lead and following vehicles, a taxonomy matrix was created as shown in Figure 3-l. A functional goal can be established for the conditions represented by each cell in the taxonomy matrix and the six primary categories are modifiers of that functional goal. Because of system design considerations not all dynamic situations are necessarily applicable for each system type, but the entire taxonomy matrix is included for completeness.

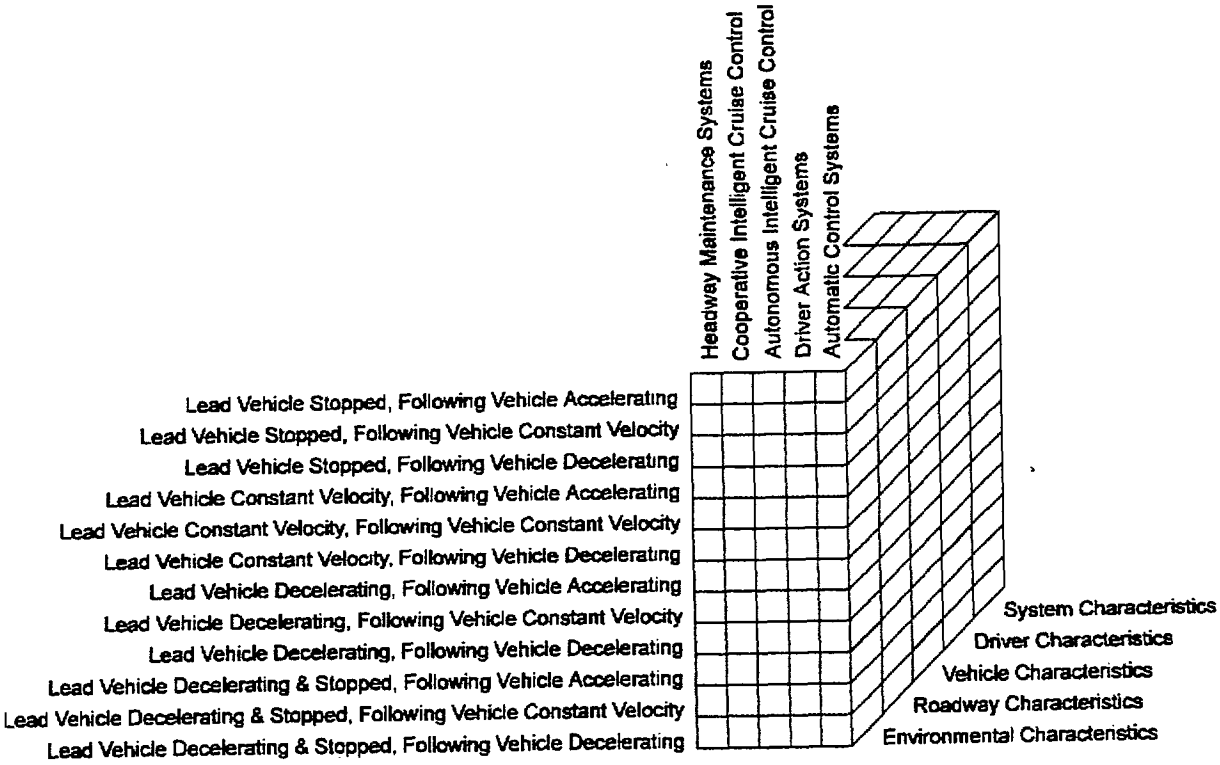

Figure 3-1 Taxonomy Matrix

SECTION 4

FUNCTIONAL GOALS

The primary goal of a collision countermeasures system is to prevent or mitigate the severity of an impending collision. This may involve different intensities of action as time passes in the sequence of events leading to a potential collision. Functional goals are defined as opportunities for intervention, or changes to the situation, that would help to eliminate or mitigate the severity of the impending collisions. Functional goals fall into three basic categories:

1. Modifications or changes to the roadway or infrastructure that enhance driver performance.
2. Modifications to other vehicles located on the roadway that enhance driver performance.
3. Modifications or changes to the driver's vehicle that enhance the driver's performance.

Item one, would be a costly approach. With the millions of miles of roadways in the United States, any modification to the roadway would be expensive and would slow development of rear-end collision avoidance technology. On a smaller scale though, specific areas of roadways, that have a high instance of collisions, could be modified to enhance the performance of those drivers and vehicles that frequent the roadway.

Item two would require a modification be made to every vehicle on the roadway and this modification would need to be in good working order at ail times to be effective. Such modifications might include reflectors on the back of a vehicle to enhance detection or transponders that send a rearward signal.

ltem three works non-cooperatively with other vehicles on the roadway and is the most cost efficient approach. As part of Task 3 nearly eighty companies have been identified as performing work in the longitudinal collision avoidance area. None of these companies currently relies on modifications to the roadway or other vehicles to perform the countermeasures task. As a result, item three will be the main focus of the functional goals presented within this report; however, this does not dismiss items one and two as invalid countermeasures.

There are five countermeasures system types: Headway Maintenance, AICC, CICC, Driver Warning, and Automatic Control. For each of these five system types there are up to fifteen dynamic situations that need to be considered. Because of system design considerations not all dynamic situations are necessarily applicable for each system type. e.g. AICC systems may work properly, in conjunction with driver training, without the need to sense stopped vehicles.

A functional goal is defined as a qualitative description of the data processing algorithms which w-ill drive the processing function whose goal is to eliminate or mitigate the severity of the potential rear-end collision. The functional goals may be the same for each of the three functional goal categories presented above but would accomplish the goal differently. The functional goal may be unique to each system type and possibly unique to each dynamic situation.

4.1 HEADWAY MAINTENANCE SYSTEMS

4.1.1 Manual Headway Maintenance System

4.1.1.1 Manual Headway Maintenance System Definitions

A manual headway maintenance system presents information to the driver such that the driver can maintain an adequate headway from the vehicle in front. The driver maintains full control of the vehicle. For example such systems could present range information and/or relative velocity information to the driver. The driver could have been pre-instructed to maintain a fixed range and/or relative velocity in order to maintain the desired headway. A manual headway maintenance system would not attempt to warn the driver when an unsafe condition occurs. The block diagram of a manual headway maintenance system is shown in Figure 4.1.1.1-1. The following paragraphs describe the blocks within this system block diagram.

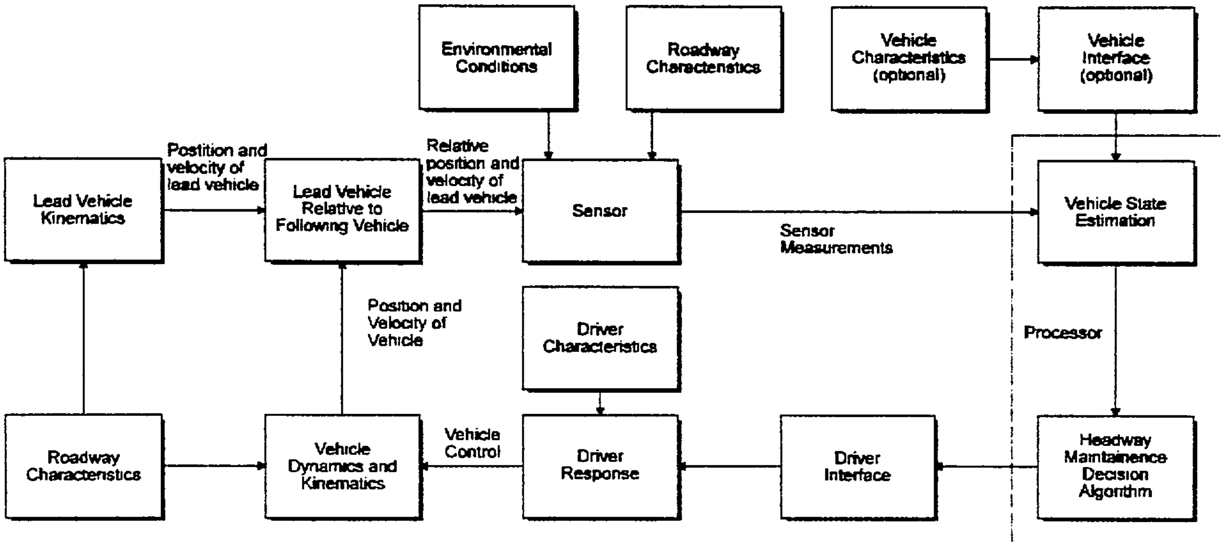

Figure 4.1.1.1-1 Manual Headway Maintenance System Block Diagram

Referring to Figure 4.1.1.1-1, the lead vehicle kinematics block refers to the motion of the vehicle in front, such as accelerating, decelerating, constant velocity, stopped. The lead vehicle's motion is influenced by various roadway characteristics such as curvature, grade, etc.

The lead vehicle relative to following vehicle block describes the dynamic situations presented previously. The lead vehicle relative to the following vehicle is dependent on both the lead vehicle's kinematics as well as the following vehicle's kinematics and dynamics. The following vehicle is the vehicle with the manual headway maintenance system installed.

Based on the relative position and velocity of the lead and following vehicles, the sensor must sense, or detect, the presence of the vehicle in front. The information the sensor receives may be non-cooperative such as a forward looking sensor, or it may be from the infrastructure, or it may be enhanced by modifications to the vehicle in front. The sensor's performance is affected by environmental conditions such as weather, lighting, and traffic congestion, as well as roadway characteristics such as curvature or grade.

The sensor measurements are presented to the processor which must extract from the raw sensor data the desired information. This is done in the vehicle state estimation block. Certain systems may (optional) require additional information from the vehicle such as absolute velocity, turning angle, etc. These are vehicle characteristics from the vehicle interface. Once the processor has extracted the desired information, it is presented to the driver by the driver interface.

The driver responds, or not, to the information presented based on the driver's characteristics such as age, aggressiveness, etc. The driver in turn provides complete lateral and longitudinal control of the vehicle's dynamics and kinematics.

4.1.1.2 Manual Headway Maintenance Functional Goals

Two distinctions must be made regarding the dynamic situations that are applicable for manual headway maintenance systems. Manual headway maintenance systems may or may not detect stopped vehicles since the lack of this feature makes the system easier technologically. For the purposes of this report, it will be assumed that the manual headway maintenance system will only operate on moving vehicles. This keeps manual headway maintenance systems consistent with AICC and CICC systems. This limits the number of dynamics situations to be considered to twelve:

- Lead vehicle constant velocity, following vehicle accelerating
- Lead vehicle constant velocity, following vehicle constant velocity

- Lead vehicle constant velocity, following vehicle decelerating
- Lead vehicle decelerating, following vehicle accelerating
- Lead vehicle decelerating, following vehicle constant velocity
- Lead vehicle decelerating, following vehicle decelerating
- Lead vehicle accelerating, following vehicle accelerating
- Lead vehicle accelerating, following vehicle constant velocity
- Lead vehicle accelerating, following vehicle decelerating
- Lead vehicle decelerating and stopped, following vehicle accelerating
- Lead vehicle decelerating and stopped, following vehicle constant velocity
- Lead vehicle decelerating, and stopped, following vehicle decelerating

In all cases, the functional goal of the system is to:

- Detect the presence of the vehicle in front
- Process the sensor measurements regarding this situation. For most systems of this type, this will be either range between the vehicles, and/or relative velocity.
- Present this information to the driver. The information must be accurate, reliable, timely and understandable.

It is the responsibility of the driver to avoid the vehicle in front and maintain control of the following vehicle. The range to the lead vehicle of interest will typically be decreasing or constant, while the relative velocity to the lead vehicle will be negative or zero and either increasing or decreasing.

One possible use of a manual headway maintenance system is for vehicles performing platooning with the driver controlling the vehicle instead of the system controlling the vehicle. Although manual headway maintenance systems have been produced in the past, it is not currently anticipated that manual headway maintenance systems are practical because they perform such a basic function that with the addition of some extra signal processing, or vehicle control, a manual headway maintenance system can be adapted to perform the more robust functions of ICC or Driver Warning.

4.1.2 AICC System

4.1.2.1 AICC System Definitions

Autonomous Intelligent Cruise Control systems are "smart" extensions of the traditional cruise control available in most passenger cars today. They allow the driver the extra convenience and flexibility of being able to dynamically vary the set speed based on vehicles in the forward path thereby maintaining a safe headway between vehicles. There are numerous variations that can be envisioned available as an AICC system: systems that merely disengage vehicle control upon detection of a vehicle in the forward path; systems that prompt the driver with regards to tracking a vehicle in the forward path; and systems that can automatically acquire and disengage vehicles in the forward path. Others are also possible. For the purposes of this report, the AICC function will have the ability to automatically acquire and disengage a vehicle in the forward path. It will also be assumed that the AICC system will not be required to sense non-moving objects. A block diagram of an AICC system is shown in Figure 4.1.2-1.

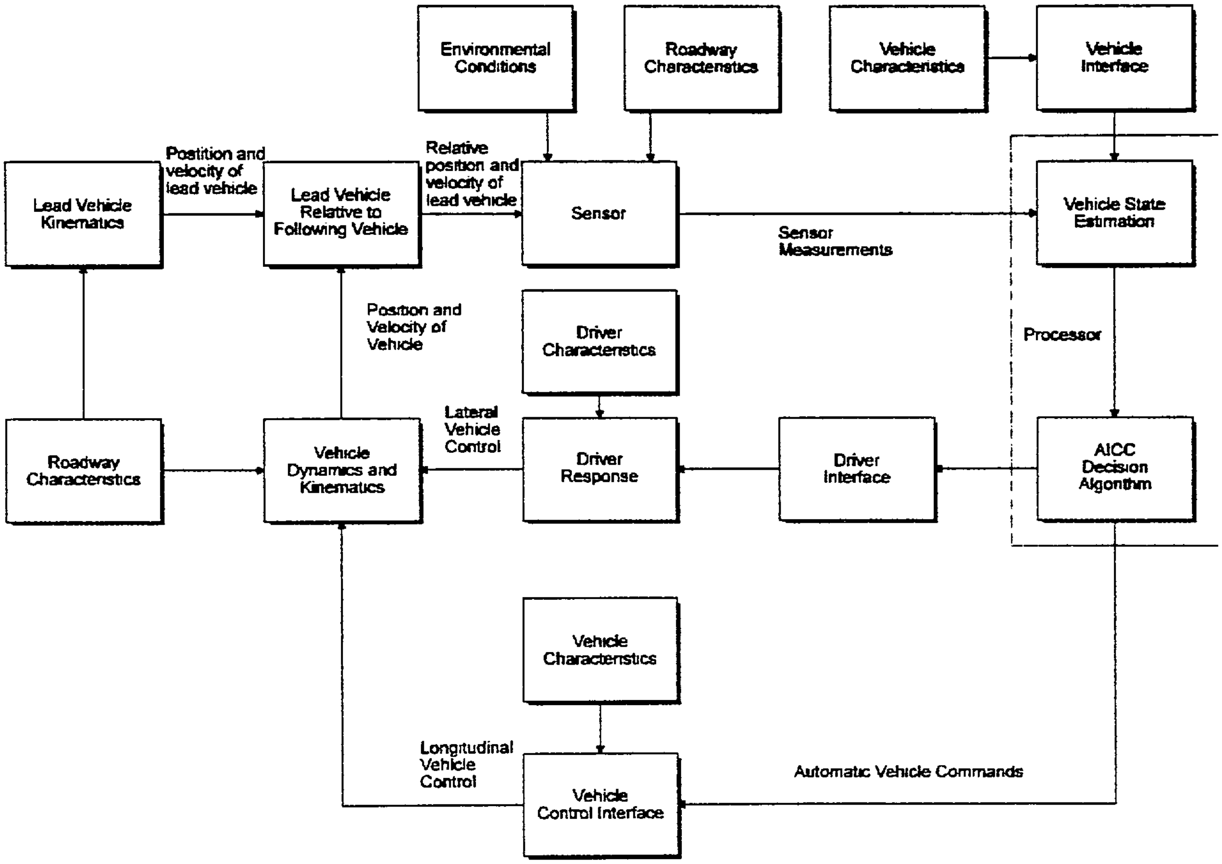

Figure 4.1.2.1-1 AICC System Block Diagram

The main difference between the manual headway maintenance system block diagram presented in Figure 4.1.1, l-l and the AICC system block diagram shown in Figure 4.1.2.1-l are as follows.

The driver interface may be minimal depending on overall system operation. It may be as basic as an indication of system operation, to a relatively complex display of system acquisition, absolute velocity, adjustable headway, etc.

The processor in an AICC system presents information to the driver interface and also the vehicle control interface. The vehicle control interface controls the vehicle's acceleration and deceleration. Deceleration may be obtained through coasting, or downshifting, or even soft braking. The purpose of the vehicle control interface is to allow commands from the processor to provide longitudinal vehicle control based on the driver's preferred set speed and sensor inputs, while the driver provides the lateral (steering) control.

4.1.2.2 AICC Functional Goals

As previously stated, for the purposes of this report, it will be assumed that AICC systems will only operate on moving vehicles. This limits the number of dynamics situations to be considered to twelve.

- Lead vehicle constant velocity, following vehicle accelerating
- Lead vehicle constant velocity, following vehicle constant velocity
- Lead vehicle constant velocity, following vehicle decelerating
- Lead vehicle decelerating, following vehicle accelerating
- Lead vehicle decelerating, following vehicle constant velocity
- Lead vehicle decelerating, following vehicle decelerating
- Lead vehicle accelerating, following vehicle accelerating
- Lead vehicle accelerating, following vehicle constant velocity
- Lead vehicle accelerating, following vehicle decelerating
- Lead vehicle decelerating and stopped. following vehicle accelerating
- Lead vehicle decelerating and stopped, following vehicle constant velocity
- Lead vehicle decelerating, and stopped, following vehicle decelerating

In all cases, the functional goal of the system is to:

- Detect the presence of the vehicle in front
- Process the sensor measurements regarding this situation.
- Adjust the speed of the vehicle to maintain the set speed or a fixed (safe) headway from the vehicle in front.
- Speed adjustment may be through acceleration, coasting, down-shifting the transmission, or soft braking.
- Present some information regarding system operation to the driver.

It is the responsibility of the driver to provide lateral control to avoid the vehicle in front and maintain control of the following vehicle. The AICC system is responsible for longitudinal control under normal conditions. In certain instances it is the driver's responsibility to disengage the AICC system and provide longitudinal control to avoid the vehicle in front. The driver should have some means of adjusting or selecting the desired headway. Very little information need be given to the driver, perhaps merely on and off.

The AICC systems will most probably be the first introduced into consumer vehicles.

4.1.3 CICC System

4.1.3.1 CICC System Definitions

CICC systems are an extension of AICC systems. The main difference being that CICC systems employ a vehicle-to-vehicle communication system to receive information such as velocity and acceleration from other vehicles within the platoon. A block diagram of an CICC system is shown in Figure 4.1.3.1-1.

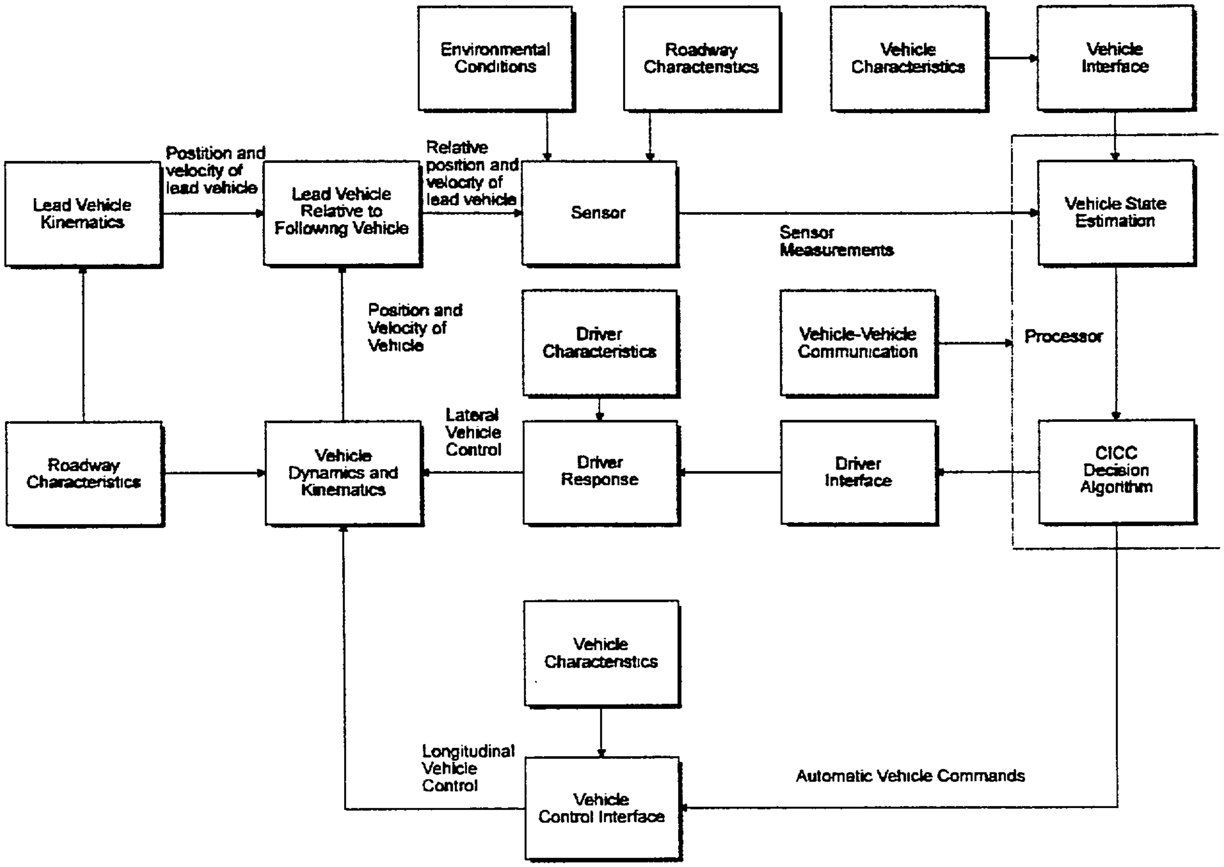

Figure 4.1.3.1-1 CICC System Block Diagram

The main difference between the AICC system block diagram presented in Figure 4.1.2.1-1 and the CICC system block diagram shown in Figure 4.1.3.1-1 is the addition of vehicle-to-vehicle communications that allow the CICC system to receive information from other vehicles in the forward path such as acceleration and deceleration information.

4.1.3.2 CICC Functional Goals

As previously stated, CICC systems are merely an extension of AICC systems. The main difference is with vehicle-to-vehicle communication the system knows apriori when a vehicle is accelerating, decelerating, etc. This information is used to augment the measurements being taken by the sensor. The lead vehicle in the platoon can use its sensor to perform AICC functions or driver warning functions. The functional goals for the CICC system are therefore the same as for the AICC system.

4.2 DRIVER WARNING SYSTEM

4.2.1 Driver Warning System Definitions

The initial action for a driver warning system should be to warn the driver adequately such as to prevent what it senses as an impending collision. Subsequent actions would provide the driver with continuous information regarding vehicles in the forward path. Driver warning would contain two parts: (1) an announcement that action was needed, without specifics; and (2) an announcement that specific actions are needed. A block diagram of a driver warning system is shown in Figure 4.2.1-1.

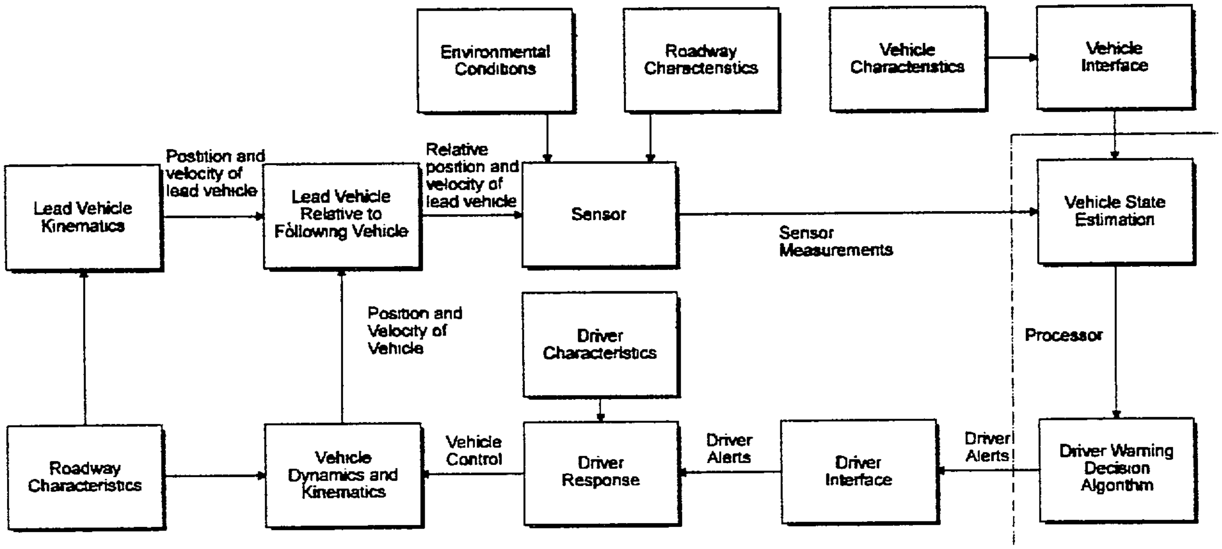

Figure 4.2.1-1 Driver Warning System Block Diagram

Upon comparison of the driver warning system block diagram in Figure 4.2. l-l with the manual headway maintenance system in Figure 4.1.1.1- 1 it can be seen that the systems are nearly identical. The main differences are in the driver interface.

The processor takes information from the sensor and additional information from the vehicle interface and provides a warning to the driver when a dangerous situation exists between the following and lead vehicle. The driver interface must accurately and efficiently convey this information to the driver so as to elicit the proper countermeasures response. The driver interface is either visual, auditory, haptic, or some combination.

4.2.2 Driver Warning Functional Goals

For a Driver Warning system to be successful it must operate on stopped vehicles. In 1990 almost seventy percent of the police reported rear-end collisions occurred with the lead vehicle stopped. Therefore, all the dynamic situations shown in Section 2 apply.

In all cases, the functional goal of the system is to:

- Detect the presence of the vehicle in front
- Process the sensor measurements regarding this situation.
- Warn the driver when a dangerous situation exists and possibly suggest avoidance maneuvers.

In all cases, it is the responsibility of the driver to avoid the vehicle in front and maintain control of the following vehicle. The warning times to the driver may require the driver to perform soft braking, hard braking or steering to avoid a collision. For the driver warning system to suggest an avoidance maneuver to the driver to avoid a collision it would need to work in conjunction with other side looking sensors. The display may be visual, auditory, haptic or some combination.

4.3 AUTOMATIC CONTROL SYSTEMS

4.3.1 Automatic Control System Definitions

Automatic control systems are extensions of driver warning systems. In this case if the system warns the driver and no response is received, or improper action it taken, then the system takes temporary control of the vehicle to avoid a collision. A block diagram of an automatic control system is shown in Figure 4.3.1-1.

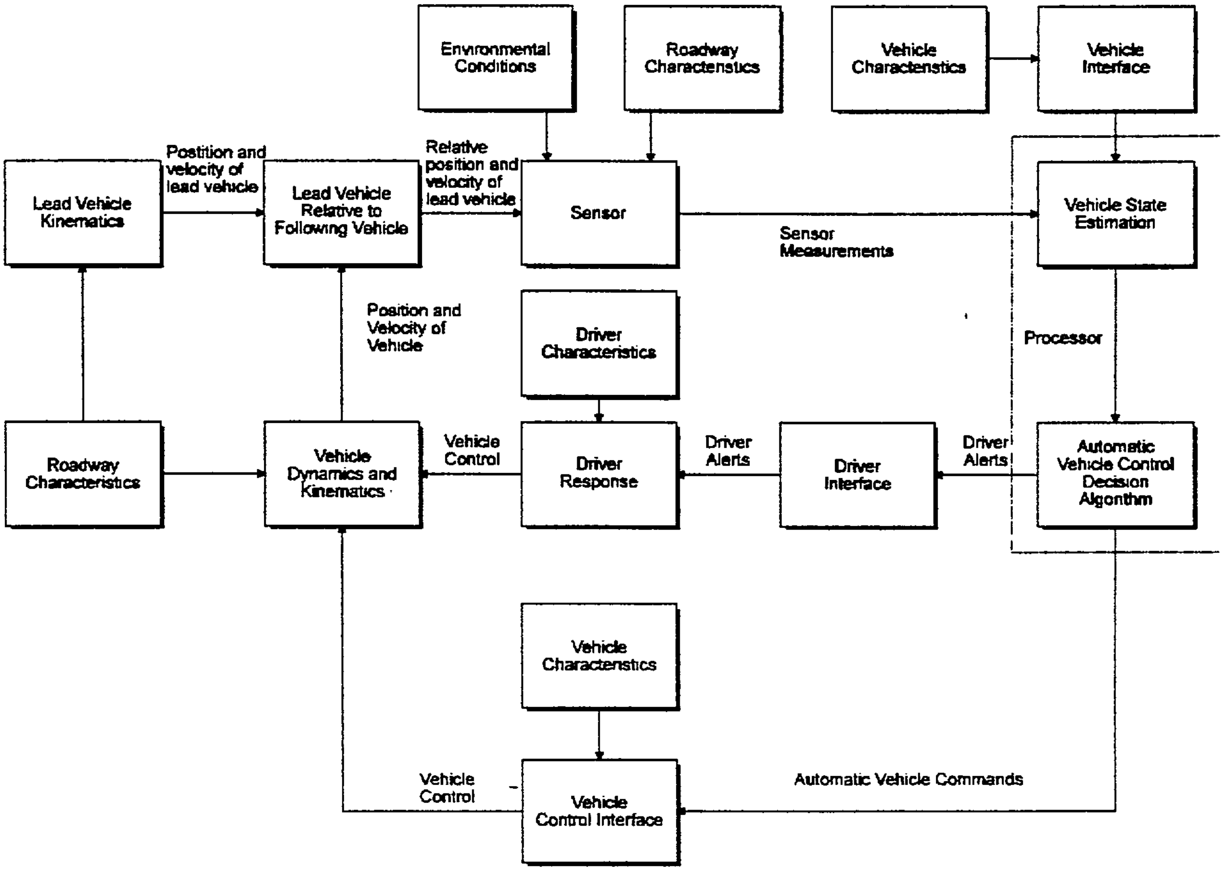

Figure 4.3.1-1 Automatic Control System Block Diagram

The main difference between the driver warning system block diagram shown in Figure 4.2.1-1 and the automatic control system block diagram shown in Figure 4.3.1-1 is the addition of a vehicle control interface. The vehicle control interface receives information from the processor based on the driver's response, or lack of, to a dangerous situation. The vehicle control interface may provide vehicle control through acceleration, soft braking, hard braking, steering, or a combination of these.

4.3.2 Automatic Control Functional Goals

As previously stated, automatic control systems are extensions of driver warning systems. Each functional goal presented under driver warning systems is equivalent for automatic control systems.

In all cases, the functional goal of the system is to:

- Detect the presence of the vehicle in front
- Process the sensor measurements regarding this situation.
- Warn the driver when a dangerous situation exists and possibly suggest avoidance maneuvers.
- If the driver does nothing, or something inappropriate, then the automatic control system takes temporary control of the vehicle and decelerates or steers the vehicle to avoid the collision.
- The system displays to the driver when it is in control, and the avoidance maneuvers are compatible with driver and vehicle limitations.

In all cases, it is the first responsibility of the driver to avoid the vehicle in front and maintain control of the following vehicle. The automatic control only takes over as a final effort to avoid the collision. Otherwise the system performs the driver warning function. The warning times to the driver may require the driver to perform soft braking, hard braking or steering to avoid a collision. The display may be visual, auditory, haptic or some combination.

SECTION 5

SUMMARY

Functional goals are defined as changes to the situation that would help to eliminate or mitigate the severity of collisions and, specifically for this report, modifications or changes to the driver's vehicle that enhance the driver's performance.

Initially a functional goal was written for each applicable dynamic situation and for each system type. There existed little difference between functional goals for different dynamic situations and therefore, to reduce redundancy, the functional goals were reduced to one for each system type.

Additionally it was considered to present characteristics for each system as shown in Appendix A under system characteristics. Again this was considered too redundant for the purposes of this report,

There are two major areas to consider for rear-end countermeasures systems. First, the system itself, sensor, processor, vehicle interface, etc. and other technical issues that must be resolved for the system to operate. And second, the driver display, driver response, and corresponding human factors issues that must be resolved for the human driver to use the system advantageously.

This report does provide a system overview of the five types of systems and presents a broad functional goal for each system type.

The report of the work in Task 2 is the second step in reaching the goal of this program: to generate a set of performance specifications for rear-end collision countermeasures system. In Task 3, hardware testing of existing countermeasures systems will be conducted using the functional goals as a guide for measuring their performance.

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 drivers as reliable?
Is the system effective for driver of diiering 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 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)?
- 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?