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Interim Report

IVHS Countermeasures for Rear–End Collisions, Task 1

Volume VI: Human Factors Studies

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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 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 (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 VI, " Human Factors," presents the results of the initial human factors literature review and study. This report (all volumes) forms the foundation for the work in the later stages of the contract. Descriptions of Volumes I - V are as follows:

a. 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 conclusions found in other volumes.
b. Volume II, "Statistical Analysis," presents the statistical analysis of rear-end collision accident data that characterizes the accidents with respect to their frequency, severity, time 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.
c. 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.
d. 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.
e. 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.

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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Preface

The National Highway and Traffic Safety Administration (NHTSA) Office of Crash Avoidance Research (OCAR) is developing a multi-disciplinary program to: Identify crash causal factor and applicable countermeasure concepts, model target crash scenarios and Intelligent Vehicle Highway Systems (IVHS) technological interventions, provide preliminary device effectiveness estimates, and identify countermeasure research data needs.

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

- Rear–End
- Backing
- Single Vehicle Roadway Departure
- Lane Change/Merge
- Signalized Intersection
- Unsignalized Intersection

This paper presents the results of a driver/human factors review of rear–end crash literature. Also included is a detailed rear–end crash scenario decomposition. The results are based on a comprehensive literature review on factors that contribute to rear-end collisions.

The authors of this report were: Daniel McGehee, Thomas Dingus, and Michael Mollenhauer, Center for Computer-Aided Design, The University of Iowa.

Other contributors to this report from the University of Iowa were (in alphabetical order): Evelyn Frey, Jon Hankey, Heidi Larson, Steffan Hofmeyer, Raj Manikkal, Loren Stowe, Thuy Tran, and Anil Yenamandra.

Executive Summary

This report reviews and examines the applicable literature on the driver/human factors issues that contribute to rear-end crashes. In addition to a review of the literature, a detailed rear-end crash scenario decomposition is discussed. A preliminary model is included as a foundation for the conduct of needed future research, and as a framework for supporting the development of a rear-end collision intervention system performance specification. By understanding the complex driver/human factors of the rear–end crash and how these factors affect the timeline of an impending crash, more effective crash avoidance systems can be designed.

NHTSA has categorized collision intervention systems into three categories:

- Driver Action systems
- Headway Maintenance Systems
- Automatic Control Systems

These systems have been defined and a summary of current and past collision intervention systems is presented. Although many existing system descriptions concentrate on sensor technologies and not the driver interface, an attempt was made to isolate driver interfaces of each system.

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). These conditions vary greatly with respect to pre-crash dynamics (e.g., closing speeds and distances) as well as a number of parameters relating to driver perception and performance.

Driver behavior and perception also greatly affect the circumstances of rear-end crashes. For example, driver inattention is the largest rear-end crash causal factor. The demand on a drivers attention is discussed in detail, as well as a behavioral analysis on why drivers follow too closely. Perceptual factors are presented in relation to driver perception-reaction time and interpretation of relative velocity cues.

Display factors are an important consideration in the design of rear-end collision intervention systems (e.g. likelihood alarm displays and warning frequency). Visual, auditory, and tactile displays are discussed in relation to Intelligent Vehicle Highway Systems (IVHS).

To facilitate the understanding of, and provide a framework for the development of driver-related system requirements, an expanded rear-end crash avoidance model will be developed as part of this project. This model will utilize existing knowledge generated from epidemiological and empirical research generated by this report to the greatest extent practical, and will build on existing models such as one developed by Knipling (1991). Additional model data will be generated from Frontier Engineering and empirical simulator research to the extent practical with project resources. Once completed, it is anticipated that the model will be useful for: (1) conducting sensitivity analyses to determine the relative impact of relaxing or tightening performance standards, and (2) determining for a variety of case studies whether a given collision avoidance system would have eliminated or mitigated a crash.

1.0 Introduction

Driving is a complex behavior that requires simultaneously using complex sensory, perceptual, cognitive, and physical factors. Technology that enhances and augments these factors may allow the reduction of one of the most common types of automobile crashes. While such technology offers great potential to improve automobile safety, beneficial effects depend on the joint performance of the system and the driver.

Many technologically sophisticated systems fail, not because of technical short comings, but because designers failed to consider the role of the human operator. This is especially important to consider for crash avoidance systems since user acceptance and performance are integral to system success. Technology, integrated properly with our understanding of human factors, has the greatest potential to mitigate front-to-rear-end crashes.

The focus of this review is on the human factors of rear-end collision intervention. The following sections review the rear-end collision scenario and provide insight on the human factors that impact the rear-end crash avoidance problem and its potential alleviation.

1.1 Project Goal

The goal of this project is to develop a performance specification for future rear-end collision intervention systems. Included in this specification will be a thorough review of hardware, software, driver/human factors and current rear-end collision intervention systems. The first task of the specification development processes is the analysis of the crash problem, accomplished by the review of the extensive statistics and case studies recorded by the Federal Government. A review of current and past collision intervention systems and driver/ human factors considerations will also be included in the overall development process.

For the first project task reported in this document, driver/human factors literature related to collision warning and avoidance is reviewed. A product of this review includes a detailed breakdown of driver reaction and avoidance behavior. This process leads to a decomposition of all of the factors that influence a rear-end crash and provides insight into the complex driver/human factors issues involved. A preliminary model describing the rear-end crash timeline and predicting these crashes is provided.

Task 1 lays the foundation for the future project tasks, From the driver/human factors perspective, this report lays the foundation for identification of system functional goals (Task 2), creating the methodology to evaluate existing technologies and systems for crash mitigation potential (Task 3), and the development and testing of new concepts based on what has been learned about collision intervention methodologies and technologies (Task 4). Task 4 will include the study and evaluation of several driver interface issues. The effects of system errors (false alarms and misses), the type and timing of information provided to the driver, and interface issues such as the sensory modality utilized will be tested in simulation. In addition, new concepts and ideas will be prototyped and tested. Information from these tests will provide critical information for the final performance specification. This process will eventually lead to a collision intervention specification, which includes recommendations for hardware, software, and driver interfaces.

1.2 Report Overview

The purpose of this review 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 specifications, 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 this document to provide the reader with more detailed information on related literature.

The first section of the review examines the literature on driver/human factors, relevant behavioral research, and previous research on collision intervention systems.

The second section describes the types of collision intervention systems that have been or are being considered in driving research. The systems described have are based in definitions provided by NHTSA.

The third section reviews past and present collision intervention systems found in the literature. Systems which display a warning to the driver will be discussed along with intervention systems that provide automated avoidance countermeasures.

The fourth section describes previous rear-end collision models, display issues, and the framework for a future rear-end collision prediction model. Also discussed in the fourth section is a description of different driver interface factors that will contribute to the design of collision intervention systems. False and nuisance alarms and warning frequency are reviewed, as well as display modality.

Following the discussion of prediction models, the fifth section discusses the elimination of variables from models that will be developed further for this project. There are many factors that can potentially be included in a prediction model of this type, and inclusion of all variables would make the model unusable. Some variables have little useful prediction value since they represent extreme variation in driver performance or do not account for much of the total variance inherent in the crash avoidance problem.

Following the section on variable elimination, a framework for new prediction models for rear-end crash follows. The goals of the model are discussed and each decision node described in detail. Data to support the model are identified and a table which identifies data sources are presented along with descriptions of each prediction variable.

Finally, a section is included on future directions. This section describes how the proposed model fits into each phase of the project plan.(i.e., evaluating existing technologies as well as the overall performance specification development).

As an addendum, an annotated bibliography is included that provides summary information of all literature reviewed.

1.3 Overview of the Rear–End Crash Problem

One of the most common types of crashes involving two motor vehicles is when one vehicle strikes the rear-end of another. Many different agencies evaluate these types of crashes. Unfortunately, a major problem with crash data gathered is that it is collected and categorized in many different ways.

Each state has its own method of recording automobile crashes. Some states classify all rear-end crashes while others do not record them if there is less than

$500 damage or there are no injuries involved. In addition, some states may classify rear-end crashes with great detail, whiles other states may record little detail.

Several clinical studies have been completed for NHTSA which have considerable detail (see Treat et al., 1979 and Knipling et al., 1993). Unfortunately, inevitable disparities exist between these and other studies due to the large reporting variance (generally at the state level). These discrepancies should be noted when reviewing crash statistics.

The NSC reported (Accident Facts, 1992) that there were approximately 11.3 million motor vehicle crashes in 1991 of which 2.7 million were rear-end crashes (about 23.8% of the total). These crashes accounted for 33% of all collisions involving two or more vehicles.

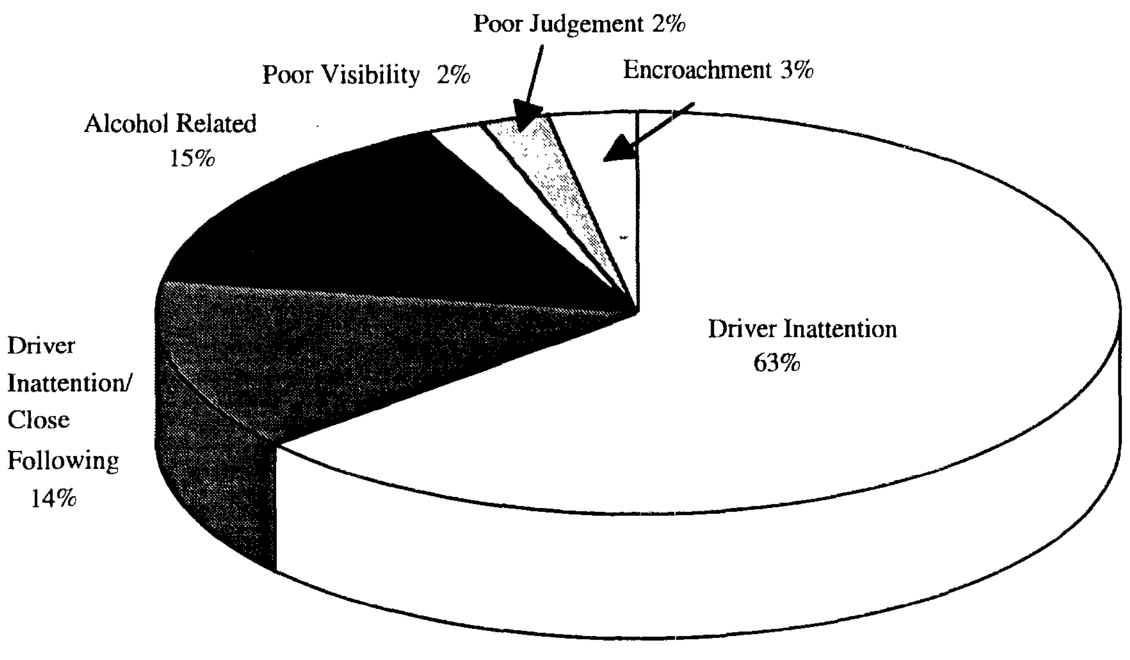

Figure 1.3–1. Rear–End Crash Causes from NASS CDS Sample Files

When the rear-end crash is decomposed, a sample of 1991 NASS CDS (Frontier Engineering, Task 1, volume III report) hard copies revealed that 63% (see figure 1.3–1) of the sampled rear-end collisions were caused by driver inattention, 15% alcohol related, 14% inattention and following too closely, 2% due to speeding and inattention, 2% due to poor judgment, and 3% due to poor visibility.

When assessing the pre-crash corrective action attempted by drivers, a sample of 1991 NASS CDS (Frontier Engineering, 1993, Task 1, Vol. III) hard copies revealed that 27% attempted no avoidance action, 32% braked, 5% steered, 12% braked and steered right, 3% braked and steered left, and 17% had unknown avoidance maneuvers.

1.4 Types of Rear-End Crashes

Rear-end crashes can be classified into two conditions: lead–vehicle stationary (LVS) and lead-vehicle moving (LVM). These conditions vary with respect to pre-crash dynamics (e.g., closing speeds and distances) as well as a variety of driver/human factors issues. A general comparison shows that in 1990, LVS crashes accounted for 69.7% of rear-end crashes (Knipling et al., 1993). In another LVS and LVM crash study which analyzed 77 rear-end crashes (Knipling et al., 1993), nearly 75% of crashes involved LVS vehicles. Knipling also found that most (54.2%) of LVM crashes occurred at non-junctions, while only 35.4% of LVS crashes occurred at non-junctions. About 54.9% of all rear-end crashes were intersection, intersection-related, or driveway/alley access-related LVS crashes. Also, about 57.3% of LVM crashes occurred on non-divided highways, while 67.1% of LVS crashes occurred on non-divided highways. When the roadway speed limits were known and the crashes analyzed, 28.6% of LVM crashes and 13.4% of LVS crashes occurred on high speed limit (55 mph +)

roadways. Mortimer (1979), also found that of the moving vehicles struck, 28% were traveling at 20 mph or less.

1.5 Behavioral and Perceptual Aspects of Rear-End Crashes

1.5.1 Driver Attention

Driver inattention accounts for the largest of rear-end crash causal factors. In one sampling (Frontier Engineering, Task 1, volume III report) by the NASS CDS (1991), 63% of rear-end crashes were caused by driver inattention. Although it is possible for a driver to "look but not see", attention in driving is generally directly related to where a driver is looking at any given time. The driver is constantly scanning the environment — looking out the forward windshield, side windows, scanning mirrors, and attending to stimuli in the vehicle. Since the human visual attention operates for all practical purposes as a single channel processor, drivers experience periods of time when no information is being processed from the forward roadway. Operating in–vehicle controls, navigating to a destination, and carrying on conversations require drivers to take their eyes off of the roadway and "attend" to other stimuli. Often, drivers return there point of gaze repeatedly "head down" or off the forward roadway. It is these repeated non–forward looking glances that create the potential for a rear-end crash.

Visual sampling both in and out of the vehicle has been modeled previously (Wierwille, 1993). See figure 1.5.1–1 for this normative, deterministic model. The model starts when the driver begins to perform an in-vehicle task by glancing to an appropriate location. Information extraction begins as time elapses. If the information can be chunked at about one second or less, the driver will comfortably and return to the forward scene. However, when experiencing time pressure, the

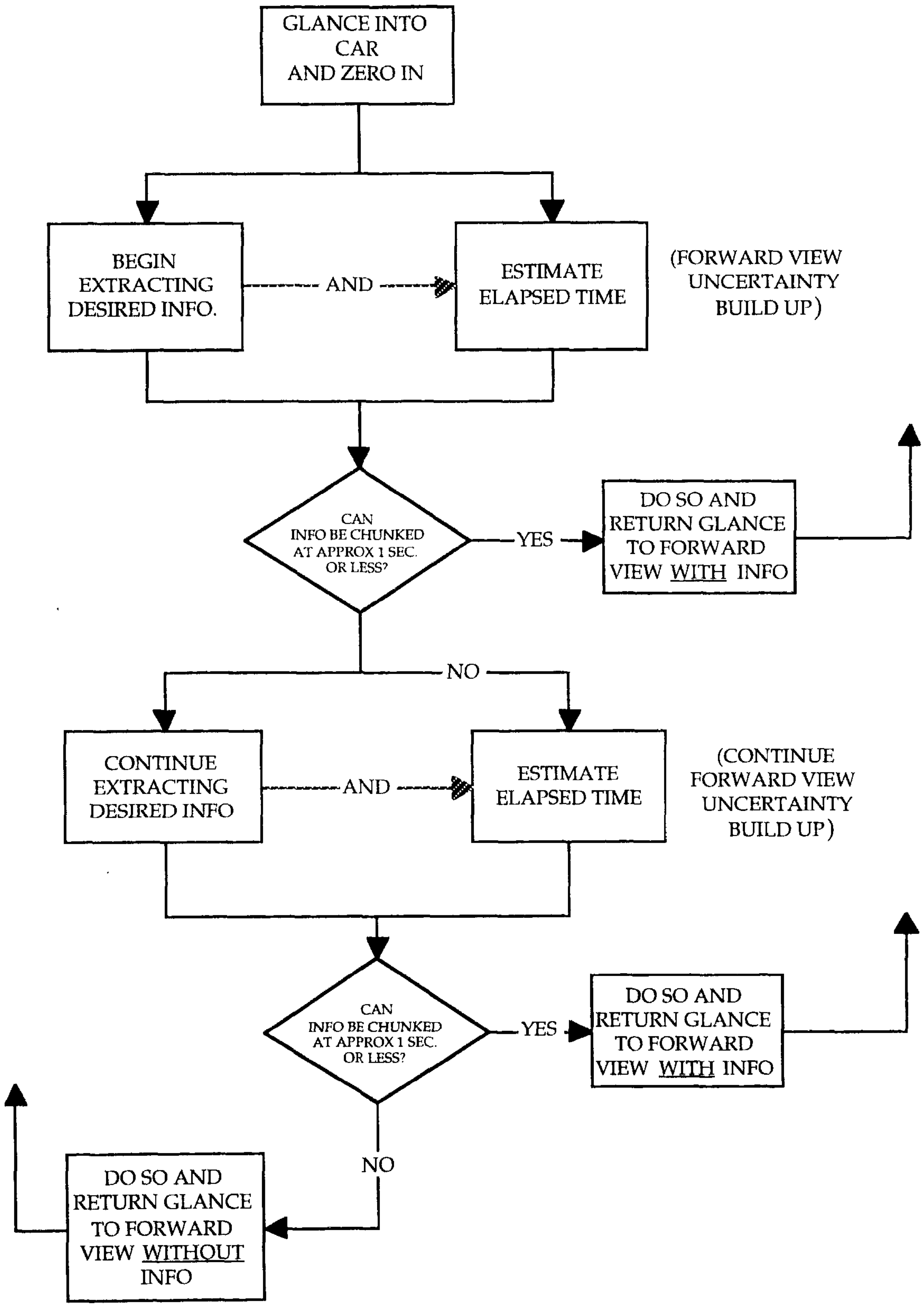

Figure 1.5.1–1. Model of visual sampling for in-vehicle tasks

driver will take up to 1.5 seconds to glance and retrieve information. If the information cannot be obtained (or chunked) in less than 1.5 seconds, the driver will return the glance to the forward scene and try again later. The driver continues to extract other information in the same way, until all required visual information is obtained.

Wierwille also states that manual tasks requiring in–vehicle glances can be separated into five categories, based largely on the needed driver resources. Some tasks are learned quickly after only a few glances, and are quickly and manually mapped out by the driver. Light switches, turn signals, and other simple controls are often performed automatically by the driver.

A subset of this control mapping (manually only) occurs when a driver looks at a control to obtain position or status information, then adjusts the control without looking. For example, checking to see where the climate control system is set and then manipulating the controls without looking at them. Wierwille classifies this type of action as *manual primarily.*

Visual only are tasks that require no manual input and are information gathering in nature. These type of tasks include the speedometer, checking the radio station frequency and time of day.

Wierwille categorizes tasks that rely heavily on vision, but require a degree of manual input as *visual primarily.* An example of this type of task is determining the radio station frequency when the initial display reads like a clock.

The last classification that Wierwille describes is that of *visual–manual.* This type of task is related to interactive activities inside the vehicle, such as repeated input and visual attention.. This input includes manually tuning a radio to a specific frequency, operating a cellular phone, and adjusting an outside rear-view mirror.

Most glances in-vehicle require more than 1.2 seconds (see figure 1.5.1–2) Bhise et al. (1986), and Dingus et al. (1990). This relatively long glance duration time is

Tasks Requiring a Single Glance		
Task	**Mean glance duration (seconds)**	
Read Analog Speedometer		
• Normal	0.4 to 0.7	
• Check	0.8	
• Exact value	1.2	
Read Analog Fuel Gauge	1.3	
Read Digital Clock	1.0 to 1.2	
Tasks Requiring Several Glances		
Task	**Number of glances**	**Mean glance duration (seconds)**
Turn on radio, find station, adjust volume	2 to 7	1.1
Read multi-level 12-button panel	7 to 15	1.0

Figure 1.5.1–2. Summary of in-vehicle glance times

one of the key factors contributing to driver loss of situation awareness to the forward vehicle. Scanning behavior resulting in the "head–down" factor in normal driving lead to reduced out the window glance times. Wierwille, Hulse, Fischer and Dingus (1988), have calculated probabilities of a driver's eyes being on the forward roadway under varying degrees of attentional demand (see figure 1.5.1–4). They found that as the driver's subjective rating of attention demand increases, so does the probability that the drivers eyes will be on the forward view. Wierwille et al., surmise that drivers undergoing increased visual loading, due to the primary task of driving adapt their visual sampling strategy. They are under greater pressure to return their glance to the forward view sooner and maintain it a greater proportion of the total time.

Wierwille and his colleagues also found that traffic density increases the driver's glance time in the forward view. As the traffic density increases, so does the glance length of the forward view (see figure 1.5.1–5).

Task	**Mean**	**Standard Deviation**
Speed	0.78	0.65
Following traffic	0.98	0.60
Time	1.04	0.56
Vent	1.13	0.99
Destination direction	1.57	0.94
Remaining fuel	1.58	0.95
Tone controls	1.59	1.03
Info. lights	1.75	0.93
Destination distance	1.83	1.09
Fan	1.95	1.29
Balance	2.23	1.50
Sentinel	2.38	1.71
Defrost	2.86	1.59
Fuel economy	2.87	1.09
Correct direction	2.96	1.86
Fuel range	3.00	1.43
Cassette tape	1.59 + 1.64*	0.96 (0.59)*
Temperature	3.50	1.73
Heading	3.58	2.23
Zoom level	4.00	2.17
Cruise control	4.82	3.80
Power mirror	5.71	2.78
Tune radio	7.60	3.41
Cross street	8.63	4.86
Roadway distance	8.84	5.20
Roadway name	10.63	5.80
Note: *Time required to search for and orient cassette tape		

Figure 1.5.1–3. In-car glance times for a variety of conventional and navigation tasks

Driver age also has a bearing on how long glance duration's take place. Hayes et al. (1989) found that middle-age and older drivers had significantly longer in-vehicle glance times than those of younger drivers. These age effects are generally due to deterioration of vision and slowing of cognitive processes (see figure 1.5.1–6). This effect is critically important to consider when designing in–vehicle controls and displays.

(regression line and averaged data shown)
(Source: Wierwille, Hulse, Fischer and Dingus, 1988).

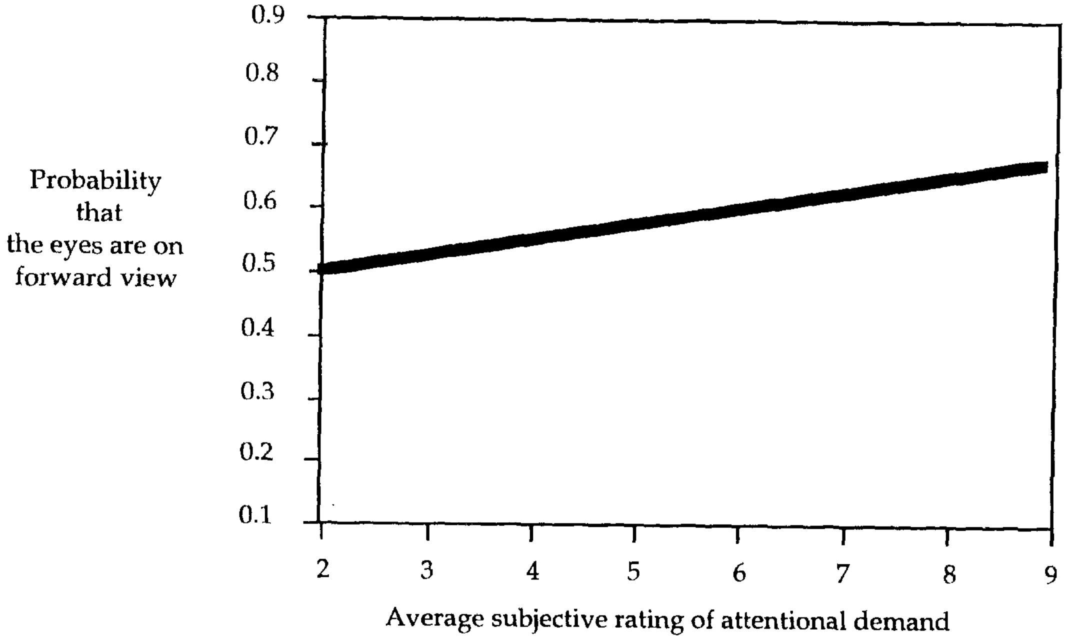

Figure 1.5.1–4. Probability that the eyes are on the forward view as a function of attention demand

(Source: Wierwillie, Hulse, Fischer and Dingus, 1988).

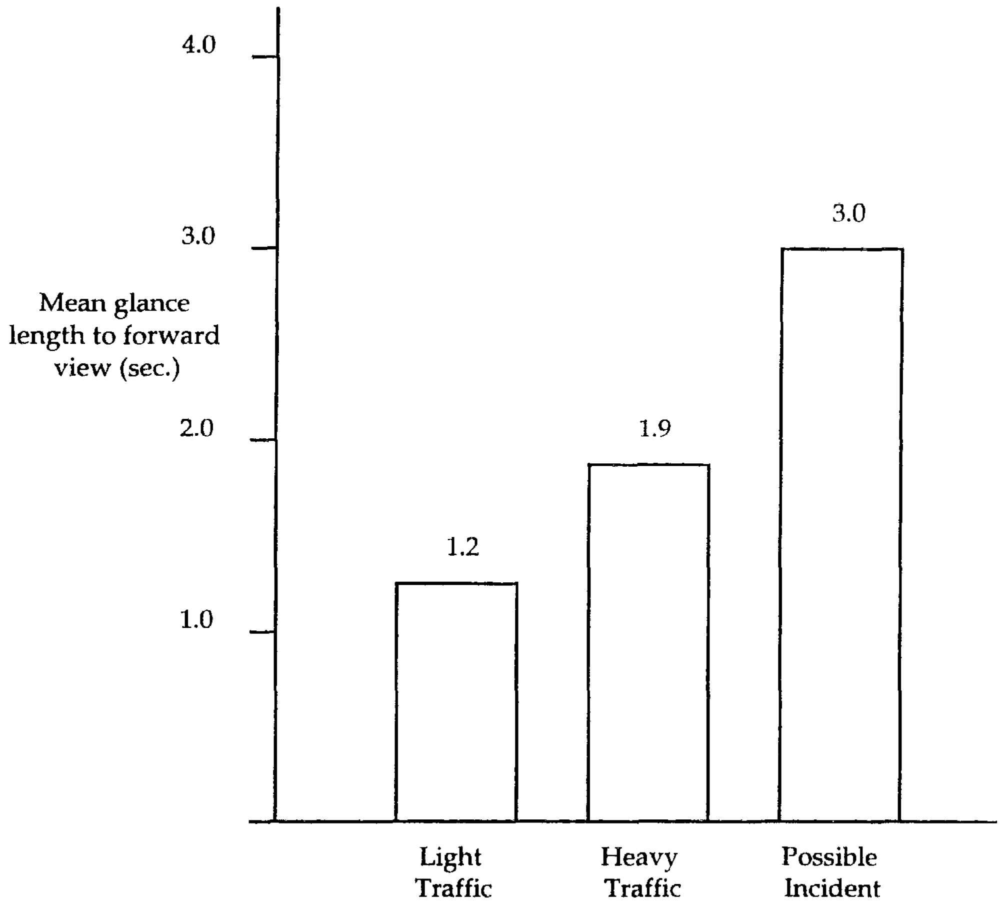

Figure 1.5.1–5. Glance length to forward view as a function of traffic type

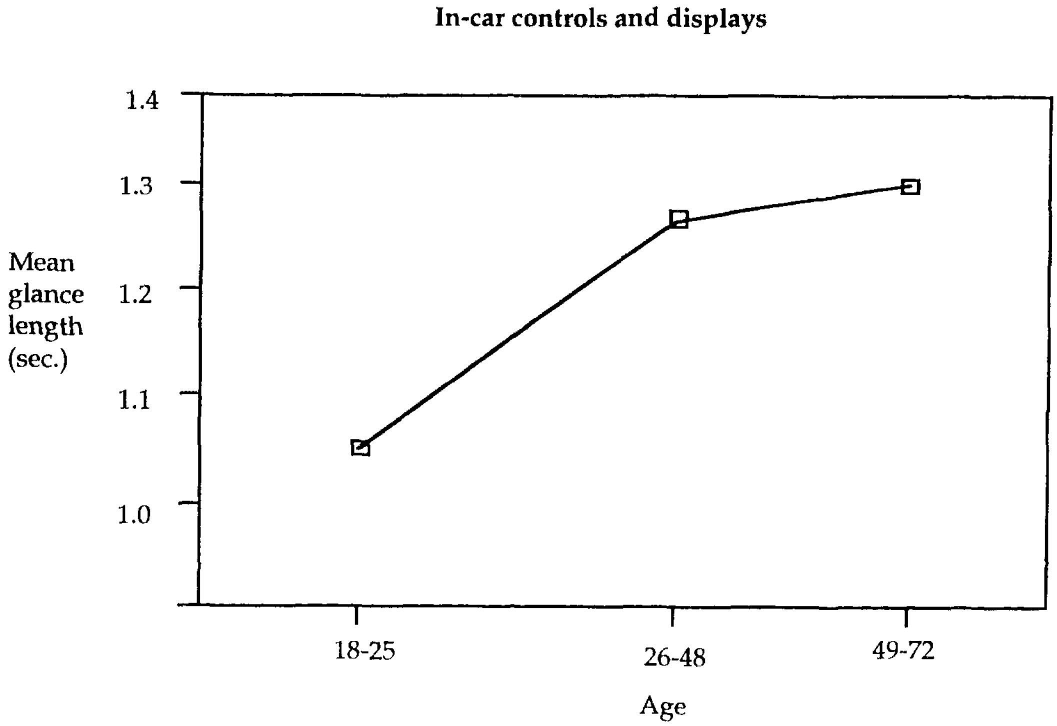

Figure 1.5.1–6. Mean in–vehicle glance length as a function of age

1.5.2 Why Drivers Follow Too Closely

According to Evans (1991), there are two likely reasons why drivers become comfortable following at headways that increase the risk of rear-end crashes. First, a dominant cue is the relative speed between the lead and following vehicle. Normally, the relative speed is close to zero. There is no risk of a rear-end collision if both vehicles maintain identical speeds, regardless of the speed. Evans believed that the largely static visual impression in vehicle-following tends to lower awareness and concern regarding speed. If the speed of the vehicle in front changes suddenly, then the ensuing dynamic behavior of both vehicles is strongly speed dependent.

The second reason Evans believes drivers become comfortable when following too closely, is that they have learned, from repeated experience without adverse consequences, that is safe to do so. Evans also indicated that experience teaches drivers that the vehicle in front does not suddenly slow down.

1.5.3 Perceptual Factors in Rear-End Crashes

Considerable evidence suggests rear-end crashes occur because the driver of the striking vehicle does not see the vehicle ahead, or because of complex perceptual factors (Mortimer, 1988). Several perceptual factors determine distance and rate of closure information for following vehicles.

When making judgments regarding depth, pictorial cues (such as *relative size)* are the strongest depth cues (Levine & Shefner, 1991). To make this judgment, the observer does not have to know anything about the actual size of objects; it is necessary only to assume that they are identical.

Ittelson and Kilpatrick (1951) illustrated this point by presenting subjects with two balloons at the same distance from the subjects. The sizes of the balloons were controlled by bellows. When the balloons were viewed monocularly under dim illumination (to eliminate other depth cues), the distances assigned to them by the subjects depended on the relative sizes. Two balloons of equal size were viewed equal distances away, but a larger balloon was always thought to be closer.

This example can be directly applied to how we view vehicles ahead. When a vehicle is far ahead, it looks smaller than it does when it is close. As a result, the visual angle is small when the vehicle is far away, and when the vehicle is up close, the visual angle is larger.

Several studies have been performed that are related to this perceptual phenomenon. One study by Baker and Steedman (1961), indicated that when a luminous object was viewed in a stimulus-free environment, motion could be inferred toward the observer when the visual angle subtended by the object had increased by about 0.02 degrees. In another study conducted by Braunstein and Laughery (1964), it was found that by using vehicles and decelerations of 0.8 - 1.48 ft/sec^2, Weber fractions (principle that the just noticeable difference is a constant fraction of the intensity of the comparison stimulus) of 0.09 - 0.12 for headway change detection were obtained .

In another driving study (Mortimer, 1971), the sensitivity of drivers' changes in headway was measured from initial headways at 70 mph of 120 feet and 320 feet, and at 35 mph of 40 feet and 120 feet. The Weber fraction for headway change detection was 0.12 degrees of visual angle, which was similar to Braunstein and Laughery. This indicates that drivers similarly view leading vehicle change in size and relative velocity.

1.5.4 Driver Perception/Decision/Reaction Time

The next stage of the collision avoidance process when considering the perceptual factors relating to the visual angle of rear-end crash is driver reaction time. The usual driver reaction to a potential collision is sudden braking and/or steering. As a major consequence, a factor in determining whether a collision will be avoided is the driver's perception–reaction time (PRT).

PRT has long been the object of study; however, large sample studies which look at reaction time as it relates to in-vehicle braking is rather sparse. More research on perception–reaction times to relevant lead vehicle deceleration is needed. Past research has generally concentrated on reaction to traffic signals and objects in the road (Sivak et al. 1982; Olson and Sivak, 1986). These studies also informed drivers that they should expect rapid slow downs.

Driver reaction time estimates vary from 0.9 seconds for unexpected events (with athletes as drivers; Davis et. al., 1990) to 1.6 seconds for 95th percentile drivers with unexpected events using a more representative population (Olson & Sivak, 1986).

Lister (1950), in a laboratory study, investigated PRT in which a subject was expected to press a pedal when a lamp was lit. Lister split the total brake PRT into perception time (time from the presentation of stimulus until the foot starts to move) and movement time (time from the start of the movement until the foot reaches the brake pedal). The mean overall brake reaction time obtained under these conditions was found to vary between .45 and .60 sec. Lister's study measured only the reaction time to the light itself, no other stimulus was tested. This accounts for the fast reaction times obtained in the study relative to other field tests.

In a experiment conducted by Olson and Sivak (1986), it was found that the 95th-percentile PRT interval for a population of ordinary drivers confronted with an unexpected roadway obstacle, was 1.1 sec, with a range (2 to 98 percentile) of 0.81 to 1.76 sec. Note that PRT may be shorter for more intimidating test conditions.

Taoka (1989) suggested that brake reaction times of unalerted drivers can be represented by a lognormal distribution. He surmised that the lognormal distribution for brake reaction time is more realistic than a standard normal distribution because of the skewness of the lognormal distribution. Most studies have shown that the distribution mean is greater than the median PRT because there are more large reaction times at the high end of the distribution than the normal distribution would indicate. More large reaction times are realistic since they describe more of the population (age and impairment effect) and take into consideration day-to-day driver inattention problems. Furthermore, detection times might vary depending on the type of signal presented (e.g., auditory or visual).

In perhaps one of the most ecologically valid studies on brake perception--reaction time, Lerner (1993) instrumented over 116 individual's personal vehicles to conduct "roadway quality" drives in older and younger drivers. At the end of about an hour of evaluating roadways, the drivers were directed onto a new section of deserted freeway. After driving 0.7 miles on the new freeway section, a bright yellow barrel was launched from behind a bridge abutment. Reaction times in the form of braking and/or steering were recorded. Lerner found that 87% of the 116 drivers made some overt vehicle maneuver. Of these, about 43% both braked and steered, 36% steered only, and 8% braked only. Mean PRT for all subjects was 1.5 seconds with a standard deviation of 0.4 sec.

After reviewing studies on PRT (see figure 1.5.4–1), a wide range of values were found. The Davis et. al. (1990) study commented that PRT in certain situations may be a simple or complex reaction according to test procedures. They found that perception reaction time increased with following distance. This effect of short PRTs for short headways, was explained by increased attention drivers had towards the lead vehicle.

In most studies, which involved car following or obstacles in the road, it was found that mean brake reaction times were well over one second. In studies where brake reaction times were found by braking according to a light or sound stimulus, mean brake reaction times were well under one second. In car following and obstacles in the road studies, where most subjects are not expecting to brake, complex reactions occurred. In most studies where subjects are often expecting to brake due to light or sound stimuli, less complex reactions occur. The study by Johannson and Rumar (1971), suggested that when braking is anticipated, a correction factor of 1.35 seconds must be used to find the correct PRT.

Study	**Measurement Condition**	**PRT Results**
Allen Corporation (1978)	Car following	mean, 1.45 sec.
Sivak (1979)	Car following	mean, 1.38 sec.
Sivak (1981)	Car following	control mean, 1.38 sec.
Sivak (1981)	Car following	mean, 1.25 sec.
Sivak et al. (1982)	Car following	mean, 1.21 sec.
Sivak (1982)	Car following	mean, 1.21 sec.
Davis et al. (1990)	Car following	males mean, 0.68 sec. females mean, 0.69 sec.
Olson and Sivak (1981)	Obstacle in road	old mean, 1.31 sec. young mean, 1.175 sec.
Triggs and Harris (1982)	Obstacle in road	85th percentile, 1.26 sec.
Olson et al. (1984)	Obstacle in road	85th percentile, 1.3 sec.
Wilson (1987)	Obstacle in road	mean, 0.70 sec. 99th percentile, 1.6 sec.
Lerner (1993)	Obstacle in road	95th percentile, 1.6 seconds
Grime (1952)	Obtrusive pedestrian in crosswalk	mean, 0.71 sec.
Barret et. al. (1982)	Simulator w/ pedestrian in path	fast group (mean, 0.83 sec.) slow group (mean, 1.13 sec.)
Gazis et al. (1960)	Yellow traffic signal to brake lights	mean, 1.14 sec.
Wortman et al. (1983)	Yellow traffic signal to brake lights	mean, 1.30 sec.
Chang et al. (1985)	Yellow traffic signal to brake lights	mean, 1.30 sec.
Konz and Daccaret (1967)	Stimulus of light in field of view	85th percentile, 0.70 sec.
Nagler and Nagler (1973)	Stimulus of light in field of view	85th percentile, 0.70 sec.
Olson and Sivak (1981)	Stimulus of light in field of view	old mean, 0.615 sec. young mean, 0.780 sec.
Olson et al. (1984)	Stimulus of light in field of view	85th percentile, 0.70 sec.
Johannson and Rumar (1971)	Brake on noise	median 0.66 sec. 85th percentile 1.0 sec.
Johannson and Rumar (1971)	Anticipated buzzer to stop	mean, 0.54 sec.
Johannson and Rumar (1971)	Surprise buzzer to stop	mean, 0.73 sec.
Sivak et al. (1982)	Thumb press when brake lights seen	mean, 0.73 sec.
McGee et al. (1983)	Literature survey	85th percentile, 2.3 seconds

Figure 1.5.4–1. Review of Brake Perception/Reaction Times

Other procedure discrepancies to find brake PRT may result in different values. The study by Taoka (1989), suggested that finding brake reaction times using yellow stoplights is less indicative of PRT values than it is in car following studies. According to Sens et. al. (1989), studies involving more risk may lead to increased brake reaction time values. Olson (1989) indicated that each brake reaction time study involves specific features; therefore, PRT values cannot be found when introducing complicating factors.

Most studies found no significant effect of gender or age on brake reaction times. However, the literature review by Olson (1989) found that females respond slower, by only 0.08 seconds and that brake reaction times slowly increase with age. A study by Wilson (1987) found that older subjects had a longer perception time, but compensated with a shorter reaction time. Most studies indicated only slight effects of age and gender on brake PRTs and are generally negated by other factors involved.

Most studies tended to indicate that 2.5 seconds, the current accepted brake reaction time value, was satisfactory or conservative. A study by Davis et. al. (1990) differed in opinion with respect to hazardous vehicles such as fuel trucks (a value of 3.0 seconds should be used). On the road studies not involving specific sound or light stimuli, showed mean, brake reaction times between 1.2 and 1.5 seconds. Taking into consideration drivers of non-high risk vehicles with the slowest reaction times, the PRT value of 2.5 seconds can be considered adequate.

1.5.5 Relative Velocity Cues

Based on the available literature, drivers are apparently able to judge accurately whether a gap between them and another vehicle is opening or closing

(Mortimer, 1971; Hoffman, 1966). However, it also appears (as mentioned in the previous section) that drivers base their closure rates heavily on changes in visual angle. Mortimer (1988) found that drivers are able to derive little information on the *velocity* and *relative velocity* of their own vehicle as well as the vehicle ahead of them. Drivers are able to make accurate estimates on the *distance* to the car ahead of them (within approximately 20%) and are reasonably sensitive in determining a *change in the headway* between their vehicle and one ahead of them (within an approximately 12% change).

A study by Hoffman (1966) found that in many situations, drivers do not have the opportunity to estimate relative velocity because the threshold for human perception of that factor is often not exceeded. He also determined in another study (Hoffman, 1974) that the threshold for angular velocity is approximately 3.5×10^{-3} radians per second. However, the same study showed that in a car-following simulator, drivers made little use of relative velocity information. Drivers were able to more effectively scale the absolute speed of the car being followed. It was concluded that unless the relative velocity between two vehicles becomes quite high, drivers use changes in their headway, or the change in angular size of the vehicle ahead to determine their speed. Even in high relative velocity situations, drivers cannot scale relative velocity into more than three or four categories. As a result, Hoffman suggested that rear-end collisions could be reduced if drivers were aided by a display which indicated the relative velocity of the car being followed.

1.6 Display Factors in Rear–End Crash Systems

1.6.1 False/Nuisance Alarms and Warning Frequency

False alarms and warning frequency are two of the most important issues that must considered in the design of collision warning devices. A false alarm is an alarm activation in which a device does not function as designed (e.g., an electronic sensor interprets ambient noise as a signal and activates the alarm). Nuisance alarms are similar to false alarms. They occur when a system functions as designed when the situation does not constitute a true crash threat (e.g., sensor signal reflects off of a guard rail while rounding a corner).

These types of alarms occurred with the design of the first generation TCAS-I, the Traffic-Collision Alerting System for commercial aircraft. TCAS I had such a high nuisance and false alarm rate in congested traffic areas that pilots no longer believed the system was producing a valid alert. This type of situation is directly transferable to the automotive collision intervention domain. Historically, warning systems have used discrete on/off criteria. Such discrete systems present several design parameters that must be estimated. If false alarm rates are too high, the user loses faith in the system and deems it useless. Since it is estimated that a driver is involved in a car crash an average of every five years (Evans, 1991), and that rear-end crashes represent about 1/5 of all collisions, a driver may only be involved in a rear-end crash every 25 years. This indicates that theoretically, collision interventions should rarely occur if the false/nuisance alarm rates are in line with the actual hazards.

Horowitz and Dingus (1992) discussed the potential for warnings to add to the attention and information processing load of drivers. Warning displays, if not properly designed, could divert attention to the wrong place at the wrong time.

In addition, frequent warnings may be ignored, because the driver may perceive it as false and useless, therefore redundant information. To overcome potential negative aspects, four concepts were suggested:

- a graded sequence of warnings
- a parallel change in modality
- individualization of warnings
- a headway only display

These recommendations are intended to optimize warning displays to their fullest. In the scope of warning signal design, it is imperative to reduce the false alarm rates as much as possible without missing any real hazards.

1.6.2 Likelihood Alarm Displays

In a likelihood alarm display (LAD), information about event likelihood is computed by an automated monitoring system and encoded into an alerting signal for the human operator. Sorkin, Kantowitz, and Kantowitz (1988) evaluated operator performance within a dual-task paradigm with two LADS: a color coded visual alarm and a linguistically coded synthetic speech alarm. The results indicated that (1) LADs can improve the allocation of attention among tasks and improve information integrated into operator decisions; and (2) LADs do not necessarily add to the operator's attentional load.

This type of display, and the recommendations brought forth by Horowitz and Dingus (1992), are similar in nature. The idea that warnings or information in general be graded, such that the driver does not react to a discrete on/off signal or warning, may have a positive affect on the design of warning systems. If an alarm demands a high mental workload and operator performance decreases, the alarm may not be useful. This can not be emphasized enough. It is crucial that the system be intelligent enough to recognize critical and non-critical situations.

1.6.3 Display Modalities

Alerting through several sensory modalities are possible for incorporation into collision intervention systems. The goal of any display modality is to display information to the driver such that a rear-end collision can be overted. A correlated goal of these information displays is to orient the attention of the driver to the collision threat. The primary modality for most of the current systems available is a visual display paired (generally a discrete on/off LED) with an audio tone. The advantages and disadvantages of several display modalities are described in figure 1.6.3–1.

1.6.3.1 Auditory Display Considerations

An alternative medium to visual displays is auditory information including voice–based systems. Several collision intervention systems utilize auditory displays of one kind or another (see Stein, 1989, 1992, Kopf, 1992, Janssen et al. (1991)). Many studies have been published discussing the use of auditory channels in advanced automotive technologies. Most however, have been related to the use of automotive navigation systems.

During some of the first prototype synthesized voice studies, Turnage and Hawthorne (1984) found that drivers did not respond as well to synthesized speech as to natural speech. Thomas et al. (1989) found that the processing of synthetic speech can produce increased demands on the short-term memory as compared to human speech. They noted that the observed performance decrements were attributed to memory capacity and not to mis–perception of

DISPLAY MODALITY	ADVANTAGES	DISADVANTAGES
VISUAL Graphical/ Qualitative	driver can discriminate the intake of information (ignore unwanted information) information is descriptive continuous situation awareness rate of change (trend) information easy to learn easy to use	may be difficult to initially alert visual attention of driver must be looking at display to gather info increase visual attention workload clutter of dashboard May be distracting draws point of regard away from collision threat
Quantitative	discrete information absolute value of indicator (information is precise)	must be looking at display to gather info discrete on/off display may increase false alarm preconceptions increase visual attention workload digital information not specific to meaning draws point of regard away from collision threat
AUDITORY Voice	does not require focus of attention provides varying information messages of danger alerts driver without overloading visual attention parallel processing personalized effect for alerting driver most likely to orient driver attention to the forward vehicle	not applicable for hearing impaired auditory message may confuse driver and cause disruption of focused attention
Tone	alerts driver without visual overloading most likely to orient driver attention to the forward vehicle does not require visual attention parallel processing short perception time	continuous tones will be annoying driver may adapt to continuous tones not applicable for hearing impaired Intensity can startle driver
HAPTIC Steering Wheel Vibration	alert driver without visual overload don't need to be paying visual attention may orient the point of regard to the forward vehicle	response conflict: steering to avoid collision, vibration may interfere at fast speeds, car (wheel) may already vibrate signal misinterpreted on rough road (gravel) may provide ambiguous cue
Shoulder Belt Tightening	alert driver without causing a jerky reaction alert driver without visual overload may orient the point of regard to the forward vehicle	use of shoulder belt may not be universal may provide ambiguous cue may misdirect attention
Seat Vibration	alert driver without visual overload may orient the point of regard to the forward vehicle	seat may vibrate when car is traveling at fast speed signal misinterpreted on rough road (gravel) may misdirect attention may provide ambiguous cue

Figure 1.6.3–1. Trade study of display modalities

synthetic speech. In contrast, later work indicates that synthetic speech has become more of an asset and that intelligibility has improved over the years.

Davis and Schmandt (1989) report that driving instructions are more helpful when modeled after the style in which people normally give instructions or in natural language. The Back Seat Driver system (Davis and Schmandt, 1989) and the DIRECT system (Gilbert et al., 1991) are two systems that have examined the use of voice-based in-vehicle information systems.

Walker et al. (1991) reported that drivers using auditory navigation devices drove more safely than when using visual devices. Subjects using visual devices missed more gauge changes, had longer reaction times, and drove more slowly than subjects using auditory devices. Presenting the same information both aurally and visually was also suggested.

Additional research assessed the workload differences between presenting information visually and aurally. For example, Labiale (1990) showed that a subject's workload is lowered when utilizing an aural presentation of navigation information as opposed to a visual presentation. It is also noteworthy that drivers preferred the auditory information and felt it was a safer system.

Despite the apparent advantages of voice systems over visual displays for in-vehicle applications, Dingus and Hulse (1993) pointed out that aural information may not be a panacea for attention and workload concerns. The workload required to process auditory messages increases as the intelligibility of these messages decreases. For collision warning applications (relative to automotive navigation displays) where very short words or commands are displayed, this may be an advantage. Dingus and Hulse point out that low cost voice synthesizers have poor quality output, whereas digitized voice is very realistic.

Even though numerous research studies have been conducted testing various forms of synthesized speech, the state-of-the-art knowledge is not yet to the point where intelligibility/comprehensibility can be predicted in all situations or environments. However, it is known that a number of factors influence intelligibility, including speech rate, message length, message content, message complexity, background noise, pitch, and loudness (Van Cott and Kincade, 1972; Marics and Williges, 1988).

One intelligibility factor that is particularly important in an automobile and affects both digitized and synthesized speech, is background noise. Noise in an automobile sometimes reaches 90 dB(A), making voice intelligibility virtually impossible in some circumstances (Bailey, 1982). The noise in an automobile also comes from many sources with different masking properties (e.g., C-Bs, cellular telephones, stereo systems, conversation, and road noise) making alleviation of the noise problem more difficult. Another consideration is that there are situations when in-vehicle auditory displays could mask other important signals (e.g., at railroad grade crossings or when emergency vehicles sirens) (Lunenfeld, 1990). Therefore, the loudness and spectral content of the voice must be carefully considered.

Labiale (1990) addressed some of the intelligibility concerns by recommending aural cues be used as a prompt to a very simple visual guidance presentation. It was also recommended that the aural message be repeated to aid in intelligibility and recall, especially if information is complex, .

How a driver interprets and prioritizes a voice message is a potentially negative issue related to the presentation of aural commands. A Japanese automobile manufacturer study indicated that drivers tended to instinctively respond to verbal information more than visual information. This instinctive behavior held true even if the in–vehicle instructions conflicted with traffic regulatory information; turning the wrong way onto a one-way street (Noy, 1991).

Dingus and Hulse (1993) recommended that the auditory modality be utilized to redundantly: (1) provide an auditory prompt to look at a visual display for changing of upcoming information (thus lessening the need for the driver to constantly scan the visual display in preparation for an upcoming event); or (2) provide simple visual information as a supplement the auditory message (so that a message that is not fully understood or remembered can be checked, or later referred to, via the visual display). These recommendations apply in large part to the application of collision warning displays. The goal of any collision intervention system should be to focus the attention of the driver on the leading vehicle. The visual displays ultimately serve as status information, while providing increased situation awareness. It is crucial that visual displays do not detract the driver's point of gaze away from a lead vehicle braking hazard.

1.6.3.2 Tactile Display Research

There are methods of information presentation that can be used to bypass visual and auditory information. Janssen and Nilsson (1990) compared a buzzer, light and a "smart gas pedal" (an accelerator pedal that would pulsate when headway was reduced) in three simulator collision warning systems. The use of lights or buzzers increased potentially negative behavior. Negative behavior was defined as an increase in driving speed, increase in acceleration and deceleration levels, and an increase in left lane driving (passing behavior). The "smart" gas pedal had none of these negative side effects and reduced following distance.

Nilsson, Alm, and Janssen (1991) further studied driver reaction to three conditions utilizing the "smart gas pedal": warned, suggested, and intervention. A "warned" subject would receive gas pedal vibration only if they were following too closely behind another vehicle. A driver in the "suggested" condition would feel gas pedal resistance, but could override the resistance by applying more pressure. In the "intervention", condition the pedal automatically slowed the car to a four-second following distance. While the "intervention" was the safest with regard to behavior, it was met with the least acceptance; drivers preferred the "warned" and "suggested" systems.

2.0 Types of Collision Intervention

NHTSA has designated three broad categories of rear-end collision avoidance systems:

1. Driver Action Systems
2. Headway Maintenance Systems
3. Automatic Control Systems.

Each of these system categories has unique driver interface issues which must be assessed before driver behavior and the resulting system performance can be understood.

2.1 Driver Action Systems

A driver action system, generally referred to as a "collision warning system", indicates to the driver the actions required to avoid an impending collision. For example, this system would warn the driver of an unsafe rate of closure and inform the driver to brake to avoid an impending collision. This system will not automatically take control of the vehicle to avoid a crash.

2.2 Headway Maintenance Systems

Headway maintenance systems provide collision threat information to the driver, but do not instruct the driver on specific actions or take total control of the vehicle. Headway maintenance systems can be broadly categorized into one of three types:

- *Manual operation subsystem* – The manual operation subsystem displays vehicle distance to the vehicle in front, information which enables the driver to maintain a constant headway. This type of system would not provide a warning, nor would it instruct the driver as to specific actions required to avoid an accident.

- *Autonomous Intelligent Cruise Control (AICC)* – The Autonomous Intelligent Cruise Control (AICC) allows the driver to select a cruise control feature that, in addition to maintaining a pre-set vehicle speed, tracks a forward vehicle (when present) and automatically maintains a safe headway. Such a device may include an alarm feature which would activate when unsafe closing speeds are detected.

- *Cooperative Intelligent Cruise Control (CICC)* – The Cooperative Intelligent Cruise Control (CICC) subsystem is an extension of AICC in which the leading vehicle uses a rearward transponder or other vehicle dynamics to transmit information to a following vehicle.

2.3 Automatic Control Systems

Automatic control systems, generally referred to as a "collision avoidance system", are those systems that have the ability to take partial or full control of the vehicle in the event that the driver is not responding properly to an unsafe situation. They may include systems that only brake or brake and steer the vehicle to avoid a crash.

3.0 Current and Past Collision Intervention Systems

3.1 Summary of the Literature on Collision Warning Systems

The collision warning systems literature review revealed that current and past research has primarily concentrated on the sensors used in detecting vehicles. An emphasis was placed on developing efficient algorithms for collision detection and keeping the number of false alarms to a minimum. Many studies cited that the intricacies involved in the design of the collision warning interfaces would be considered after the sensor and the collision detection algorithms reached acceptable levels of performance.

Several studies estimated safe headways by taking into consideration the speed of the following vehicle relative to the speed of the leading vehicle. In addition, the rate at which the host vehicle closed on the target vehicle, the coefficient of friction between the road surface and wheels of the host vehicle, the road surface (Heiner, 1992, Dull, 1983) and the type of roadway (freeway or city traffic) (Stein, 1992) were considered. The two most frequently used parameters in calculating the safe headway are the rate of closure and the relative velocity.

3.2 Previous Driver Interfaces

Although many articles did not discuss user interfaces, however, some information was obtained. The specific driver interfaces identified consisted of experimental graphical displays used in simulation (Kopf, 1992), graphical displays used in field tests (McGehee et al. (1992), and discrete on/off warnings (Hermann, 1983; Stein, 1989). These systems also utilized warning displays to alert the driver of hazardous circumstances. However, they did not provide automatic braking or release of the accelerator pedal.

Since these articles did not focus on user interface, little insight was provided on how future driver interfaces will be designed. However, both Kopf (1992) and McGehee, et al. (1992), take similar approaches in the design of their interfaces. Since drivers use relative vehicle size as the strongest depth cue, designers created icons to visually enhance a driver's perception of relative size. A set of multi-colored bars placed in perspective was used in both Kopf and McGehee et al. (1992) studies. As illustrated in figure 3.1–1, McGehee et al. also tested a multi-colored perspective roadway with a car icon that represented the lead

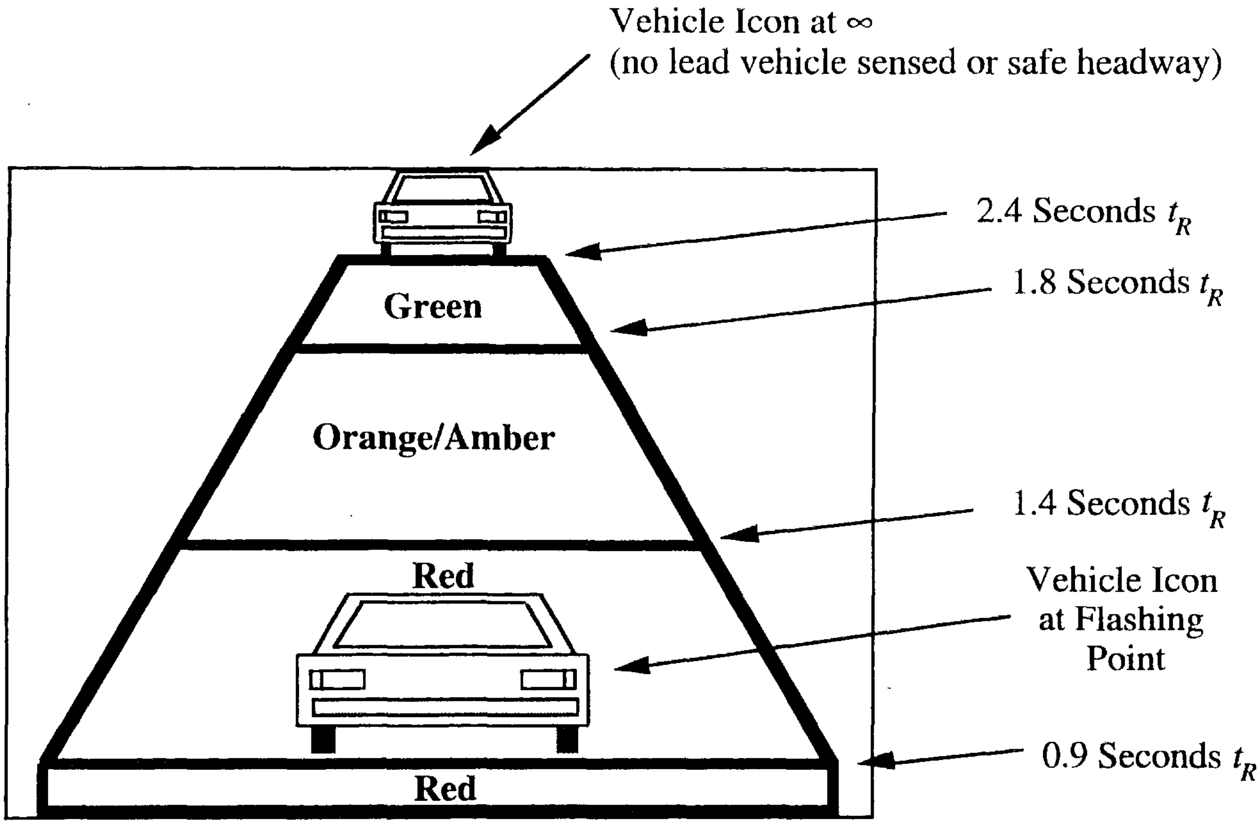

Figure 3.1–1 McGehee et al. (1992) Perspective Car Icon Display

vehicle and increased in relative size as it moved closer to the lead vehicle. Initial results indicated that the use of perspective displays did have a positive affect on the behavior of a following driver. McGehee and his colleagues also tested a similar perspective representation (see figure 3.1–2) that utilized a series of

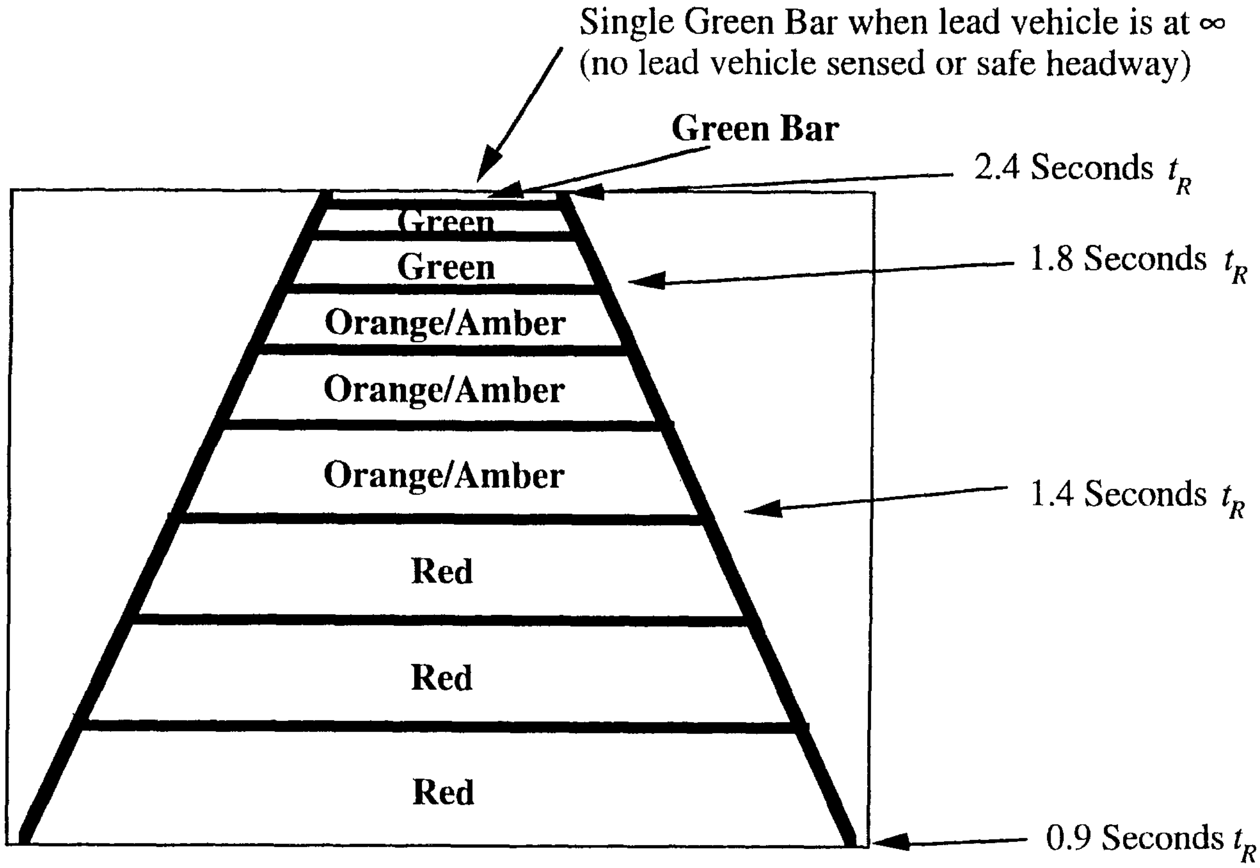

Figure 3.1–2. McGehee et al. (1992) Perspective Bars Display

perspective, multi–colored bars. As the lead vehicle came closer, the number and width of bars would increase in number and size.

3.3 False and Nuisance Alarms and Miss Rates

Except for high incidence of false and nuisance alarms, the systems reviewed seem to have performed reasonably well in traffic circumstances (Stein, 1989; 1992). False and nuisance alarm situations occur when the collision warning system is activated in the absence of a real collision situation. Nissan's Traffic Eye (Stein, 1989), showed false alarm rates in excess of 80%. Radar

Control System's Radar Collision avoidance system, which was the prototype VORAD system (Stein, 1989) showed false alarm rates of 60%. These alarms occur because of the systems inability to discriminate between clutter and the target, the inability to track stationary objects in the vehicle's path, inclement weather conditions, and traffic congestion.

Miss rates of these systems were also discussed in some of the research. Some systems failed to activate a warning signal in a potential collision situation. The Laser Collision Avoidance System (Nissan) (Stein, 1989) registered a miss rate of 3% while the Radar Collision Warning System (VORAD) (Stein, 1989) recorded a 7% miss rate.

It is important to recognize that previous research in the development and testing of collision warning systems has *not* concentrated on the design and test of related driver interfaces. Field tests conducted in many of these studies were aimed at improving the system performance rather than evaluating the usability and usefulness of the systems.

The only studies specifically testing driver interfaces were the McGehee et al. (1992) and the Janssen et al. (1989) studies. This demonstrates that more collision intervention system design research is needed. Sensor technologies advance rapidly in their capability, while the driver/human factors issues have remained relatively constant, yet unresolved.

3.4 Collision Avoidance Systems

While European investigators have generally favored driving warning systems, the U.S. has focused efforts on developing automated collision intervention systems. These systems, that take an active part in vehicle control, consist of a sensor, a control system, and a driver interface. Sensors that have been considered are radar, (either microwave or millimeter wave) infrared laser, and more recently, video imaging processors. Each has advantages and disadvantages.

Infrared laser sensors have an advantage over radar, due to the narrower beam which resulting in fewer false alarms by eliminating detection of targets outside the vehicle path (except on curves, grades etc.). However, infrared laser sensors are more sensitive to adverse environmental conditions.

The control systems on these devices utilize a decision algorithm, most often based on stopping distance, to determine appropriate system response. Stopping distance is (at least) a function of distance between vehicle and target, speed of the trailing vehicle, deceleration capability of the trailing vehicle, and the driver/system reaction time. Because driver reaction time can not be continuously monitored, it must be set by some other means. This value is usually set as a constant, though Bosch (cited in Alvisi et al., 1991) developed a system which reduces the value if the brake pedal is being depressed.

Another system which has active and passive braking eliminates the reaction time when the system is active (cited in Alvisi et al., 1991). Since deceleration is a function of road conditions, a selector switch can be employed so the driver can input the present conditions (i.e., dry, rain, or snow).

Some systems, especially active cruise control, base control on time-to-collision instead of stopping distance (Sawyer, 1993). This is especially useful with coupled vehicle systems in which the leading vehicle's velocity varies.

Systems reviewed for this paper most often provided driver interfaces that were visual. Some systems have used a series of LEDs which represent the distance between the host vehicle and its target. LCD or CRT displays which give a pictorial representation of the vehicle's relative position to the target have also been used. This often consists of a car icon which changes size (emulating perspective) on the screen and indicates safe following distances (Maretzke et al., 1992).

Auditory warnings in the form of buzzers (Jurgen, 1986) or voice (Sawyer, 1993), have been used with visual warnings as well. Haptic feedback (through the accelerator pedal) has also been applied in conjunction with a visual display. Another possibility for a visual interface is through head-up-displays (Janssen, 1990).

The biggest concern of any collision intervention system are false/nuisance alarm rates. Means of reducing these alarms include limiting coverage volume and/or reducing the sensor range, reducing the parameter limits of the sensor as a function of the steering angle, and employing target signatures (Najm, 1993). Of these, all but the latter reduce the effectiveness of the system. The most effective means of reducing false alarm rate is target identification through multiple scanning beams, image processing, or cooperative systems (Shefer et al., 1973, Alvisi et al., 1991, Palmquist, 1993). However, these systems are more costly and difficult to implement.

3.5 Intelligent Cruise Control Systems

Intelligent Cruise Control (ICC) Systems are similar to some of the other collision intervention systems discussed previously. ICC Systems take an active part in controlling the vehicle's speed. These systems are designed for coupled driving circumstances and utilize the available deceleration of the system. Deceleration can be accomplished through limited access to the brake system, use of transmission downshifting, or engine speed control (Haugen, 1992).

Different levels of system interaction are possible, ranging from informative to automatic. Most systems work the same as a typical cruise control, with the exception that if a vehicle in front slows down, the ICC matches the speed. When it is possible to resume the original speed set by the driver, the system automatically does so. The determination of the target can be either manual (the driver is required to set the system) or automatic (the system locks onto whatever is in front) (Haugen, 1992). In either case, should the vehicle require deceleration greater than that provided by the system, an audible signal alerts the driver (McCarter, et. al., 1993) that evasive measures are required.

System data acquisition and control is similar to that of collision intervention systems. They incorporate a forward looking sensor, a decision algorithm, and a human interface. The driver interface must allow the driver to at least activate, deactivate, and reactivate the system, while also setting the headway distance in time, and cruising speed desired. Other inputs include target lock and desired vehicle separation (Palmquist, 1993). System feedback is provided by lights indicating the set speed or by more detailed information displayed on a screen.

4.0 A Previous Model of Rear-End Crash Avoidance

In an attempt to model potential theoretical collision avoidance system effectiveness, Knipling (1991) developed a model of rear–end collision countermeasure action. This model is valuable because it factors in the kinematics of the vehicle deceleration problem the time required for a driver to initiate a countermeasure action. The output of the model is a prediction of the distance required to bring a vehicle to a complete stop given its initial velocity and a driver/vehicle response delay. Knipling (1991) recognized that variance in the normal driving population made it unfeasible to use a single set value when determining brake reaction times. Several different PRTs and vehicle response scenarios were analyzed to define optimistic and pessimistic values for distance required to stop the following vehicle.

The following equation defined by Knipling (1991) provides the headway distance required to assure that a collision will not occur in an LVS collision scenario:

$$\mathbf{D_{HD} = T_D V_O - 0.13 V_O + V_O^2/2A}$$

Where:

$\mathbf{D_{HD}}$ = Total distance in feet needed by the headway detection system to prevent an LVS collision.

$\mathbf{T_D}$ = Time response delay of driver/vehicle system.

$\mathbf{V_O}$ = Initial velocity of the following vehicle (ft/sec).

$\mathbf{A}$ = Rate of braking deceleration during maximum braking efficiency (feet/second^2).

To determine values for driver/vehicle response time, assumptions were made about each of these three components. The system detection delay and time to reach maximum braking were respectively assigned assumed values of 0.25 and 0.5 seconds. Driver reaction time was assigned a value 1.42 seconds which is equivalent to the brake reaction time abilities of a 90th percentile driver. These values combined to make a total driver/vehicle response delay of about 2.17 seconds. The rate of vehicle deceleration was assumed to be .45g which is equivalent to a 10th percentile vehicle braking performance value. The equation for headway distance based on the previously discussed values is as follows:

$$\mathbf{D_{HD} = 2.04V_O + V_O^2/29.0}$$

Where:

$\mathbf{D_{HD}}$ = Total distance in feet needed by the headway detection system to prevent an LVS collision.

$\mathbf{V_O}$ = Initial velocity of the following vehicle (ft/sec).

$\mathbf{A}$ = Rate of braking deceleration during maximum braking efficiency (feet/second^2).

Knipling (1991) also discussed the implications of designing a system based on both optimistic and less-than-optimistic reaction times and braking performances. Several curves were developed to show the effects of different driver and vehicle capabilities. The optimistic driver/vehicle reaction curve used a driver reaction time value that was two standard deviations below normal reaction time and a vehicle deceleration value that was two standard deviations above normal braking abilities. Conversely, the less-than-optimistic driver/vehicle reaction curves were generated using values for driver reaction and vehicle reaction that were two standard deviations above and below the respective mean values respectively. This provided Knipling (1991) with stopping distances which were compared with some actual crash report database values, to determine whether or not a collision intervention system would have helped prevent the incident.

5.0 The Development of an Expanded Model to Support Performance Specification Development

The Knipling (1991) model makes several assumptions and simplifications about the rear-end collision scenario. First, the model accounts for only those situations where the lead vehicle is stationary. The LVM rear–end crash potential can be affected by the behavior of the lead vehicle as well as differences in perceptual factors caused by the lead vehicle's motion (e.g., relative velocity cues). These differences can alter the driver's detection abilities and countermeasure response selection. The Knipling model assumes that the driver will automatically apply and maintain maximum brake force when a collision avoidance signal is given, which may or may not be the case in actual collision scenarios. The actual driver response might be affected by complicating factors that Knipling calls "real world" constraints. These "real world" factors include false and nuisance alarms, compensatory risk taking, unsafe driving behavior, and driver acceptance, as well as environmental and vehicular factors.

While Knipling's model does take into account some individual differences within the normal driving population, it does not make an attempt to quantify the affects of the "real world" factors that were identified in his analysis of the overall rear–end collision scenario. Evaluating these effects on variables inherent in the overall rear-end collision scenario is a complex task, especially since some of the effects are not yet fully understood and need to be determined by further empirical research efforts.

In order to support the project goal of performance specification development, it is critical to understand the effects of differing system parameters on performance of the total collision avoidance system, including the human operator. For example, a performance specification requirement needs to be developed specifying the maximum false alarm rate for a variety of differing circumstances. The only way to determine this requirement is to fully understand the effects of differing false alarm rates on overall system performance. This performance is very much dependent upon factors such as driver adaptation to the information reliability of the system, since reaction time will likely increase as information reliability decreases.

To facilitate the understanding of, and provide a framework for the development of, driver-related system requirements, an expanded rear-end crash avoidance model will be developed as part of this project. This model will utilize existing knowledge generated from epidemiological and empirical research to the greatest extent practical, and will build on existing models such as the one developed by Knipling (1991). Additional data will be generated from empirical, simulator research, to the extent practical with project resources. Once completed, it is anticipated that the model will be useful for: (1) conducting sensitivity analyses to determine the relative impact of relaxing or tightening performance standards, and (2) determining for a variety of case studies whether a given collision avoidance system would have eliminated or mitigated a crash.

5.1 Elimination of Variables from Further Model Consideration

The previous sections of this report defined many variables that likely contribute to the delineation of events leading to a potential rear-end collision. Many of these variables appear to be inter-related (e.g., age, risk perception, false alarm rate, reaction time). Because so many variables affect potential rear-end collisions, development of a completely comprehensive model would be extremely complex and beyond the scope of the current project. Therefore, a more realistic project goal is to develop a model comprehensive enough to be valid for analyzing the effects of a collision intervention system., yet simple enough that available data and limited additional empirical research can be utilized to determine model parameters. The goal of this section of the report, therefore, is to reduce the scope of model variables, or to eliminate the variable from the model altogether, if inclusion results in limited value-added.

Epidemiological and empirical sources of data were reviewed in the context of potential model variables. Each variable was considered for elimination or provision of a fixed value based on these data sources. Epidemiological data can be used to identify those variables that contribute to a low percentage of rear-end collisions. If a variable is found to be involved in relatively few rear–end collisions, it may be assumed that it is not a salient factor or does not occur in the natural driving scenario often enough to be considered in the model.

Empirical research can be used to reduce the possible values that a variable may have based on data collected in the study of collision intervention systems. A hypothetical example of this is the sensory mode of information display that a collision avoidance system might use. If previous studies have already shown that auditory displays are significantly more effective for collision information display, the model will not consider other modes such as visual or haptic displays.

It is necessary to reduce the number of possible variables so that only those factors that provide relevant and valuable information are included in the model. Previous attempts to model potential collision events have also used simplified variables to reduce complexity. In an attempt to model potential rear–end collision situations where the lead vehicle is stationary (LVS), Knipling (1991) included a list of variables that make up a driver/vehicle time response delay from when a potential rear–end collision first exists until the vehicle attains maximum braking. The list of variables includes system detection delay, driver response time, and the amount of time required to develop maximum braking from the onset of braking control input. This list does not include any variables representing the effects of sensory modes of information display, the type of information that is presented, or the drivers initial attention location.

The actual driver response component of the Knipling (1991) model uses a 90th percentile brake reaction time figure that was obtained through previous research. The elimination or use of constant values for variables can reduce model complexity, but it also can reduce the accuracy of the model in scenarios that include non-standard factors.

5.2 Candidate Variables for Elimination

5.2.1 System Factors

Many different system design parameters could be used as variables in a model to describe a potential rear–end collision scenario. In an effort to keep this model valid and usable, the following variables will be assigned a constant value based on the results of previous research efforts.

Graded Warning Levels - A report defining guidelines for collision avoidance devices *(COMSIS, In press)*, suggested that two distinct levels of warning information need to be provided to the driver; imminent crash and cautionary crash avoidance warnings. The imminent crash avoidance warning should be presented in situations where immediate corrective actions are required. This warning should be displayed in the most salient method available. The cautionary crash avoidance warning should be used in situations that require immediate attention and corrective action. This warning should be presented in a method that will capture the driver's attention, but will not be as annoying or disturbing as the immediate crash warning. The cautionary warning will be triggered more often due in false and nuisance alarm situations. These two warning levels allow a less annoying alarm to be used for the cautionary message, by providing a more salient message when immediate action is required.

Sensory Modes of Presentation - Imminent crash avoidance warnings need at least two sensory modes (*COMSIS, In press*). One of the sensory modes should be visual, and the other either auditory or tactile. The auditory method is the most desired mode of presentation when it is necessary to command the driver's attention. The haptic sensory mode also holds promise, but requires additional research in the context of collision warning. Using the visual mode of presentation in combination with the auditory mode provides the ability to efficiently get the drivers attention and convey situation specific information.

Cautionary crash avoidance warnings are generally less urgent than imminent warnings and be displayed more often. In order to minimize the driver distraction and annoyance that might be created by an abundance of auditory cues, the *COMSIS* report (1993. In press) recommends that the visual mode of presentation be used alone for cautionary information.

Some research has been performed on the use of haptic cues for conveying collision avoidance information to the driver. To date, there is no clear understanding of the effectiveness of these types of displays. The use of this type of display requires more research before a determination about its effectiveness can be made. For purposes of this analysis, it is assumed that the

COMSIS recommendations for display modality are correct, but future display modality research will include haptic displays.

5.2.2 Environmental Factors

Environmental factors can affect the system's and driver's ability to detect an imminent collision situation and how the vehicle will react when countermeasures to avoid the collision situation are applied. As defined in a previous section of this report, there are an abundance of environmental factors that could be included in a model to predict the outcome of a potential-rear-end collision situation.

In a review of the 1990 NASS General Estimates System (GES) crash statistics database, it was found that at least one environmental variable was a factor in approximately half of all LVS rear-end collisions. While all environmental variables combined have a substantial affect on the rear-end collision scenario, several individual variables contribute to such a low percentage (less than 10%) of collisions that their elimination from a prediction model would not affect its validity in most cases, particularly if those cases are not considered as model inputs.

Roadway Curvature and Elevation Changes The 1990 GES crash statistics show that less than 10 percent of all rear-end collisions occurred on curved roadways. Even fewer (less than 3%) of all rear-end collisions were reported to have occurred in the vicinity of a hill crest. The affects of a hill crest or change in roadway curvature are technically challenging circumstances that will result in increased probability of system errors. Due to the relatively low involvement of these variables, and the inability of current, low-cost technologies to provide error-free data, they will not be considered in the development of a rear-end collision prediction model for this project.

Weather - The significant variable associated with weather appears to be its affect on the vehicle's ability to brake effectively, rather than any affects it may have on the driver's ability to perceive a potential collision situation. According to 1990 GES statistics, 72 percent of rear-end collisions occurred on dry pavement and around 25 percent occurred on wet pavement. Snow and ice were listed as a contributing factor in less than four percent of rear-end collisions, while fog was listed as a factor in less than one percent of all rear-end collisions. The low percentages for visibility-impairing weather indicate that it is the weather's affect on roadway friction that contributes most to rear-end collision situations, rather than decrements to visibility. Because of the low percentages, fog and snow will not be considered in the development of the rear-end collision prediction model.

Ambient illumination - Less than six percent of all rear-end collisions occurred due to a lack of ambient illumination. All other collisions occurred in conditions of artificial street lighting or daylight.. This is not surprising, since it is easier for a driver to detect the brake lights of a slow moving vehicle in high-contrast, darker background conditions. These results suggest that a lack of ambient illumination is not a significant factor in the rear-end collision scenario and should not be considered in the development of a near-term model.

5.2.3 Human and Behavioral Factors

Driver Impairment - Driver impairment, due to the use of alcohol, contributed to less than three percent of rear–end collisions according to the 1990 GES crash database and less than nine percent according to the Indiana Tri-Level Crash statistics (Treat *et al.*, 1979). While alcohol induced driver impairment is a significant problem in overall driving safety, it appears to be a less significant factor in rear-end collision scenarios. Because of the relatively low impact of driver alcohol impairment on the rear-end collision scenario, and the resources required to assess affected model parameters initially, it will not be considered in the rear-end collision prediction model developed for this project.

Gender There is now evidence to support that gender has any affect on the rear-end collision scenario. For both LVS and LVM scenarios, the percentages of male and female drivers involved in rear-end collisions is equal. There is also no clear evidence that indicates that gender affects other aspects of driving behavior such as following distances or reaction times. Therefore, gender will not be used in developing a collision model.

5.2.4 Vehicle Factors

According to the Indiana Tri-Level Crash statistics (Treat *et al.*, 1979), vehicular factors were reported to have contributed to 11 percent of LVS crashes and 17 percent of LVM crashes. With the exception that most crashes were related to the brake system, details were not available. Even though vehicular factors contributed to a relatively high percentage of rear-end collisions, they will not be included as a variable in future modeling efforts beyond the definition of the normal braking characteristics of the vehicle.

While brake system failures have a very high potential to create a rear-end collision, a rear-end collision avoidance system could do very little to resolve this problem. In the case of poorly operating brake systems, the collision avoidance system could notify the driver of the condition. However, since this condition is rare on a day-to-day operations basis, further consideration in future rear-end collision modeling efforts would have limited utility.

5.3 Preliminary Collision Intervention Model

Previous sections of this paper have delineated the rear-end crash scenario based on human and environmental factors. While these sections also pointed out a large number of variables that can contribute to the occurrence of a rear-end collisions, the last section identified several variables that can be effectively eliminated from a predictive rear-end collision model.

This section describes the components of the collision scenario and the remaining relevant variables that contribute to driver/vehicle performance within each component. The variables do not include the standard kinematic inputs from previously discussed rear–end collision models. These components can be used and expanded upon without a great deal of additional consideration. Instead, those components that contribute significantly to variances in collision avoidance response time will be discussed. Figure 5.3–1 shows the components of a rear-end collision scenario and lists some of the variables that influence driver/vehicle behavior for each component.

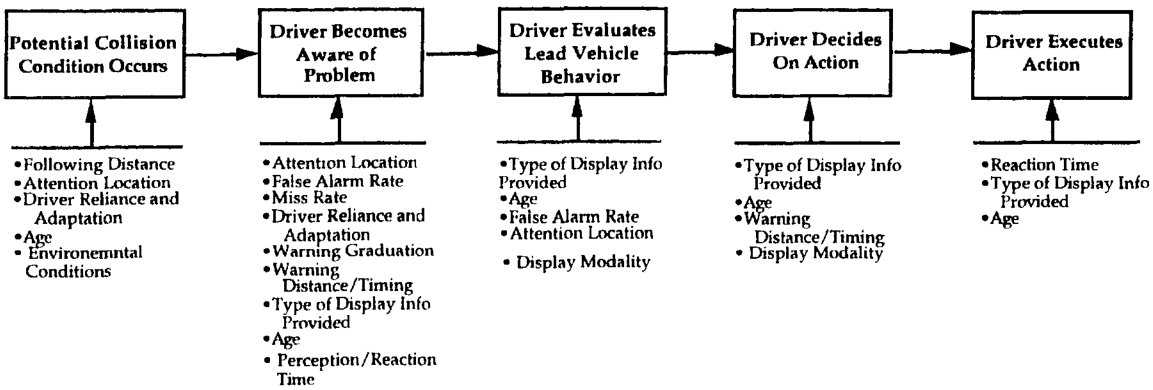

Figure 5.3–1 Collision Scenario and Contributing Variables

The first component involves the development of a collision situation. In a normal driving environment, the status of the driving condition would be safe with little potential for a rear-end collision to occur. As the conditions (i.e., traffic, lead vehicle behavior, use of a collision avoidance system) surrounding the driving environment change, the potential for a rear-end collision will change. This component involves the potential rear–end collision pre-cursor events requiring immediate driver/vehicle action to avoid an impending collision.

Currently, in the normal driving environment, drivers must rely solely on their own attentional and sensory abilities to detect the presence of a collision situation. Since this paper is interested in the effects of collision avoidance systems, it is necessary to include those factors that may affect the driver's awareness. Making the driver aware that a collision situation exists is the most important feature of collision avoidance systems. Several variables listed for this component can have a direct effect on how efficiently the driver detects a problem.

The next portion of the collision scenario pertains to the driver's evaluation of the lead vehicle's behavior. The driver attempts to gather information about the behavior of the vehicle ahead to determine the criticality of the situation. At this point the driver is aware of potential collision situations through either his/her own abilities or the collision avoidance system.

After evaluating the information gathered about the lead vehicle, the driver must decide the appropriate action to be taken. This will ultimately determine whether or not the crash will be avoided.

The final step in the model is to execute the action that has been decided upon. This step will often consist of moving the foot from the accelerator to the brake pedal and pressing it. The use of a collision avoidance system could affect this portion of the scenario. For example, systems have been suggested that would initiate the brake response automatically for the driver.

The variables that have been included in figure 5.3–1 have an affect on the driver reaction component of a rear–end collision model. Previous models (Knipling, 1991) have developed kinematic equations for analyzing rear–end collisions which include driver reaction time and some set value for system reaction delay. The value for driver reaction time was determined by selecting a percentile level of a distribution of driver reaction times to some unknown type of braking event. As discussed previously, many factors can have an affect on reaction times, especially when a collision avoidance system is in use. A model that will develop performance specifications for a collision avoidance should take these factors into account in order to support detailed performance specification development. The effects of some of these variables on reaction time in a driving situation are as of yet unknown.

Based on the variables identified in figure 5.3–1, figure 5.3–2 describes both the knowns and the unknowns of the rear–end collision scenario that warrant consideration in a rear–end collision prediction model. Figure 5.3–2 also lists each variable and the source (or future source) of information to be gathered to determine the overall effect on driver/system reaction time.

The knowns have been determined by reviewing epidemiological data or by interpreting the results of existing empirical research and analysis. The unknowns are research questions that will be studied at the University of Iowa's Center for Computer–Aided Design.

	Existing Literature	GES Crash Data	Vehicle Perf. Data	Exper-imentation
Driver Behavior				
Initial Attention Location	•			•
Reaction Time	•			
Decision Time/Accuracy	•			
Countermeasure Action		•		
Reliance and Adaptation				•
Following Distance	•			•
Age	•			•
System and Display Characteristics				
Warning Graduation	•			•
Warning Distance/Timing	•			•
False Alarm Rate				•
Miss Rate				•
Type of Display Interface:				
Visual	•			•
Auditory	•			•
Haptic	•			•
Type of Info Provided	•			•
Vehicle Dynamics				
Coupled Headway			•	
Relative Velocity			•	
Rate of Closure			•	
Host Vehicle Sensor			•	
Host Vehicle Braking Perf.			•	
Lead Vehicle Braking Perf.			•	
Environmental Conditions				
Pavement Wet/Dry		•	•	

Figure 5.3–2. Collision Intervention Information Source Matrix

As the information about the effects of the defined variables becomes available, it will be incorporated into a collision intervention model similar to Knipling's (1991). This will be accomplished by either adding new terms to the existing equations or by making a more accurate assessment of reaction time given the system parameters and driver characteristics that are available.

6.0 Future Directions

As discussed above, future research conducted as part of this project will assess driver/human factors that can will likely impact a detailed rear-end crash prediction model. In order to develop a performance specification which provides parameter requirements for collision intervention systems that affect driver/system reaction, a number of "unknown" issues must be addressed (as shown in figure 5.3–2 above).

Since it has been shown that driver attention is the leading causal factor in rear–end crashes, it is imperative that any type of collision intervention system orient the driver's attention to the forward vehicle. Furthermore, since following too closely is also a causal factor, it is important to increase the drivers situation awareness of the leading vehicle. This increased situation awareness may ultimately allow drivers more time to make decisions on lead vehicles changes resulting in a reduction of one of the most common types of automobile crashes.

Since there have been few empirical tests done on existing collision intervention systems, little information has been gathered on the usability of such devices. This research program will empirically test a variety of interface parameters, and include these results, as appropriate, in the specification of crash intervention system performance. Information obtained from these evaluations will identify interfaces that are effective in increasing a driver's situation awareness and those that may not be as effective.

Finally, a driver interface/driver performance specification can be written after all of the information from the research, and test and evaluation phases of the project are complete. The specification will utilize models created by Knipling, Frontier

Engineering, and expanded by the Iowa research staff to address each variable that significantly affects the rear–end crash timeline. By breaking down the driver/human factors of the rear-end crash scenario and fully understanding the complex interactions involved in driving, the most effective collision intervention systems can be specified.

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8.0 Annotated Bibliography

Name of Reviewer: Loren Stowe

Authors: Alvisi, M., Deloof, P., Linss W., Preti G., & Rolland, A.

Year: 1991

Title of Article/Report: Anti-collision Radar: State of the Art

Journal: Advanced Telematics in Road Transport of the DRIVE Conference, Brussels, Feb. 4-6

Pages: 943-961.

Type of Article/Report: Lit review

System Studied: Anti-collision radar

Application To Collision Intervention: Conditions of anti-collision radar and the requirements for most effective use.

ABSTRACT: The media of specific interest to this study is that of microwave radar. Acoustic radar has been rejected due to its limitations in adverse weather conditions. Frequency range is between 22 and 94 GHz with the range around 60 GHz having possible advantages due to atmospheric attenuation in this bandwidth. However, increase frequency corresponds to higher cost. The modulation is most often in one of the following forms: pulsed (well suited for multiple targets but expensive), frequency modulation in continuos wave or FM/CW (cheaper with increased cost in signal processing), and bi-frequency or diplex Doppler (simplest but not effective in for multiple targets and rain clutter).

Braking systems have been approached differently. In the US the approach has been to reduce the range of the radar to 50m on freeways (35m on curves) and incorporate automatic braking to improve efficiency. This is effective in reducing the number of false alarms. Due to the higher speeds in Europe, the approach there has been to focus on prevention through Previous work done about anti-collision (ac) radar is reviewed with requirements for the components of the systems given. The main requirements of ac radar are: physical media for target detection, automatic or manual braking, autonomous or cooperative systems, and antenna diagram warnings. Ranges in excess of 100m are necessary which results in an increase in false alarms.

Autonomous systems are independent of other vehicles. Cooperative systems require reflectors on targets. The advantage of the latter being the possibility of vehicle information exchange. However, the danger of not detecting an unmarked target may be great enough to eliminate this option.

The antenna diagram must be such to minimize false alarms while maximizing hazard detection. This is accomplished by confining the horizontal range to one lane. Vertically, the radar must not pick up overpasses or tops of tunnels whose height is generally around 6m. As such, the effective beam size is 2.5 degrees horizontally and 3.5 to 5 degrees in elevation.

Field trials can be done with the following measure taken: target RCS (Radar Cross Section) which allows for target discrimination; multi-path analysis which evaluates surface effect on the radar; and target speed and position to determine the accuracy of the radar. For multi-target environments, both distance and angle would need to be measured.

Problems that need further evaluation are false alarm rate, compatibility between different radar, and ergonomic aspects.

Key Words: Radar media, radar range, autonomous systems, cooperative systems, antenna diagram.

Name of Reviewer: Loren Stowe

Year: 1978

Title of Article/Report: Anti-collision Radar Making Progress

Journal: Automotive Engineering

Volume: 87

Issue: July, 1978
Pages: 78-80

Type of Article/Report: Lit review

System Studied: Warning

Type of Display: Auditory Visual

Application To Collision Intervention: Bosch and Daimler-Benz have developed successful collision warning systems but decided against automatic braking systems due to high incidence of false alarms.

ABSTRACT: Two collision warning systems, one by Bosch and the other by Daimler-Benz, are reviewed. Bosch uses a pulse radar which renders only the distance between the vehicle and the target. Distance, vehicle speed, and assumed braking efficiency are used to calculate a safe driving distance. When the drivers foot is not on the brake pedal, a driver reaction time of one second is included in the distance calculation. To help minimize false alarms on curves, the sensor range is reduced based on the steering angle of the vehicle. User interface includes a three position "dry-wet-snow" weather selector and a vertical row of twelve LED's.

Bosch Prototype Display

A single yellow light comes on when a target is within range. As the headway decreases the green lights come on in an ascending sequence eventually passing the yellow and entering the red zone. Beyond a critical point a larger red light flashes and a buzzer sounds.

The Daimler-Benz system uses a continuous-wave Doppler radar which measures both distance and relative speed. Daimler-Benz claims less false alarms with the radar since it is possible to distinguish between moving and stationary objects. For demonstration purposes, user interface includes a road-condition selector, a warning buzzer, and a display showing true following distance, computed safe distance, and actual speed differential.

Both companies have ruled out automatic braking due to the risk involved with false alarms and the increased cost.

Key Words: Bosch, Daimler-Benz, collision warning systems.

Name of Reviewer: Anil Kumar Yenamandra

Authors: Assman, E.

Year: 1988

Title of Article/Report: The Indication of Braking Distance in Head-Up Display: A Contribution to Enhance Driving Safety

Journal: Z.F. Verkehrssicherheit

Volume: 33

Issue: 2

Pages: 55-59

Place Published:

Type of Article/Report: Experiment

Independent Variables: Road Type

Dependent Variables: Inter-vehicle Separation

Controls: Road Type, Head-Up Display

Data Analysis Techniques:

System Studied: Warning

Type of Display: Visual

Application To Collision Intervention: A contribution to enhance driving safety.

Subject Population: 50 Subjects

ABSTRACT: This article describes a display system that provides drivers with information on the braking performance of their own vehicle. The braking distance is calculated by an onboard analog computer considering the instantaneous speed, coefficient of friction between the four wheels and the road and the average reaction time of the driver. This information is projected on to the wind shield in the form of a spot indicating the minimum distance the vehicle would travel before coming to a complete stop. A filament lamp is used to produce the spot and the motion of the filament lamp is controlled by a motorized potentiometer.

50 people participated in the experiment comprising of 180 km of driving track (18% street, 46% rural and 36% highway) and 3 trials per subject. The

subjects used the braking distance display during the second trial and were later required to answer several questionnaires. The traffic situations in which the subjects drove were classified into safe and unsafe situations and the relative frequencies of these situations were considered in the analysis.

The results from the analysis showed that there was a difference in the driving behavior of subjects with and without the display at 95% confidence for the following driving situations: a. intersection with right before left rule, b. in the case of the distance from a vehicle being passed, c: in the case of the distance from a vehicle in front and when re-entering the lane after passing, d. in the case of the distance from a vehicle in front during heavy traffic.

Key Words: Braking Distance, Spacing Between Vehicles, Speed, Head-Up Display.

Name of Reviewer: Thuy Tran

Authors: Baker, C.A., and Steedman, W.C.

Year: Sept. 1961

Title of Article/Report: Perceived Movement in Depth as a Function of Luminance and Velocity

Journal: Human Factors

Volume: 3

Issue:

Pages: 166-173

Place Published:

Type of Article/Report: Experiment

Independent Variables: visual angle

Dependent Variables: response time

Controls:

Data Analysis Techniques: none

System Studied: none

Type of Display: none

Application To Collision Intervention: The visual tasks involved in the assessment of the relative movement in depth.

Subject Population: 4 Adults

ABSTRACT: Under certain conditions, the human visual system was able to detect movement, achieved at the 75 percent threshold criterion, when the visual angle of the target changed by approximately 2 percent of the original distance. The subjects' cue in determining whether an object was approaching or moving away was the perception of the direction of a change in angular subtends of the object. Subsequent empirical research will likely indicate that perceived movement in depth as a function of original angular subtends of the target object will fall somewhere between the Weber prediction (percent visual angle change) and the prediction based on a constant increment change of 0.8 min.

Key Words: Threshold criterion level, Visual angle

Name of Reviewer: Loren Stowe

Authors: Belohoubek, E. F.

Year: 1982.

Title of Article/Report: Radar Control for Automotive Collision Mitigation and Headway Spacing

Journal: IEEE Transactions on Vehicular Technology

Volume: Vt-31.

Issue: No. 2, May

Pages: 89-99

Type of Article/Report: Field Test

System Studied: Automated Cruise Brake Headway

Application To Collision Intervention: Use of automatic headway control system and radar based collision--mitigation braking initiated at 20 to 25 m when the closure rate is high enough to make a collision unavoidable.

ABSTRACT: A radar based collision--mitigation braking and automatic headway control system is discussed. The latter of these two function maintains a safe distance between two vehicles traveling in the same direction while the former involves the actuation of the braking system in the case of an impending collision. To have an effective collision avoidance system, false alarms must be kept to a minimum. Since longer ranges would increase the false alarms rate, the effective sensor range would be limited to 25 to 30 m. For the particular system being considered, a 17.5 GHz sensor was employed, as gives an acceptable compromise between a narrow antenna beam and readily available technology. At 10 m the range rate error for the system is 0.23 m/s.

The signal from the sensor is converted into range and range rate which are then used in the control algorithm. These inputs, combined with the velocity of the vehicle, steering angle, brake pedal status indicator, and set parameters of reaction time delay and maximum deceleration, are used in the control algorithm.

To test the detection ability of the system, the radar response was recorded while approaching an expendable target at different speeds. As well, the IF signals were recorded in a wide variety of weather and road conditions. For testing the complete system, the expendable target was again used. It was found that at speed up to 40 mph the vehicle stopped just short of the target. Speeds above this caused the vehicle to hit the target but at slower speeds which corresponds to a lower impact energy.

The automatic headway control may be a means by which public acceptance of radar system may be increased. Five states exist within the system:

cruise, which is the normal driving condition; headway, where the system maintains the spacing between vehicles; resume, where the driver set speed is slowly acquired again after a target is lost; capture, which is the opposite of resume, that is the gradual slowing of the vehicle when a target is acquired; and lost target, during which the throttle is held constant while for a set time period in case of a momentary signal loss. For this system, only the accelerator was interfaced with the radar to control the vehicle speed. To smooth the response of the system, a time delay of 0.5 s was included in the algorithm. Care must be taken to not significantly reduce the effectiveness of the system in an attempt to eliminate the annoying jerky motions caused by a highly responsive system. With the given system parameters, the distance between vehicles was kept to within ±2 m.

With this system tuned to all but eliminate false alarms, braking is initiated at 20 to 25 m when the closure rate is high enough to make a collision unavoidable. This resulted in reduction of crash energy by approximately 40% for a car traveling at 55 mph. The automatic headway control successfully maintained a more consistent spacing between vehicles than drivers can, and as such, provides the possibility of a better throughput on highways while decreasing safety hazards such as bunching and tailgating.

Key Words: Automatic headway control, collision--mitigation braking system, cruise, resume cruise, capture (decelerating when target acquired), lost target (loss of signal).

Name of Reviewer: Anil Kumar Yenamandra

Authors: Belohoubek E., Cusack J., and Rosen, J.

Year: 1977

Title of Article/Report: Microcomputer Controlled Radar and Display System for Cars.

Journal: SAE Report No. 770267

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Design Rec.

System Studied: Radar Brake

Type of Display: Haptic

Application To Collision Intervention: Safety related sensors.

Subject Population: none

ABSTRACT: The collision warning and avoidance system discussed in this paper employs a non-cooperative FM/CW radar with a maximum range of 30 meters. The system gives an audio alarm when a collision is imminent and goes on to initiate a braking action to avoid the collision. The collision detection algorithms and the working of the radar are discussed at length. A Burrough's gas-plasma, single-line, 32-character self-scan display was selected to display information on the general diagnostics of the vehicle. The display had two modes, one mode displaying information on fuel level, RPM, analog display of speed while the other mode displayed trip mileage, time, fuel economy etc. The display did not provide any collision warning information.

A series of tests were conducted on the highways and winding country roads to evaluate the system performance. The system performed well and was able to track cars ahead with less number of false alarms.

The study mainly aimed at evaluating the performance of microprocessors in automotive applications, the validity of the collision warning algorithms and the efficiency of interfacing the information from various sensors.

Key Words: Collision Warning and Avoidance System, Radar Braking

Bierley, R.L., (1963). Investigation of an Inter- vehicle Spacing Display. Highway Research Record, No. 25, p. 58-75.

Name of Reviewer: Anil Kumar Yenamandra

Authors: Bierley, R.L.

Year: 1963

Title of Article/Report: Investigation of an Inter- vehicle Spacing Display

Journal: Highway Research Record

Volume: No. 25

Issue:

Pages: 58-75

Place Published:

Type of Article/Report: Experiment

Independent Variables: Information display type

Dependent Variables: Inter- vehicle separation, Relative velocity, Reaction time

Controls:

Data Analysis Techniques: ANOVA

System Studied: Warning

Type of Display: Visual

Application To Collision Intervention: Investigates the effect on spacing control of more information about vehicle spacing and relative speed.

Subject Population: 12 Drivers

ABSTRACT: The paper discusses an inter-vehicle spacing display. An analog, mechanical display (analogous to the speedometer) was employed to display the inter- vehicle distance. The display was located on the left side of the front hood. Two types of the display were considered. The first type provided information on the spacing between the subject vehicle and the vehicle in front while the second display provided information on the algebraic sum of the relative speed between the two vehicles and the distance between them. Both the displays were compensatory in nature in a sense that the driver is given information on the error and expected to compensate for it.

The one mile test track at General Motors Technical Center was employed to carry on the experiments. Each driver was given three trials namely the constant speed (the lead vehicle maintains a constant speed), acceleration and deceleration trials. Twelve drivers were given the first display and twelve others the second display. The drivers were informed to maintain the 80 ft spacing. And each subject got a trial without any display as the base-line.

The reaction times of the drivers along with average maximum spacing change were recorded for each of the display conditions and analyzed. The results show that there was no significant change in the reaction times between the display and the non-display conditions for the spacing display while there was a considerable decrease in the reaction times for the velocity-aided spacing display. There was also significant change in the average maximum spacing between the display and the no-display conditions for the second display type. The average maximum distance was reduced in the second display condition.

By changing the position display into a velocity-aided spacing display, following performance was significantly improved. There was a great reduction in the average spacing error variance and also decrease in the maximum absolute spacing change.

Key Words: Reaction time, Inter- vehicle Spacing

Name of Reviewer: Thuy Tran

Authors: Braunstein, M.L., and Laughery, K.R.

Year: 1964

Title of Article/Report: Detection of Vehicle Velocity Changes During Expressway Driving.

Journal: Human Factors

Volume: 6

Issue: 4

Pages: 327-331

Place Published:

Type of Article/Report: Experiment

Independent Variables: relative velocity

Dependent Variables: detection time

Controls: Velocity

Data Analysis Techniques: ANOVA

System Studied: none

Type of Display: none

Application To Collision Intervention: Acceleration and deceleration detection time

Subject Population: 8 subjects

ABSTRACT: This experiment attempts to measure the ability of an observer to detect accelerations and decelerations of the vehicle he is following, as a function of rate of change and initial inter-vehicular separation. Braunstein and Laughery measured the inability of a subject to detect velocity changes of a lead vehicle, by an observer seated in a vehicle traveling behind it at a fixed distance and at constant velocity. They concluded that detection time increased with inter- vehicle separation and decreased with increasing rate of change. The amount of distance change and velocity change at the time of response is greater for faster rates of change, while response latency is reduced with faster rates.

Key Words: Detection time, Inter- vehicle separation, Velocity changes, Latency

Name of Reviewer: Stefan Hofmeyer

Authors: Brill, E.A.

Year: 1971

Title of Article/Report: A Car-Following Model Relating Reaction Time and Temporal Headways to Accident Frequency

Journal: United States Naval Postgraduate School

Volume: April

Issue:

Pages:

Place Published:

Type of Article/Report: Design Of Equation

Independent Variables:

Dependent Variables:

Application to collision intervention: Develops equations to asses the sensitivity of collision probability to a shift in expected reaction times.

ABSTRACT:

The research goals of Brill (1971) was to asses the sensitivity of collision probability to a shift in expected reaction times. A formula was developed to indicate the probability of an accident according to brake reaction times. For an example of a change in a mean reaction time of 0.1 seconds, the chance of an accident in a particular case would increase from 1/65 to 1/8. The Formulas hold for only very specific instances.

Key Words: Brake Reaction Time, Car Following

Name of Reviewer: Loren Stowe

Authors: Broqua F., Lerner G., Mauro V., & Morello E.

Year: 1991

Title of Article/Report: Cooperative Driving: Basic Concepts and a First Assessment of "Intelligent Cruise Control" Strategies

Journal: Advanced Telematics in Road Transport: Proceeding of the Drive Conference, Brussels, Feb., 4-6

Pages: 908-929.

Type of Article/Report: Field Test

Systems Studied: Automated Cruise

Application To Collision Intervention: Intelligent Cruise Control is used to maintain speed and distance from preceding vehicle through the use of the speed-distance law

ABSTRACT: Four cooperative driving schemes are addressed:
Intelligent Cruise Control (ICC). Goals of ICC are threefold: 1.) harmonic speed and distance keeping, 2.) performance of basic safety functions for individual vehicle, and 3.) to provide recommendations to the driver. ICC is only a longitudinal control system whose final outputs are speed and distance from the preceding vehicle. ICC can be an autonomous or cooperative system.
Intelligent Maneuvering and Control (IMC). The goal of IMC is safeguarding and optimization of lane changing and overtaking maneuvers in unidirectional traffic flow. Cooperation between vehicles is necessary for IMC.
Emergency Warning (EW). EW provides short-range information of emergencies.
Medium Range Pre-information (MRP). Information about downstream traffic is given to the driver.

Of these schemes, ICC is the most basic and was therefore analyzed first. The system was restricted to vehicles approaching in the same lane. The four levels of automation possible are informative, warning, assist, and automatic. Parameters for the speed-distance law which control the automation is dependent upon speed of the vehicles, maximum deceleration of the vehicles, reaction time of the driver/vehicle, and effective length. The traffic scenario determines the form of the speed-distance law. For this study, the scenario was limited to driving in a file (coupled) while operating in the latter two levels of automation. This allows a basic, simplified form of the speed-distance law given as $ds = s + vt$, where ds is the distance between vehicles, s is the effective length, v is the velocity, and t is the driver/system reaction time.

Rating the effectiveness of the system is based on change in traffic density and flow. Trials were performed using the SPEACS mini-simulator. The first

assessment of the ICC is that improvements in traffic efficiency can be significant with the system. This includes improved safety.

Key Words: Intelligent Cruise Control, speed-distance law, SPEACS mini-simulator.

Bubb, H., (1976). Improvement of the Speed Control in Motor Vehicles by Display of the Braking Distance. Z. F. Verkehrssicherheit, 109-119.

Name of Reviewer: Anil Kumar Yenamandra

Authors: Bubb, H.

Year: 1976

Title of Article/Report: Improvement of the Speed Control in Motor Vehicles by Display of the Braking Distance

Journal: Z. F. Verkehrssicherheit

Volume:

Issue:

Pages: 109-119

Place Published:

Type of Article/Report: Lit review

System Studied: Collision Warning

Type of Display: Visual

Application To Collision Intervention: Driver can use the braking distance display to check up on his speed control as a kind of feedback.

Subject Population: none

ABSTRACT: This article describes a display system that provides the driver information about the braking distance. The braking distance is calculated by an onboard analog computer considering the instantaneous speed, coefficient of friction between the four wheels and the road and the average reaction time driver. This information is projected onto the wind shield in the form of a spot indicating the minimum distance the vehicle would travel before coming to a complete stop. A filament lamp is used to produce the spot and the motion of the filament lamp is controlled by a motorized potentiometer.

The display has an inherent advantage of simplicity of information presentation. The driver can see the spot on the road and just ensures that there is no vehicles within that distance. The display system is expected to function equally well under all weather conditions with the minimum speed of 18 km/hr as a limitation. When the subject vehicle travels slower than 18km/hr this display would not give accurate information.

Key Words: Driver Information Display, Braking Distance

Name of Reviewer: Loren Stowe

Authors: Chandler R. A., Wood L. F., and Lemeshewsky, W.A.

Year: 1974

Title of Article/Report: A Review of Philosophical Considerations in the Development of Radar Brake Systems.

Journal: SAE

Issue: Tech. Report No, 750086

Pages: 1-18.

Place Published: Warrendale, Pa.

Type of Article/Report: Lit review

System Studied: Radar Brake

Application To Collision Intervention: Better braking systems would reduce the number of accidents.

ABSTRACT: Several system application philosophies are defined and discussed with consideration given to the proposed economic and safety benefits afforded by each. Accident investigations have shown that in a significant number of cases, brakes were not applied. This along with insufficient or late braking implies that better braking systems would reduce the number of accidents. Data were specifically evaluated to investigate the effectiveness of a radar braking system. Ten different systems having different characteristic combinations were considered. The characteristics included driver warning only, non cooperative (normal radar), cooperative (specially tagged targets), automatic brake actuation, two wheel anti-lock, and four wheel anti-lock. For three levels of certainty, a non cooperative, automatic brake actuation, with four wheel anti-lock system would theoretically prevent 14-41% of accidents and reduce the severity between 4% and 12%. The other system proved theoretically less effective. A weighting scheme, based on relative confidence, was used to estimate the actual number of accident prevented.

Some of the technical aspects that must be considered have been under investigation. These include target signature, effect of weather on radar, prediction of radiation hazard, and analysis of intersystem effects and road geometry. From the study of these areas thus far, the following conclusions have been made. Signatures of typical targets are detectable, including those of pedestrians and cyclists. With the expected power levels, radiation does not appear to be a hazard given the present acceptable limits. Precipitation effects can be reduced through careful selection of modulation format and signal processing. The choice of the modulation format will also play a role in

intersystem binding. Road geometry, particularly curves, presents significant problems in the area of false alarm rate. This is especially true for minimum radius curves. While these considerations will prove challenging to overcome, it has been determined that none of the above are insurmountable obstacles for radar controlled braking systems.

Key Words: Braking, radar braking system, driver warning only, non cooperative (normal radar), cooperative (specially tagged targets), automatic brake actuation, two wheel anti-lock, and four wheel anti-lock, target signature, road geometry, false alarm rate.

Name of Reviewer: Stefan Hofmeyer

Authors: Davis, G., Schweitzer, N., Parosh, A., Liebermann, D.G., Aptor, Y.

Year: 1990

Title of Article/Report: Measurement of the Minimum Reaction Time for Braking of Vehicles.

Journal:

Volume:

Issue:

Pages: 1-60

Place Published:

Type of Article/Report: Field Test

Independent Variables: Vehicle Speed, Following Distance

Dependent Variables: Brake Reaction Time

Controls: Visibility, Weather and Road Conditions, Test Route,

Data Analysis Techniques: Three Dimensional Variance Analysis, Average, St. Deviations, Range, Most Probable Value, Probability Distribution.

System Studied: Collision Warning

Application to collision intervention: Determined time to brake in accordance with a driver's expectancy.

Subject Population: 36 male and 9 female athletes ages 21-30

ABSTRACT:

A study by Davis et. al. (1990) was completed to determine the minimum time required by a driver to brake in an emergency situation. The definition of brake reaction time used was the time which permits any driver, with a reasonably high probability, to safely brake his or her vehicle as a response to an emergency braking of a vehicle ahead.

To find the actual brake reaction time, the time between the appearance of the brake lights of a leading vehicle and the release of the gas pedal of a following vehicle was measured. This time was then added to the time interval between the release of the gas pedal and contact with the brake pedal of the following vehicle. The measurements were completed by a high frequency radio transmitter system with sensors on the lead vehicle's brake pedal and the

following vehicle's brake and gas pedals. The information was then integrated by computer.

The subjects included 36 males and 9 females from 21-30 years of age. The subjects were divided into three groups. The first group was instructed to keep a constant distance from a lead vehicle, the second group was instructed to keep a constant distance from a lead vehicle and to brake when the lead vehicle braked. The third group was also instructed to keep a constant distance from the lead vehicle and to brake when the lead vehicle braked. Additionally the third group was given an audible warning a few seconds before the lead vehicle braked.

It was found that speed had no effect on reaction time. The first group had the longest BRT and the third group had the shortest BRT. In groups one and two, a significance in the BRT was found according to following distance. The BRT when using dummy breaks, just the initiation of brake lights, was found to be slower. It was also found that there was no significant effects of gender. An average reaction time of 0.68 and 0.69 seconds was found for males and females respectively.

In conclusion, the Davis et. al. (1990) study hypothesized that subjects in group 1 were performing a complex reaction where groups 2 and 3 were performing a simple reaction. It was concluded that brake reaction times are more influenced by following distance rather than speed, and reaction times are not a fixed constant. It was found that a safe brake reaction time was 0.80 seconds and suggested that a BRT should be 1.3 seconds for private vehicles, 2.0 seconds for buses and trucks, and 3 seconds for high risk vehicles such as fuel trucks.

Key Words: Brake Expectancy, Brake Reaction Time, Car Following

Name of Reviewer: Brian McKinney

Authors: Deloof, P., Haese, N., and Rolland, P.

Year: 1991

Title of Article/Report: A Low Cost Approach for an Anti-collision Radar Front End

Journal: ISATA International Symposium on Automotive Technology and Automation

Pages: 201-208

Place Published: Florence, Italy

Type of Article/Report: Design rec.

System Studied: Radar brake

Abstract: This paper studies the feasibility of a low cost radar front end for collision avoidance. The functional and technical requirements of anti-collision radar systems to be developed are defined, and the main limitations are evaluated.
Key Words: Radar front end, Requirements

Name of Reviewer: Thuy Tran

Authors: Duckstein, L., Unwin, E.A., and Boyd, E.T.

Year: Sept. 1970

Title of Article/Report: Variable Perception Time in Car Following and Its Effect on Model Stability

Journal: IEEE Transactions on Man-Machine Systems
Volume: MMS-11

Issue: 3
Pages: 149-156

Place Published:

Type of Article/Report: Experiment

Independent Variables: Following distance

Dependent Variables: Reaction time

Controls: Film scene duration

Data Analysis Techniques: ANOVA, Taylor approximation

System Studied: none

Type of Display: none

Application To Collision Intervention: Introducing a variable time delay into a nonlinear car following model.

Subject Population: 12 subjects

ABSTRACT: The functional variation of perception time in car following was studied for the purpose of introducing a variable time delay into a previously proposed nonlinear model. A Weber ratio for the visual angle of a following driver can be hypothesized to explain the variation of the perception time with relative distance, speed, and acceleration. This model does not depend on the threshold concept. To clarify the stability analysis, a variable time delay and ideal following distance was introduced into the proposed car-following model. These variables change the size of the minimum asymptotic stability region but not the basic properties of the model.

Key Words: Ideal following distance, Perception time, Visual angle

Name of Reviewer: Anil Kumar Yenamandra

Authors: Dull, E.H., and Peters, H.J.

Year: 1979

Title of Article/Report: Collision Avoidance Systems for Automobiles

Journal: SAE Report No. 780263

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Design Rec.

System Studied: Warning

Type of Display: Radar

Application To Collision Intervention: Non-cooperative collision avoidance systems may help lead to avoided or less serious accidents.

Subject Population: none

ABSTRACT: The paper discusses a collision avoidance system employing a non-cooperative radar that gave warning based on the safe distance. A detailed description of radar technology along with information on the safe headway calculating algorithms is provided in this paper. The user interface of this system comprises of an intermittent acoustic warning with a flashing indicator when the following distance falls below the safe distance and an insistent acoustic warning when the following distance falls less than half the safe distance. The driver can toggle a switch to account for the road conditions (dry, wet and snowy road surface).

About 100000 km were covered using the experimental vehicles equipped with the collision warning system. The results show that there were no false alarms and the drivers found the system very helpful and useful.

Key Words: Radar, Collision Avoidance System

Name of Reviewer: Thuy Tran

Authors: Editor of Bulletin of the Association for the Advancement of Automotive Medicine

Year: Jan. 1991

Title of Article/Report: Book Review: Traffic Safety and the Driver by Leonard Evans

Journal: Bulletin of the Association for the Advancement of Automotive Medicine

Volume: 4

Issue: #1

Pages: 14-15

Place Published:

Type of Article/Report: Book review

System Studied: none

Type of Display: none

Application To Collision Intervention: Traffic safety

Subject Population: none

ABSTRACT: A review of a book by Evans (1990) stresses the importance of changes in behavior. Research indicates that drivers often consider themselves to be better than most other drivers; therefore their perception of their driving skills may be biased. This leads to high risk and high speed driving behaviors that threaten the efforts to improve vehicles and roadways. Evans stresses the importance of changes in driving behavior to reduce harm from traffic crashes.

Key Words: Traffic safety

Name of Reviewer: Loren Stowe

Authors: Enke K.

Year: 1979

Title of Article/Report: Possibilities for Improving Safety Within the Driver-Vehicle-Environment Control Loop

Journal: International Technical Conference on Experimental Safety Vehicles, 7th Report, NHTSA

Pages: 789-802

Type of Article/Report: Lit review

System Studied: Automated Cruise

Application To Collision Intervention: An earlier maneuver initiation, and greater deceleration or increased lateral acceleration during evasive maneuvers.

ABSTRACT: Two possibilities are considered for reducing the number of accidents: an earlier maneuver initiation, and greater deceleration or increased lateral acceleration during evasive maneuvers. Through use of kinematic analysis, the magnitude of these actions are calculated.

Key Words: Accidents, evasive maneuvers.

Name of Reviewer: Thuy Tran

Authors: Evans, L., and Rothery, R.

Year: Jan. 1973

Title of Article/Report: Experimental Measurements of Perceptual Thresholds in Car-Following

Journal: Highway Research Board Meeting

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Experiment

Independent Variables: Variable headways

Dependent Variables: Detection of positive or negative motion

Controls: Following and lead car speeds, Controlled looks

Data Analysis Techniques: Descriptive statistics

System Studied: none

Type of Display:

Application To Collision Intervention: Relative motion detection by drivers in car following.

Subject Population: 10 subjects

ABSTRACT: Perceptual thresholds of drivers were measured in car-following. The experiment consisted of two vehicles that were driven on a single lane of roadway. Subjects in a following car were given controlled looks while traveling at a near constant speed. The lead car was responsible for controlling the relative speed and spacing between vehicles. The following car subject's task was to judge whether the cars moved farther apart (positive relative motion) or came closer together (negative response) during a period of time. Three conclusions were found in this study. First, the dominant response in detecting the sign of relative motion is the average value of relative speed divided by spacing. Second, there exits a negative relative motion response bias as an increasing function of spacing. Third, there is a high level of sensitivity to the

sign of relative motion. These results indicate that accidents are likely due to attention problems and the inability to correctly judge the magnitude of relative motion. A driver can determine that he is gaining on the lead car, but he cannot accurately estimate the rate at which he is gaining.

Key Words: Relative motion thresholds, Perceptual factors,

Name of Reviewer: Loren Stowe

Authors: Farber, E., and Paley, M.

Title of Article/Report: Using Freeway Traffic Data to Estimate the Effectiveness of Rear-End Collision Countermeasures

Journal: Ford Motor Company

Pages: 260-268

Type of Article/Report: Simulation

System Studied: Warning

Application To Collision Intervention: The warning system reduces the overall crash rate. For a system with a range of 250 feet, a 50% reduction in all rear-end crashes is possible. In the same range, impact speed could be reduced by as much as 38%. This is important since crash severity is proportional to the square of the impact speed. The false alarm rate (as defined) was 0.0343% or 3.1 warnings per crash.

ABSTRACT: The REAMACS (Rear-End Accident Model And Countermeasure Simulation) model, used to predict whether a crash occurs, was used to estimate the effectiveness of a collision avoidance algorithm. The model incorporates freeway data on speeds, closure rates, and headway to evaluate the effectiveness of a rear-end collision warning device. Parameters used to determine if a crash occurs are: lead and following vehicle speeds, closure rate, headway, lead vehicle deceleration, and reaction of driver to the onset of lead car braking, collision warning signal, or following vehicle's deceleration. Traffic data used in the REAMACS model is from the New Mexico data base and is assumed to be representative of U.S. freeway traffic. Deceleration of the following vehicle is set at 0.7g to represent emergency braking on a dry road.

The lead vehicles deceleration and driver reaction time are random variables obtained from log-normal distributions whose mean and standard deviation depends on the gap time between vehicles. Reaction time to a warning signal was generated from a normal distribution with a mean of 1.1 seconds and a standard deviation of 0.3 seconds. Lead vehicle deceleration was generated from a normal distribution with a mean of 0.17g and a standard deviation of 0.1g.

The countermeasure evaluated was a rear-end collision warning system with the following assumptions: 1.) the following vehicle can measure headway and relative velocity, 2.) system always works perfectly, 3.) when the warning criterion is met, the driver is alerted, 4.) the following driver heeds the warning, and 5.) the system has a 0.2 second lag which is added to the driver reaction time.

For this model, a false alarm is defined as a warning given in a situation that would not result in a collision if no warning was supplied. Thus the efficiency of the algorithm can be tested. The effective range of the system was varied through the trials to determine the balance between maximum target detection

and minimum false alarms. The primary performance measures are 1.) occurrence of a collision and 2.) speed difference at impact if a collision does occur.

The result of the experiment was to show that the warning system reduces the overall crash rate. For a system with a range of 250 feet, a 50% reduction in all rear-end crashes is possible. In the same range, impact speed could be reduced by as much as 38%. This is important since crash severity is proportional to the square of the impact speed. The false alarm rate (as defined) was 0.0343% or 3.1 warnings per crash.

Key Words: Collision avoidance algorithm, REAMACS model, headway and relative velocity, warning system, impact speed.

Name of Reviewer: Brian McKinney

Authors: Fenton, Robert, and Rule, Ronald

Title of Article/Report: On the Effects of State–Variable Feedback on Driver–Vehicle Behavior in Car Following

Journal: Symposium on Psychological Aspects of Driver Behavior

Volume: 2

Pages: 3-19

Type of Article/Report: Experiment

Application to Collision Intervention: Increased situation awareness in car following

Subject Population: 11 males, 17-27 yrs old, 20/20 vision

Abstract: The goal of the research reported here examines various approaches toward unburdening the driver by reducing the information-collecting demands. For this study, a control stick with a built-in kinesthetic-tactile display was mounted in a conventional vehicle, and several car-following experiments were conducted over a five-year period. It was discovered that a driver's dynamic performance can be greatly improved and made more predictable via the use of a driver aid. Also, the average driver performance can be substantially improved.
Key Words: Work load, Driver aid, Car following

Name of Reviewer: Loren Stowe

Authors: Flannery , J.

Year: 1975

Title of Article/Report: Automatic Braking By Radar.

Journal: SAE Report No. 740094

Volume:

Type of Article/Report: Lit review

System Studied: Warning Radar Brake

Application To Collision Intervention: To reduce driver reaction time and stopping distance through warning and intervention if necessary.

ABSTRACT: An automatic braking system developed by AutoStop Corp. is discussed including technical information on the electronics. The goal of the system is to reduce driver reaction time and stopping distance through warning and intervention if necessary. A mean reaction time of 1.5 seconds is used in system operation. The next step is to develop target recognition in order to reduce the number of false alarms. This is done in part by requiring a continuous train of return signals before braking action is initiated. Since unwanted system braking is inevitable, an override feature is included.

Key Words: Automatic braking system, AutoStop Corp.

Name of Reviewer: Loren Stowe

Authors: Haden, C. R.

Year: Feb. 1978

Title of Article/Report: A Student Designed Automotive Collision Avoidance System

Journal: IEEE Transactions on Vehicular Technology

Volume: VT-27

Issue: No. 1, February

Pages: 31-34

Type of Article/Report: Lit review

System Studied: Warning

Type of Display: Auditory Visual

Application To Collision Intervention: Approaching vehicles equipped with a receiver are warned of emergency or hazardous situation ahead.

ABSTRACT: A receiver-transmitter system at 99 MHz is used in a collision warning system. The system consists of transmitter on the lead vehicle which is turned on by a shock activated switch (in case of an accident) or manually (in case of a stalled vehicle). Approaching vehicles which are equipped with a receiver can be warned of the emergency or hazardous situation ahead. Transmitters could also be used for road hazards, such as in construction zones. Warning interface for the approaching vehicle include an audible and visible signal.

Key Words: Collision warning system

Name of Reviewer: Loren Stowe

Authors: Haugen, J.

Year: 1992

Title of Article/Report: Cruise Control With Eyes

Journal: Automotive Industries

Volume: 172

Issue: No. 6, June

Pages: 64-65

Type of Article/Report: Lit review

System Studied: Automated Cruise

Type of Display: Visual

Application To Collision Intervention: Range and range-rate from the sensor are used to control throttle and brake to maintain a safe and consistent following distance behind slower vehicles.

ABSTRACT: A review of the Daimler-Benz "smart" cruise control system. The system uses an infrared transmitter/receiver developed by Leica Corporation. Range and range-rate from the sensor are used to control throttle and brake to maintain a safe and consistent following distance behind slower vehicles. It uses only a quarter of the vehicles maximum braking to gradually reduce speed. The driver is responsible for hard braking maneuvers. Feedback to the driver is supplied by a light on the speedometer representing the set speed and by the system initiated braking.

Key Words: "Smart" cruise control system, Daimler-Benz, Leica Corporation.

Name of Reviewer: Loren Stowe

Authors: Haugen, J.

Year: 1992

Title of Article/Report: Smart Cruise: A Deployment Issue

Journal: Automotive Industries

Issue: May

Pages: 58

Type of Article/Report: Lit review

System Studied: Automated Cruise

Application To Collision Intervention: Discussed are the alternatives in sensor type, manual and automatic target acquisition, and means of deceleration and the advantages and disadvantages of all.

ABSTRACT: Several important issues are considered concerning Autonomous Intelligent Cruise Control (AICC). First is the question of sensor type: radar or infrared. Against the radar is its cost, wide beam which results in the possibility of more false alarms, and the difficulty of obtaining accurate distance measurements. However the radar has all-weather capability and does not need periodic cleaning. Infrared sensors give accurate distance measurements, may be significantly cheaper, and can have a more precisely shaped beam resulting in fewer false alarms. Weather and cleanliness of the sensor are the two major problems with this technology.

The second issue is the operating philosophy which is divided into manual target acquisition and automatic target acquisition. The former requires the driver to personally engage the system so they know which vehicle the sensor is "locked" onto. With the latter the system automatically tracks whatever is directly in front of the vehicle.

Thirdly is the issue of deceleration which involves the means by which the system will slow the vehicle. This can be accomplished through braking or transmission downshifting. The latter should result in a cheaper system which would be more available to the public. By utilizing the brakes, more consistent braking is possible.

Key Words: Autonomous Intelligent Cruise Control, manual target acquisition, automatic target acquisition.

Name of Reviewer: Loren Stowe

Authors: Haugen, J.
Year: 1992

Title of Article/Report: Smart Cruise--The Next Safety Breakthrough?

Journal: Automotive Industries
Issue: May

Pages: 68-69

Type of Article/Report: Experiment

Independent Variables: Traffic Density, environmental condition

Dependent Variables: Headway, physiological measures and subjective measures

Controls: Traffic and weather conditions

System Studied: Warning Automated Cruise Radar Brake

Application To Collision Intervention: Brakes automatically activated based on calculations using range and range-rate with respect to the vehicle ahead; rated with a high level of comfort, ease, and safety.

Subject Population: 20 subjects, eleven male and nine female, whose age ranged between 22 and 57

ABSTRACT: Consumer tests of the Daimler-Benz Autonomous Intelligent Cruise Control (AICC) showed that drivers feel the system enhances their driving safety. The system uses a laser infrared sensor to determine the range and range-rate with respect to the vehicle ahead. Calculations based on these data are used to automatically activate the brakes (up to 25% of maximum) and remain at a safe following distance.

A study consisted of 20 subjects, eleven male and nine female, whose age ranged between 22 and 57. Each subject drove one of two instrumented vehicles in several traffic and weather conditions. During the drive, vehicle speed, throttle position, brake pressure, longitudinal acceleration, and driver heart rate were recorded.. After the drive, drivers were asked to rate the system on a -3 (unacceptable) to +3 (perfect) scale for the following three maneuvers: following; approach and braking; and slower vehicle cutting in ahead. These received +1.89, +1.89, and +0.88 respectively. In terms of comfort , ease, and safety, the system received ratings of +2.1, +1.75, and +2.15 respectively. Overall attitude toward the system received a rating of +2.15.

Key Words: Daimler-Benz, Autonomous Intelligent Cruise Control, laser infrared sensor.

Name of Reviewer: Loren Stowe

Authors: Hitchcock, A.

Year: 1992

Title of Article/Report: How to Evaluate Safety of AVCS Devices

Journal: The Proceedings of the 1992 Annual Meeting of IVHS America

Volume: 2

Issue: May 17-20, 1992

Type of Article/Report: Lit review

System Studied: Warnings Automated Cruise

Application To Collision Intervention: Methods used in estimating the reduction in accidents due to AVCS.

ABSTRACT: Methods used in estimating the reduction in accidents due to AVCS systems are reviewed. These estimations are important for cost-benefit analyses, setting research and development priorities, aiding in regulatory action, and providing reassurance to the consumer. One such method was first applied by Hitchcock and has since been refined by Fontaine. The method utilizes data from accidents which include appropriate detail. However, to aid in evaluation driver intention is necessary. This type of data is not readily available in North America. The National Accident Sampling System (NASS) is fairly in-depth but the Police Accident Report (PAR) and interviews are not available to researchers. Consequently NASS data can only be effective in evaluating some AVCS devices. Subsequent data sources which are unedited may prove more effective.

Measurement techniques are designed to measure correction as it applies to all drivers. Problems with the technique may arise in that drivers with equipped vehicles would not be representative of the population.

Estimates are made based on ideal conditions: equipment always functions; warnings are always heeded; no changes occur in the external situation; and the operation of the equipment does not cause accidents. Warnings must be designed so they do not divert driver attention from the driving task and such that the driver response is appropriate. Data are necessary to determine the response of drivers to these systems. Risk compensation need to be considered. At this time there is no theory by which to measure the effect and a hypothesis for such a theory of compensation is proposed. Habituation is another driver reaction that must be considered. This effect may occur when a driver with an equipped car drives an unequipped car. An example of this has been given with the advent of anti-lock braking systems.

Key Words: Automatic vehicle control systems, drivers response, measurement techniques, the National Accident Sampling System (NASS)

Name of Reviewer: Brian McKinney

Authors: Hitchcock, Anthony

Year: 1991

Title of Article/Report: Intelligent Vehicle-Highway System Safety: Approaches for Driver Warning and Copilot Devices

Journal: Transportation Research Record

Issue: No. 1318

Pages: 93-97

Place Published: Washington, D.C.

Type of Article/Report: Design rec.

System Studied: Warning

Application to Collision Intervention: preemptive control action to avoid head-on, rear-end, angle, and sideswipe collisions

Abstract: The impact of the introduction of the IVHS on highway deaths and injuries was studied. This paper examines what extent a warning (or preemptive control action) would be beneficial. It was suggested that a small set of in-depth accident reports applicable to US. conditions be completed. Also, full functional specifications for all IVHS devices present on the roads must be available so that standardization can be developed.
Key Words: IVHS, configuration management, cost-benefit analysis

Name of Reviewer: Thuy Tran

Authors: Hoffman, E.R.

Year: April 1966

Title of Article/Report: Note on Detection of Vehicle Velocity Changes

Journal: Human Factors

Volume:

Issue:

Pages: 139-141

Place Published:

Type of Article/Report: Lit review

System Studied: none

Type of Display: none

Application To Collision Intervention: Latency time is an important variable for car following models.

Subject Population: none

ABSTRACT: A study was conducted to investigate the latency time required by an observer in a moving vehicle to detect accelerations and decelerations of a leading vehicle. The expressions derived were consistent with the experimental results of Braunstein and Laughery (1964). Latency time is dependent on vehicle separation distance, lead vehicle acceleration, and initial vehicle speed. Specifically, latency time is expressed as the square root of separation distance and as the inverse square of lead vehicle acceleration. This expression was derived by the use of dimensional analysis. Also, it was noted that the sign of acceleration is as important as its magnitude.

Key Words: Latency time, Velocity changes, Relative motion

Name of Reviewer: Thuy Tran

Authors: Janssen, W., Nilsson L., Alm, H.

Year: Jan. 1992

Title of Article/Report: Human Factors of Front-to-Rear-End Collision Avoidance Systems: A Driving Simulator Study

Journal:

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Experiment

Independent Variables: type of display modality

Dependent Variables: headway, speed and amount of time in left lane

Controls:

Data Analysis Techniques: ANOVA

System Studied: Collision Avoidance

Type of Display: Fixed-based simulator

Application To Collision Intervention: "Time-to Collision criterion + Pedal" CAS appeared to be optimal.

Subject Population: 8 groups of 7 subjects each

ABSTRACT: Risky driving behavior may be associated with the use of collision avoidance systems (CAS). A study by Janssen et al. (1992) was conducted to address the behavioral factors associated with CAS. A simulator was programmed so that a subject driving the CAS-vehicle approached a leading vehicle, moving at a certain speed, often enough to assess behavior in dealing with that vehicle under the influence of CAS. Results indicate that with the use of the CAS, the occurrence of short headways were reduced, the overall driving speed was increased, the variability in speed, relative to control, was increased, and driving time in the left lane of a two-lane road was increased. One system was not indicative of these types of effects; however, in all others the potential gain in safety obtained by headway reduction was offset by the increases in the

other, more risky, behaviors. Further investigation should be performed, studying the CAS time-to-collision (TTC) criterion, coupled with the "smart" accelerator (Pedal). The simulator's accelerator was activated by an increase in pedal force whenever and for as long as the criterion was met.

Key Words: Collision avoidance systems, Driving simulators, Perception, Smart accelerator

Name of Reviewer: Stefan Hofmeyer

Authors: Johannson, G., and Rumar, K.

Year: 1971

Title of Article/Report: Drivers' Brake Reaction Times

Journal: Human Factors

Volume: 13

Issue: 1

Pages: 23-27

Place Published:

Type of Article/Report: Field Test

Independent Variables: display presentation

Dependent Variables: Brake Reaction Time

Controls:

Data Analysis Techniques: descriptive stats

System Studied: Collision Warning

Type of Display: Auditory

Application to collision intervention: To obtain a correction factor to create realistic brake reaction times when braking is expected and to determine the brake reaction time distribution of a representative sample of drivers when braking is unexpected.

Subject Population: Cars Stopped on Road, 4 Drivers Ages 25-35, 1 Driver Age 50.

ABSTRACT:
The goal of a study by Johannson and Rumar (1971) was to obtain a correction factor to create realistic brake reaction times when braking is expected and to determine the brake reaction time distribution of a representative sample of drivers when braking is unexpected. BRT was defined as the perception time (time from the presentation of the stimulus until the foot starts to move) in addition to the movement time (start of the movement until the foot reaches the pedal).

Brake reaction times were measured in two ways. For the single measures of a large sample, The time between the sound of a loud horn until brake lights were initiated. For the repeated measures of a small sample, time was measured by the time it took from the onset of an in-car buzzer to initiating the brake.

In experiment 1, the single measures of a large sample, police stopped cars on a road and told them to brake when they heard a horn go off. The mean BRT for the sample of 321 drivers was found to be 0.66 seconds with a range from 0.3 to 2.0 seconds.

In experiment 2, a buzzer was installed in a car that was turned off by the brake which recorded a time. BRT was completed ten times using this technique and BRT was found ten times using the technique in experiment 1. The subjects included 4 drivers ages 25-35 years old and one driver 50 years old.

Results of the study included a mean anticipated BRT of 0.54 seconds with a range of 0.4 seconds and a mean surprise BRT of 0.73 seconds with a range of 0.6 seconds. Johannson and Rumar (1971) concluded the correction factor for anticipation vs. surprise BRT to be 1.35. The 75th percentile for experiment 2 was found to be 0.90 seconds.

Key Words: Brake Reaction Time, Brake Expectancy

Name of Reviewer: Loren Stowe

Authors: Jurgen, R. K.

Year: 1986

Title of Article/Report: Whatever Happened To Automatic Radar Braking

Journal: . IEEE Spectrum

Volume: 23

Issue: May

Pages: 26

Type of Article/Report: Lit review

System Studied: Radar Brake

Type of Display: Auditory Visual

Application To Collision Intervention: Possible solutions to the false alarm problem in radar braking systems.

ABSTRACT: The problem of false alarms and its effect on radar braking research since the early seventies is briefly discussed. In automatic braking false alarms can at least be an annoyance and at worst cause serious accidents. Consequently such systems now have a lower priority with manufacturers.

One possible solution to incorrect hazard assessment was a system developed by RCA. The system uses a radar whose receiver is tuned to the second harmonic frequency of the transmitted signal. Special reflective tags attached to the rear of vehicles return the second harmonic frequency. The system uses the distance between the vehicles, their closing rate, and the vehicle speed of the following vehicle to determine the safe driving distance. Danger is indicated by an audible signal and flashing light. Instead of an active braking system, GM is looking at the use of radar as the basis for a warning system. In October of 1985, Nissan exhibited a show car called CUE-X which includes a laser radar system which has automatic braking and a smart cruise.

Key Words: CUE-X, harmonic frequency of the transmitted signal, reflective tags, GM.

Name of Reviewer: Tim Brown

Authors: Hiroshi Kawata, Hiroshi Endo, and Yoshiyuki Eto

Year: 1985

Title of Article/Report: Tenth International Conference on Experimental Safety Vehicles

Pages: 230- 235

Type of Article/Report: Lit review

System Studied: Laser

Type of Display:

Application to Collision Intervention: Background on laser range detection

Abstract: This paper discussed basic laser technology, and compared why lasers are better than standard radar for range detection. It also examined weather related restrictions related to fog, snow, and rain.
Key Words: Laser

Name of Reviewer: Loren Stowe

Authors: Kemeny, A., and Piroird, J.M.

Year: 1991

Title of Article/Report: A Simulator For Cooperative Driving

Journal: Advanced Telematics in Road Transport: Proceedings of the DRIVE Conference, Brussels, Feb. 4-6,

Pages: 930-942

Type of Article/Report: Lit Review

System Studied: Automated Cruise

Application To Collision Intervention: Simulation of intelligent cruise control (driving in file and autonomous cruise control); intelligent maneuvering and control (overtaking vehicles, lane changes, and entering and exiting motorways); medium range preinformation (traffic and environmental data); and emergency warning.

ABSTRACT: The Simulator for Cooperative Automotive Network (SCAN) is a project developed by Renault to evaluate inter-vehicle communication concepts as well as driver reaction. It consists of a decision making engine, a communication system, and a three-dimensional graphics computing and display workstation with appropriate interface, all working in real time.

Applications of this type of simulator include: intelligent cruise control (driving in file and autonomous cruise control); intelligent maneuvering and control (overtaking vehicles, lane changes, and entering and exiting motorways); medium range preinformation (traffic and environmental data); and emergency warning.

Key Words: Inter-vehicle communication concepts, Renault, Simulator for Cooperative Automotive Network (SCAN), intelligent cruise control, intelligent maneuvering and control, medium range preinformation, collision warning.

Name of Reviewer: Loren Stowe

Authors: Kiyoto, M., Fujiki, N., Fujiwara, T.

Year: 1979

Title of Article/Report: A Study Of The Automatic Braking System

Journal: Seventh International Technical Conference on Experimental Safety Vehicles, NHTSA

Pages: 754-764

Type of Article/Report: Lit review

System Studied: Warning Radar Brake

Application To Collision Intervention: Successful warning systems can be developed but the false alarm rate in automatic braking is difficult to keep within an acceptable limit even under controlled situations.

ABSTRACT: An automatic braking system that employs a short pulse modulation microwave radar and the results of experiments of a target discrimination study are discussed. The system transmits a 24 GHz signal that is used to measure distance from a target and relative velocity. These signals are then used along with the carrier vehicle velocity, driver reaction time, and the desired safety interval to compute a safe following distance. When braking is under system control, reaction time is considered negligible. A proper and safe following distance is calculated three different ways depending on the scenario, i.e. both vehicles slow and come to a stop, a vehicle pulls out in front of the carrier vehicle and proceeds to accelerate, etc. To address the problem of false alarms on corners, the range of the radar is limited based on the wheel base, steering angle, lane width, and radar beam width.

To collect data from road tests, video cameras recorded the receiver signal and road view while the range, relative velocity, steering wheel angle, and warning signal were recorded on tape. These data were then evaluated to determine the number of false alarms. Road tests were conducted on public highways using the warning system and on proving grounds for the automatic braking. Results show that deceleration setting and range limit imposed by steering wheel angle are effective in reducing the number of false alarms. For the warning system, the false alarm rate was acceptable. For automatic braking it is difficult to accomplish consistent results with acceptable false alarm rates , even in a highly controlled environment.

These tests indicate several things. Warning systems are within reach of development. However, correct safe driving distance is not easily determined due to the various driving situations. Range restrictions are effective in reducing false alarms but the possibility of missing a potential hazard also increases as range decreases. In automatic braking, full braking is useful in decreasing reaction time

but it could cause problems for the vehicle following the carrier vehicle. Finally, it is important to determine the worth of this type of system to the consumer.

Key Words: Warning systems, automatic braking, automatic braking system, short pulse modulation microwave radar, target discrimination.

Name of Reviewer: Anil Kumar Yenamandra

Authors: Kopf, M., and Onken, R.

Year: 1992

Title of Article/Report: DAISY, A Knowledgeable Monitoring and Warning Aid for the Driver on German Motorways

Journal: IFAC Man-Machine Symposium.

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Design Rec

System Studied: Warning

Type of Display: Haptic

Application To Collision Intervention: Driver monitoring and warning system.

Subject Population: none

ABSTRACT: An intelligent and knowledgeable warning system was developed and tested. Information from the onboard sensors was utilized in determining the collision situation. Information was then given to the driver in form of visual and haptic display.

The display comprised of colored bars displayed on the scene outside along with an auditory alarm and steering loading.

Experiments were carried over in the fixed base driving simulator which had the DAISY system resident on it. Collision information was provided to the drivers in the form of colored bars (green bar when the driver entered the unsafe zone, yellow, orange and red bars with increase in the unsafe distance, followed by an auditory alarm while in the red zone). The steering wheel gets loaded when driving in the unsafe zone so that the driver can steer easily in the direction of collision avoidance.

The paper described the logic behind an intelligent collision warning system and the theoretical models it employed. Full scale experimentation was yet to be carried over on the system.

Key Words: Man-machine systems, Driver support, Driver modeling, situation analysis, haptic displays, time reserve.

Name of Reviewer: Anil Kumar Yenamandra

Authors: Kopf, M., and Onken, R.

Year: 1992

Title of Article/Report: Monitoring and Warning System for Driver Support on German Autobahn

Journal:

Volume:

Issue:

Pages: 499-505

Place Published:

Type of Article/Report: Theoretical Paper

System Studied: Collision Warning

Type of Display: None

Application to collision intervention: Presents monitoring and warning system concepts.

ABSTRACT:

This paper gives a detailed description of a collision warning system and the theoretical models it employs. The collision warning system comprises of a Driver Model module which has information on the average driving behavior (time headway under different situations, time taken for lane change etc.), a Driver Picture module which monitors the drivers performance and develops a model unique to the driver under consideration and a Discrepancy Interpreter module that compares the information from the other two modules and gives a warning signal to the driver when a collision behavior is detected.

Complex models were developed to represent true driving behavior. The paper presents these models along with the logic behind the collision warning algorithms. No experiments were conducted.

Key Words: Collision Warning

Name of Reviewer: Thuy Tran

Authors: Korteling J.E

Year: 1990

Title of Article/Report: Perception-Response Speed and Driving Capabilities of Brain-Damaged and Older Drivers

Journal: Human Factors

Volume: 32

Issue: 1

Pages: 95-108

Place Published:

Type of Article/Report: Experiment

Independent Variables: time variation, task load

Dependent Variables: Reaction time

Controls:

Data Analysis Techniques: ANOVA

System Studied: none

Type of Display: none

Application To Collision Intervention: Perception-response speed during driving tasks

Subject Population: 30 Males

ABSTRACT: Reaction time (RT) tasks were investigated to determine whether they related to driving performance. The first experiment, the discrete choice RT, involved a varied sequence of compound stimuli with an unstraightforward mapping to responses. The results indicated that the perception-response speed of the older subjects decreased disproportionately with increasing difference in subsequent compound stimuli. The second experiment involved a RT task that was chosen to elicit quick and accurate responses based on time estimations. The findings were generally compatible to the notion that older people take more time in task performance while their accuracy remains unaffected. The RT effects were associated with the information-processing and visual motor demands specific to car driving as a complex dual task. In the third experiment conducted, the brake RT was investigated in a platoon-car-following task in high and low task load conditions. It was hypothesized that the brake RT would increase as a consequence of increasing task load. Performance was poor for older subjects in a driving task where perception-response speed was critical and sensitivity was low to brake RT's to increasing task demands. The speed-related differences between the older subjects and the controls were not significant in the platoon-car-following tasks (brake RT, delay time) even when task load was increased.

Key Words: Reaction time, Driver performance, Driver Perception

Name of Reviewer: Stefan Hofmeyer

Authors: Lerner, N.D.

Year: 1993

Title of Article/Report: Brake Reaction Times of Older and Younger Drivers

Journal: Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting

Volume:

Issue:

Pages: 208-210

Place Published:

Type of Article/Report: Field Test

Independent Variables: 3 levels of age

Dependent Variables: Brake reaction time, type of response

Controls: Roadway

Data Analysis Techniques: Analysis of Variance, Mean

System Studied: None

Type of Display: None

Application to collision intervention: To decide whether the current brake reaction time value used in highway design and operation is adequate.

Subject Population: 30 Subjects Ages 20-40, 43 Subjects Ages 65-69, 43 Subjects Ages 70-

ABSTRACT:

A study by Lerner (1993) was initiated to decide whether the current brake reaction time value used in highway design and operation is adequate to meet the requirements of all drivers. Brake reaction time was defined as the time required to perceive, interpret, decide , and initiate braking to some stimulus-- an obstacle in a vehicles path.

The BRT was measured as the interval between the emergence of a barrel rolling towards the road and the activation of a test vehicles brake lights. The

barrel was a yellow crash barrel which looked like it was going to roll into the car's path. Time was measured by an in-car camera.

The subjects included 30 people in the 20-40 age group, 43 people in the 65-69 age group, and 43 people in the 70 or older age group. After one hour in a false "road quality" experiment, subjects drove on a segment of road that triggered a barrel that looked like it was going across the road, BRT was then measured.

It was found that the overall BRT was 1.5 seconds and no significance was found in the main effects of gender or age. There was borderline significance of the combination of age and gender (p=0.055) where the BRT for young females was 1.22 seconds.

The Lerner (1993) study concluded that the 2.5 second value for BRT on highway applications appear to provide adequate coverage for the full range of driver ages. No indication of meaningfully slower braking occurred in older age groups.

Key Words: Brake Reaction Time

Name of Reviewer: Thuy Tran

Authors: Lerner, N.D.

Year: 1991

Title of Article/Report: Older Driver Perception-Reaction Time and Sight Distance Design Criteria

Journal: ITE Compendium of Technical Papers.

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Lit review

System Studied: none

Type of Display: none

Application To Collision Intervention: Perceptual reaction times of older drivers with the models of driver reaction that underlie highway design criteria.

Subject Population: none

ABSTRACT: This study suggests that as a driver gets older, it takes longer to acquire information, process information, select and plan a response, and execute that response. The magnitude of age effects varies from task to task, and from study to study. Actual on-the-road experiments have not demonstrated significant age-related slowing of driver reaction times. The time from the initial visibility of an event, to the initiation of a response, is defined as perception-reaction time (PRT). Various experiments were performed to compare older and younger people for brake reaction time or decision time in a driving simulator. Generally, the studies found that the age effect was statistically significant, although not necessarily large. More complex procedures such as choice reaction time and response alterations required, generally resulted in more pronounced age differences. Older drivers have a higher accident rate, per mile driven, than middle aged drivers. The age-related increase in accident rates do not directly implicate slower PRT's as the primary cause; however, it is a contributing factor since accident types were also increased with age. These higher accident rates for the older driver may be caused by difficulties of attention sharing, or perceptual errors, rather than slowing PRT's. The study suggests that further research needs to investigate how to quantitatively specify how much longer it takes older drivers to respond in various situations, the

degree to which current design standards encompass these PRT's, and the safety implications of various degrees of failure to fully include the complete distribution of older driver PRT's.

Key Words: Perception reaction time, Older Drivers

Name of Reviewer: Anil Kumar Yenamandra

Authors: Leutzbach, W., Jahnke, C.D., Steierwald, G., and Zackor, H.

Year: 1983

Title of Article/Report: Technical Evaluation of Collision Avoidance Systems

Journal: SAE Report No. 830661

Volume:

Issue:

Pages:

Place Published:

Type of Article/Report: Field Test

Independent Variables:

Dependent Variables: Following Distance, Speed, Speed Difference, Number of Alarms, Number of Brake Activations, Questionnaire Results, Traffic Flow

Controls: Travel Routes,

Data Analysis Techniques: descriptive stats

System Studied: Collision Warning

Type of Display: Not Determined

Application to collision intervention: Evaluates Driver Responses to a collision warning system

Subject Population: Drivers of Outfitted Cars (16) and Light Trucks (14)

ABSTRACT:

This paper discusses the effects of collision warning systems on traffic flow, the driver acceptance of warning, the influence of vehicle surroundings on the warning and the influence of the warning signal on safety.

Sixteen passenger cars and fourteen light trucks were equipped with the warning system. Information was gathered from questionnaires administered to the drivers of the test vehicles. The measurement of traffic parameters during the controlled trials and the manual recording of the alarms provided the additional information for analysis.

The results from the analysis of the questionnaire data shows that 57% of the drivers agreed that the system would be assistance mainly on autobahns and were willing to pay about 600 DM for the system. In addition, the drivers considered that the safe distance indicated was appropriate.

Fifty percent of the alarms given by the system were false alarms. It was observed that the drivers ignored alarms having duration less than 2 seconds.

Key Words: Collision Warning Systems

Name of Reviewer: Timothy Brown

Authors: P. Mallinson and A. G. Stove

Year: 1989

Title of Article/Report: Car obstacle avoidance radar at 94GHz

Journal: Proceedings of the Institution of Mechanical Engineers

Volume: Seventh International Conference

Issue: C391/081

Place Published: London

Type of Article/Report: Experiment

System Studied: Warning

Type of Display: Auditory

Application to Collision Intervention: Possible headway detection technique using millimeter wave radar -- no human interface information.

Abstract: This article discussed the use of millimeter wave radar in headway detection. The advantages of millimeter wave radar, such as its small size, were enumerated

Key Words: Radar Frequency modulated continuous wave(FMCW) millimeter wave

Name of Reviewer: Loren Stowe

Authors: Maretzke, J., and Jacob, U.

Year: 1992

Title of Article/Report: Distance Warning And Control As A Means Of Increasing Road Safety And Ease Of Operation

Journal: IMechE

Pages: 105-114

Type of Article/Report: Research Review

System Studied: Warning Automated Cruise

Type of Display: Visual Haptic

Application To Collision Intervention: Time to collision is criterion to receive driver information or warning. Visual display represents the distance between vehicles. Intervention (force applied to opposite side of accelerator) keeps driver from maintaining hazardous behavior.

ABSTRACT: Research work on the components and function of a distance warning and control system is presented. The system employs a 4-beam infrared impulse laser. This configuration allows the system to detect targets on corners. When driving in a string of cars at relatively constant speeds, the warning system uses the time interval between vehicles. This is a function of vehicle speed, braking capacity, and driver reaction time. There are three stages based on the time interval (TR): 1.) 1.8 > TR > 1.3, yields information; 2.) 1.3 > TR > 0.9, yields clear information; and 3.) 0.9 > TR yields a warning. The first two stages are to provide information to the driver and as such can be turned off by the driver. Break points for TR are based on German government standards and research. When approaching a slower vehicle, warning is based on the criterion of time to collision (TTC) which is dependent upon distance and relative speed.

Driver interface is both visual and haptic. The visual display consists of a car in perspective. Initially the car is far away and green indicating a safe distance (stage 1). As each subsequent stage is reached the car gets bigger on the display and changes color from yellow (stage 2) to red (stage 3). To warn of an impending collision the system displays a red flashing vehicle that alternates between small and large. Haptic information is provided through the accelerator pedal. As the driver enters stage 3, a force of approximately 50N is applied opposite to the that of the drivers foot. Consequently an increased amount of force is required to maintain the present driving behavior.

Key Words: Time interval, time to collision (TTC), German government standards and research, distance warning and control system.

Name of Reviewer: Loren Stowe

Authors: McCarter, O. and Schmidt, E.

Year: 1993

Title of Article/Report: Application Of A 60 GHz Radar Sensor To Adaptive Cruise Control

Type of Article/Report: Review of technology

System Studied: Warning Radar Brake

Type of Display: Visual

Application To Collision Intervention: System featuring automatic target detection, driver adjustable separation, automatic vehicle spacing, limited deceleration, and a head up display to enhance safety and convenience of highway driving.

ABSTRACT: An adaptive cruise control (ACC) system featuring automatic target detection, driver adjustable separation, automatic vehicle spacing, limited deceleration, and a head up display is discussed. A continuous, millimeter wave radar operating at 60 GHz is used to determine range and range rate of the vehicle. Antenna time/position information combined with the filtered signal yields a map of all dynamic targets in the sensor viewing area. Steering angle data is also used in determining the closest target. Using the relative speed, vehicle speed, distance, deceleration rate, and driver reaction time along with inputs of the set speed and separation control settings from the driver, desired speed and spacing are computed by the system. These are maintained under normal driving. Since the system is not designed to stop the vehicle, in case of an emergency an audible alarm sounds to alert the driver to brake.

Field experience demonstrated that drivers are initially apprehensive, but soon gain confidence with the system. However overconfidence results in the drivers using the system in situations for which it was not designed, such as in heavy traffic. The system does appear to have the potential to enhance safety and convenience of highway driving.

Key Words: Adaptive cruise control (ACC), automatic target detection, driver adjustable separation, automatic vehicle spacing, limited deceleration, head up display.

Name of Reviewer: Thuy Tran

Authors: Michaels, R.M.

Year: 1963

Title of Article/Report: Perceptual Factors in Car Following.

Journal: Proceedings of the 2nd Int'l Symposium on the Theory of Road Traffic Flow

Volume:

Issue:

Pages: 44-59

Place Published:

Type of Article/Report: Lit review

System Studied: none

Type of Display: none

Application To Collision Intervention: Perceptual factors in car following

Subject Population: none

ABSTRACT: In this paper the analysis of behavior of the driver in car-following situations was observed. The driver was asked to respond to three scenarios dealing with the angular velocity of the lead vehicle. The three cases were: overtaking, steady state following, and responses to lead vehicle acceleration.

The variation in headway for a given relative velocity is dependent on the following distance. Results of the study indicate the absolute threshold of angular velocity is a function of the distance between vehicles and the relative velocity. This threshold is the minimum response time of the driver and the maximum distance traveled before action was taken.

Key Words: Perceptual factors, Angular velocity, Relative velocity, Steady state

Name of Reviewer: Thuy Tran

Authors: Moray, N.

Year: 1990

Title of Article/Report: Designing For Transportation Safety in the Light of Perception, Attention, and Mental Models

Journal: Ergonomics

Volume: 33

Issue: 10/11

Pages: 1201-1213

Place Published:

Type of Article/Report: Design Rec.

System Studied: none

Type of Display: none

Application To Collision Intervention: Quantitative models in transportation safety

Subject Population: none

ABSTRACT: The necessary use of quantitative models in the design of displays. Through these models, designers can reach an understanding of how problems at the input side of human information processing can cause errors. This study was concerned with errors in the acquisition of information which were caused by perceptual and attentional mechanisms. Transportation systems need to be designed in accordance to the principles of information display, sampling, and acquisition. Even if an operator were to have perfect knowledge of the state of the system, a mistake can easily be made. There is evidence that visual attention is controlled by unconscious, automatic, habits. The experimenters investigated the use of scheduling theory to model the information processing characteristics of operators, while understanding that habits tend to control what drivers do next.

Key Words: Theoretical models, Mental models, Quantitative models

Name of Reviewer: Thuy Tran

Authors: Mortimer, R.G.

Year: 1972

Title of Article/Report: Weber's Law and Rear-End Collisions

Journal: The Michigan Academician
Pages: 99-105

Type of Article/Report: Experiment

Independent Variables: Lead car velocity change, Following distance

Dependent Variables: Response time, Driver sensitivity

Controls: Vehicle speed

Data Analysis Techniques:

System Studied: none

Type of Display: none

Application To Collision Intervention: Primary and augmenting driver cues used for controlling vehicles

Subject Population: 40 subjects

ABSTRACT: A study was performed to evaluate the sensitivity of drivers who used primary cues to detect changes in headway between their vehicle and the lead vehicle. Under two driving conditions, day and night, it was found that a Weber function of 0.12 fit the data. Simulation and nighttime driving tests were conducted to investigate the effect of three rear lighting displays in affecting the driver's sensitivity to headway change detection. The purpose of the tests were to determine if the following car driver's sensitivity to detect closure with the lead car ahead of him could be increased by changes in the rear presence light display. An array of four lamps, representing each corner of the vehicle, produced a 20 percent increase in sensitivity. This supports the claim that the informational, primary cue to detect closure with a leading car may be the change in visual angle subtended by it at the following driver's eyes, while signal lights can act as alerting and informational, augmenting cues. These augmenting cues can be used to improve driver sensitivity to closure.

Key Words: Primary cues, Closure rates, Relative velocity detection, Weber ratios

Name of Reviewer: Thuy Tran

Authors: Mortimer, R.G.

Year: 1988

Title of Article/Report: Rear-End Crashes

Journal: Automotive. Engineering and Litigation, Chapter 9

Volume:

Issue:

Pages: 275-303

Place Published:

Type of Article/Report: Lit Review

System Studied: none

Type of Display: none

Application To Collision Intervention: Perceptual factors determine driver responses in car following situations.

Subject Population: none

ABSTRACT: Rear-end crashes are the most common types of crashes involving two vehicles. A driver can accurately judge whether a gap between themselves and another vehicle is opening or closing but lack the ability to make estimates of an approaching car's speed. Therefore, rear-end crashes could be reduced if drivers were aided by a display of the velocity of the speed of the car being followed. This is true assuming the driver could infer the relative velocity of the lead vehicle, based on the knowledge of their own velocity. Unless the relative velocity between two vehicles becomes quite high, the driver will respond to changes in their headway, or the change in angular size of the vehicle ahead. Drivers then use that as a cue to determine the speed that they should adopt, when following another vehicle. When the relative velocity is quite high, only then can drivers make use of this cue.

Key Words: Perceptual factors, Relative velocity

Name of Reviewer: Thuy Tran

Authors: Mortimer, R.G.

Year: 1990

Title of Article/Report: Perceptual Factors in Rear-End Crashes

Journal: Proceedings of the Human Factors Society 34th Annual Meeting

Pages: 591-594

Place Published:

Type of Article/Report: Lit review

System Studied: none

Type of Display: none

Application To Collision Intervention: Perceptual factors related to rear-end crashes.

Subject Population: none

ABSTRACT: The magnitude of relative velocity is very difficult to scale by drivers especially during the time available before a collision occurs. Thus, perceptual factors are involved in rear-end crashes. Drivers can make reasonable, accurate, estimates (approximately 20 percent) of the headway distance of the lead car. They are also sensitive in the detection of a change in headway between their vehicle and the lead car (approximately 12 percent change). A decreasing in the headway, will provide an increase in perceived width of the lead vehicle and possibly an increase in the perceived area of the lead vehicle. The rate of change of the headway distance is necessary information to the driver of the following car. This rate information gives a detection of change in velocity of the lead car and alerts the following driver.

Key Words: Perceptual factors, Headway change, Relative velocity, rear-end crashes

Name of Reviewer: Thuy Tran

Authors: Mortimer, R.G.

Year: 1993

Title of Article/Report: The High Mounted Brake Lamp: A Cause Without a Theory

Journal: Proceedings of the Human Factors Society 37th Annual Meeting
Pages: 955-958

Place Published:

Type of Article/Report: Lit review

System Studied: Warning

Type of Display: Visual

Application To Collision Intervention: The significance of high mounted brake lamp in the reduction of rear-end crashes.

Subject Population: none

ABSTRACT: This study questioned the theory behind the high mounted brake lamp. He claims there exists little research to support the original claim of a 50 percent reduction in rear-end crashes with the installation of a separate brake light mounted in the rear window of passenger cars. The function of the brake lamp is only to alert the driver that a vehicle is braking, they do not often elicit a braking response. The lamp adds separation of function and redundancy to the vehicle rear lighting and signaling systems. However, they only aid in the detection of the brake signal and do not inform drivers about their distance and relative speed with respect to the vehicle ahead. This latter information is essential for drivers to use to determine their response.

Key Words: Center high mounted brake lamp

Name of Reviewer: Anil Kumar Yenamandra

Authors: Muramoto, I., Okabayashi, S., and Sakata, M.

Year: 1991

Title of Article/Report: The First Practical Application of a Laser Radar Rear-End Collision Warning System in Production Heavy-duty Trucks

Journal: 13th International Technical Conference on Experimental Safety Vehicles

Volume: November, Pages: 212-219

Type of Article/Report: Lit review

System Studied: Collision Warning

Type of Display: Auditory

Application to collision intervention: Refine a collision warning algorithm and establish the scope of the system under study.

ABSTRACT:

The collision warning system discussed in this paper employs a high power pulse laser diode to generate a laser beam to measure the following distance and the rate of closure between the subject vehicle and the vehicle in front. A two staged auditory alarm constitutes the warning display. An attention alert is given when the following distance of the subject vehicle is less than the safe distance and an caution alert (8db audio alarm) is given when the following distance is less than half the safe distance. The system is expected to be mounted on heavy-duty trucks and intended for highway operations and has a range of 100 meters in length and 3.5 meters in width.

An initial field test was conducted and the system was improved based on the results. Seventy three trucks were then equipped with the system and the drivers were queried about their impressions on the system. The results showed that the drivers preferred the middle distance mode based on the type of road they traveled, found the audio signal effective, were concerned about the continuous alarms during congested traffic, found that system assisted them in safe driving and strongly agreed on the concept of introducing the system on all the trucks on the freeway.

This paper mainly aimed at refining the collision warning algorithm and establishing the scope of the system under consideration.

The system limitations are : a minimum speed of 35 kmph for it to function and a speed differential (not purely dependent on the headway).

Key Words: Collision Warning System, Laser Radar

Name of Reviewer: Loren Stowe

Authors: Najm, W.

Year: 1993

Title of Article/Report: A Literature Review of Rear-End Crash Avoidance Technologies

Journal: Technical Information Exchange

Issue: June, DTS-73

Pages: 1-14

Type of Article/Report: Lit review

System Studied: Warning Automated Cruise

Type of Display: Visual Haptic

Application To Collision Intervention: Alternatives in system design and some of their advantages and disadvantages.

ABSTRACT: Collision data is reviewed as a rationale for collision avoidance system development. These systems comprise three main components: a forward looking sensor, a decision making algorithm, and a human interface.

Possible sensors include microwave and millimeter wave radar or infrared. Of these, pulsed sensors work well for multiple target tracking and have better range accuracy than FM/CW sensors but require more transmitting power. Diplex sensors are ineffective for multiple targets and work poorly in rain. Recent systems have also utilized video image processing equipment.

Most warning systems use stopping distance as the parameter for system control. Cruise systems may be based on time to collision to detect slower moving vehicles. Driver interface is usually visual often using a series of LED's. Haptic feedback through the accelerator pedal has also been used.

System design considerations from an engineering perspective encompass six areas: 1.) atmospheric and weather conditions, 2.) road surface, 3.) traffic, 4.) other detection or communication systems, 5.) the host vehicle and its subsystems, and 6.) the driver. Table 4 summarizes driving environment effects and possible solutions.

A major concern with improving the system is the reduction of false/nuisance alarms. This can be accomplished in the following ways: 1.) limiting coverage volume, 2.) reducing range of sensor, 3.) reducing parameter limits as a function of steering angle, and 4.) target signatures. The first three reduce the systems overall effectiveness. The most effective means of reducing false alarms is to identify surrounding targets and their position and determine the relative hazard to the host vehicle. This can be accomplished through multiple or

scanning beams, or through image processing. Cooperative systems provide another possible solution.

Several field evaluations have been conducted on systems which incorporate some of the above mentioned technologies.

Key Words: False alarms, multiple or scanning beams, image processing, cooperative systems, driving environment effects, forward looking sensor, decision making algorithm, human interface.

Name of Reviewer: Brian McKinney

Authors: Nogami, T. and Sakamoto, T.

Year: 1984

Title of Article/Report: Automotive Warning System Using 50GHz Band Radar

Journal: Ninth International Technical Conference on Experimental Safety Vehicles

Pages: 917-923

Place Published: Washington, D.C.

Type of Article/Report: Experiment results

System Studies: Warning Radar Brake

Application to Collision Intervention: Using a 50GHz Band Radar to prevent rear-end collisions -- no driver interface discussed.

Abstract: A compact 50GHz band radar system for keeping safe headway and for warning has been developed. This paper outlines the system and discusses some experimental results of sensitivity tests and road tests using the radar.

Key Words: front grill design, radar range, weather effect, false alarm, collision warning

Name of Reviewer: Stefan Hofmeyer

Authors: Olson, P.L.

Year: 1989

Title of Article/Report: Driver Perception Response Time

Journal: SAE Report No. 890731.

Type of Article/Report: Lit review

System Studied: None

Type of Display: None

Application to collision intervention: Find a proper brake reaction time.

ABSTRACT:

In a report by Olson (1989), brake reaction time studies were reviewed and contrasted to find a proper BRT. According to Olson (1989), BRT is broken down into 4 components: detection with a conscious awareness that something is present, identification where sufficient information is gathered to make a decision, decision where an operator must decide what action is appropriate, and response where commands are issued by the motor center of the brain. The following paragraphs are a short review of the some of the studies contrasted.

Studies by Olson et. al. (1984), Konz and Daccaret (1967), and Nagler and Nagler (1973) found reaction times from the time between initiation of a light to the initiation of brakes. In all three studies, the 85th percentile BRT was found to be 0.70 seconds.

In a study completed by Barret, Kobayashi, and Fox (1982), a driving simulator was used where a pedestrian suddenly appeared in the automobile's path. It was found that there were two groups of drivers. The fast group had a BRT of .83 seconds and the slow group had a BRT of 1.13 seconds.

In a study by Johannson and Rumar (1971), drivers were stopped and asked to react to a sound signal by tapping on their brakes within ten kilometers. The results indicated a median BRT of .66 seconds with an 85th percentile of 1.0 seconds.

In the studies by Gazis (1960) and Wortman and Mathias (1983), brake reaction times were found by time the initiation of break light from the initiation of a yellow light. Brake reaction times of these studies were found to be 1.14 and 1.30 seconds respectively.

The three studies of the Allen Corporation (1978), Sivak et. al. (1979), and Sivak et. al. (1981) used the trap technique. The trap technique involves putting an unknowing driver between a lead vehicle and a following vehicle and observing the unknowing drivers BRT while the lead vehicle brakes. The mean BRT for these three studies were 1.45, 1.38, and 1.25 seconds respectively.

In a literature survey by McGee et. al. (1983), brake reaction time was attempted to be deduced by past studies. It was found that the 85th percentile for brake reaction time was 2.3 seconds.

Studies by Triggs and Harris (1982) and Olson et. al. (1984) used obstacles that appeared over a hill. The obstacles were a slow moving car and foam respectively. It was found that the 85 percentile of the two studies were 1.26 and 1.3 seconds respectively.

The literature Review by Olson (1989), which used the proceeding studies, found that brake reaction times slowly increase with age and that women tend to respond slower, but by only on the average of 0.08 seconds. It was emphasized that studies involve specific features and therefore conclusions cannot be drawn for Brake reaction times when introducing complicating factors.

Key Words: Brake Reaction Time

Name of Reviewer: Stefan Hofmeyer

Authors: Olson, P.L., and Sivak, M.

Year: 1986

Title of Article/Report: Perception-Response Time to Unexpected Roadway Hazards

Journal: Human Factors

Volume: 28, Issue: 1

Pages: 91-96

Type of Article/Report: Field Test

Independent Variables: Age, type of obstacle, obstacle location, type of brake light presentation

Dependent Variables: Brake Reaction Time (Perception and Response Time)

Controls: Test Route, Vehicle

Data Analysis Techniques: Mean, Distribution of Times

System Studied: Collision Warning

Type of Display: Visual

Application to collision intervention: Determine a safe stopping sight distance.

Subject Population: 32 Males, 17 Females Ages 18-40; 7 Males, 8 Females Ages 50-84;

ABSTRACT:

In a study by Olson and Sivak (1986), a safe stopping sight distance was to be determined. The definition for BRT used for this study was the time an obstacle is first sighted until the time a driver initiates brakes. BRT was measured by the time from the first visibility of an obstacle until the release of the accelerator added to the time of the accelerator release to contacting the brake.

The study involved 32 males and 17 females between the ages 18-40 and 7 males and 8 females between the ages 50-84. The study consisted of 11 trials. In the first trial, using an unexpected obstacle, the subject came over a hill and found a piece of foam in the road. In trials 2-6, using expected obstacles, the same circumstance occurred, but the foam was placed in different locations. In trials 7-11, subjects were told to brake when lights placed on the hood of the car were initiated.

No significance was found between the age and gender groups. It was found that the 95th percentile of BRT was 1.6 seconds. According to the Olson and Sivak (1986) study, the standard guideline of 2.5 seconds is reasonable.

Key Words: Brake Reaction Time, Safe Stopping Distance, Perception and Reaction Time

Name of Reviewer: Thuy Tran

Authors: Olson, P., Wachsler, P., and Bauer, H.

Year: 1961

Title of Article/Report: Driver Judgment of Relative Car Velocity

Journal: Journal of Applied Psychology

Volume: 45

Issue: 3

Pages: 161-164

Place Published:

Type of Article/Report: Experiment

Independent Variables: Direction and rate of change vehicle separation distance, spacing

Dependent Variables: Driver judgments

Controls: none

Data Analysis Techniques: ANOVA

System Studied: none

Type of Display: none

Application To Collision Intervention: Driver ability to discriminate the relative velocity judgments.

Subject Population: 11

ABSTRACT: In this study subjects were evaluated for their ability to detect the direction and rate of change of the interval separating the car in which they were riding from a preceding car. The interval was set at one of two magnitudes and could remain constant or open or close at one of three rates. Results indicate that people are capable of accurate discriminations in making judgments regarding velocity differentials. There was seldom an error in judging whether the gap was opening or closing, but there was some confusion with the constant situation. It was concluded that subjects could determine the direction of change without too much trouble, however, they were much less certain when estimating the precise speed differential. The most accurate judgments were made at the closer distances and under conditions where the gap was closing at the minimum rate. In the range of speed differences studied, subjects tended to underestimate the relative speed differential between their car and the lead car. However, they exhibited a better than chance ability to discriminate between opening and closing rates at least as fine as 10 mph.

Key Words: Driver perception, Driver judgment, Relative velocity

Name of Reviewer: Loren Stowe

Authors: Palmquist, U.

Year: 1993

Title of Article/Report: Intelligent Cruise Control and Roadside Information.

Journal: IEEE Micro

Issue: February

Pages: 20-28

Type of Article/Report: Field Test

System Studied: Automated Cruise

Type of Display: Visual

Application To Collision Intervention: A computer is required to evaluate the data and make necessary adjustments to the vehicles control systems. A means of human interface is necessary to allow the driver to activate, deactivate, and reactivate the system, set speed value, and change set speed value.

ABSTRACT: General requirement for Autonomous Intelligent Cruise Control (AICC) systems are discussed and Volvo's AICC described in detail. AICC requires a target sensor to measure the distance between the vehicle and target. This sensor needs a range of between 150 to 300 meters forward and three lanes wide. Some form of computer is required to evaluate the data and make necessary adjustments to the vehicles control systems. A means of human interface is necessary to allow the driver to activate, deactivate, and reactivate the system, set speed value, and change set speed value. The system needs to give the driver verification of the input, mode of operation, and object for control (driver's set speed or preceding vehicle). To aid the system, short-range communication (SRC) allows the vehicle to interact with roadside beacons and other vehicles resulting in more accurate information. Volvo's system aids the driver in adapting their speed in regard to desired cruise speed, distance to and velocity of preceding vehicle, speed recommendations and limits, and traffic light information. The sensor employed is made by Leica and consists of five fixed, non-overlapping infrared beams. Since these beams are not activated simultaneously it is possible to determine distance and angle to the target. The SRC uses a transceiver/transponder operating at 17.5 GHz. Static and dynamic information, including roadside information, vehicle state, traffic signal status, etc., is relayed through the SRC.

Field trials will be run for traffic flow harmonization along a city highway in Sweden. Subjects will drive the vehicle in one of three conditions: manual,

informative, or automatic. The roadside information system will be evaluated on a closed track.

Key Words: Volvo's AICC, Autonomous Intelligent Cruise Control (AICC), short-range communication (SRC), Leica sensor.

Name of Reviewer: Stefan Hofmeyer

Authors: Pasta, M., and Soardo, P.

Year: 1993

Title of Article/Report: An Optimum Visibility Design for the Stop Lamp

Journal: Seventh International Technical Conference on Experimental Safety Vehicles

Pages: 880-883

Place Published:

Type of Article/Report: Experiment Field Test

Independent Variables: Luminous Intensity, Time of Day, Following Distance

Dependent Variables: Stop Lamp Visibility

Data Analysis Techniques: descriptive

System Studied: Stop Lamp

Type of Display: Visual

Application to collision intervention: Luminous intensity of a stop lamps and glare

Subject Population: 22 subjects, 8 subjects

ABSTRACT:

To reduce glare and improve visibility, the luminous intensity of a stop lamp has been optimized. Laboratory and field tests were carried out on samples of the optimized stop lamp, by day and by night. Testing should that the stop lamps were visible at a distance over 1000 m, while night glare was acceptable at short distances. The influence of the load on a car was also examined.

Key Words: Stop Lamp Glare, Luminous intensity

Name of Reviewer: Anil Kumar Yenamandra

Authors: Saad F.

Year: 1993

Title of Article/Report: Driver strategies in car-following situations

Journal: Fifth International Conference on Vision in Vehicles

Type of Article/Report: Field study

Controls: Travel Route, Time of Day, Automobile

Data Analysis Techniques: None

System Studied: None

Type of Display: None

Application to collision intervention: Describes behavior in car following situations

Subject Population: 6 males

ABSTRACT:

This paper provides useful information on the driving strategies in car-following situations. A 20.7 km stretch of urban roadway in Paris was used for the experiment and the experimental drives were made at the same time (2 to 3 pm) to ensure consistency of results. On board video camera recorded the entire trial, and the subjects were extensively interviewed (about 1.5 hours each) about the various incidents during the test run.

The results brought out two distinct driving strategies among the drivers. One was to increase following distance and the other to decrease the following distance depending on the type of interactions existing with the other vehicles. Increased headway resulted from a. interaction with the traffic that prevented the drivers from anticipating traffic status (e.g. driving behind a HGV) and b. traffic instability within the lane (frequent slow downs). Reduced following distances resulted when the drivers a. tried to overtake vehicles, b. tried to prevent other vehicles from cutting in, c. anticipated the preceding vehicle to pull back into other lane or to accelerate and d. experienced heavy traffic.

The article goes to show that experienced drivers adopt certain intuitive strategies while driving and the type of strategy adopted depends on the driving situation, the alertness of the driver, stability of the traffic and the nature of immediate interactions with other drivers.

Key Words: Car-Following

Name of Reviewer: Loren Stowe

Authors: Sawyer, C. A.

Year: 1993

Title of Article/Report: Collision Avoidance!

Journal: Automotive Industries

Issue: January

Pages: 53

Type of Article/Report: Lit review

System Studied: Warning

Type of Display: Auditory Visual

Application To Collision Intervention: Collision avoidance system tracks up to 12 objects at simultaneously, computes stopping distance, gives a warning when driver has followed too close or changes lanes without signaling his intentions.

ABSTRACT: As part of Europe's Prometheus, Lucas Industries is developing a collision avoidance system which utilizes a 75 GHz, three beam radar to measure range and relative velocity, and a video camera to measure target position relative to the vehicle. Together the system is capable of tracking 12 objects simultaneously. The primary display is based on time-to-impact (TTI). If TTI drops below 3.5 seconds, a verbal "Look ahead" command is given while a yellow flashing light arrow is displayed. The system also computes stopping distance based on sensor data, vehicle speed, and road adhesion. If the driver has followed too close for too long, a warning is given first visually and then audibly. The video camera also detects when the vehicle is about to cross a lane boundary and gives a subsequent warning if the driver fails to signal his or her intentions.

Key Words: collision warning

Name of Reviewer: Brian McKinney

Authors: Sekine, Manabu, Senoo, Tetuso, Morita, Ikuhiro, and Endi, Hiroshi

Year: 1992

Title of Article/Report: Design Method for an Automotive Laser Radar System and Future Prospects for Laser Radar

Journal: Proceedings of the Intelligent Vehicles '92 Symposium

Issue: #84670

Pages: 120-125

Place Published: Detroit, Michigan

Type of Article/Report: Design rec.

System Studied: Warning Radar brake

Application to Collision Intervention: Using an automotive laser radar system for collision avoidance -- no mention of driver interface.

Abstract: This paper presents a technical explanation of the specific procedure used in designing an automotive laser radar system. Laser radar represents an effective collision avoidance technology that can contribute to improved vehicle and traffic safety. An analysis is given of the problems involved in the practical application of laser radar and ways of overcoming them. The future prospects for automotive laser radar are also discussed.

Key Words: Laser radar system

Name of Reviewer: Stefan Hofmeyer

Authors: Sens, M.J., Cheng, P.H., Weichel, J.F., and Guenther, D.A.

Year: 1989

Title of Article/Report: Perception / Reaction Time Values for Accident Reconstruction .

Journal: SAE Report No. 890732

Pages: 79-94

Place Published:

Type of Article/Report: Lit review

System Studied: Collision Warning Applications

Type of Display: Auditory and Visual Applications

Application to collision intervention: Determine Brake Reaction Times

ABSTRACT:

A literature review was also completed by Sens et. al. (1989) where the goal was to address questions on the parameters of driving performance. Perception reaction time, or brake reaction time, was defined as a predominately visual process of understanding, or perceiving stimuli and reacting to it. Vehicle perception response time studies were reviewed including many brake reaction time studies which are described in the following paragraphs.

Four studies that were reviewed involved simulators and BRT. An early study by Greenshields (1936) used a car mockup. BRT was found from the time it took a green light to turn red and the time to touch a brake pedal. The mean BRT was found to be 0.496 seconds. In a study by Richter and Hyman (1974), driver controls were simulated and BRT was found by the time a light turned red to the time the brake pedal was touched. The mean BRT was found to be 0.5 seconds. A third study was completed by Nagler and Nagler (1973) which used a simulator. BRT was found by measuring the time between the initiation of a flashing light to the touch of a brake pedal. A median BRT was found to be 0.63 seconds. In a simulator study by Barret et. al. (1968), 11 male subjects were used to find the BRT from the time when a dummy was thrown into the road to the initiation of brakes. The BRT results ranged from 0.8-1.35 seconds.

A unique study was performed by Currie (1964) where a 1/32 scale car was used and controlled by regular brake and gas pedals. Subjects were divided into two groups: an accident prone group and a non-accident prone group. Simple brake reaction times were found to be 0.373 seconds and 0.377 seconds respectively.

Eight on road studies were reviewed. The first of these were Grime (1952) and Normann (1953). Grime (1952) found brake reaction times from the time of a reaction of a car in relation to obtrusive pedestrian movement in a cross walk. The mean BRT was found to be 0.71 seconds. Normann (1953) found brake reaction times from the time a light initiated to the time brakes were initiated. Drivers drove at high speeds on a runway at Andrews Air Force Base. BRT was found to be 0.73 seconds.

Three studies were reviewed which involved braked reaction times from car following. Sivak (1981) measured brake reaction times of unsuspecting drivers with the use of 1 HMSL, 2 HMSLs, and a control group of no HMSLs. BRT were found to be 1.38, 1.30, and 1.39 seconds respectively. Triggs and Harris (1982) found brake reaction times of car following to be 0.92 seconds for the 50th percentile and 1.26 seconds for the 85th percentile. Rockwell and Safford (1986) found the time between a car's brake light display to a following car's brake pedal initiation to be 0.71 seconds.

Several studies involved braking in reaction to a stimulus. Johannson and Rumar (1971) found the brake reaction time of a roadside buzzer with subjects using their own cars. The median BRT was found to be 0.66 seconds with a BRT correct to indicate surprise to be 0.90 seconds. Olson And Sivak (1986) used a foam obstacle in the road (test 1) and also a stimulus from a light located on the hood of a car (test 2). For older drivers test 1 had a mean BRT of 1.31 and 0.825 seconds for unalerted and alerted drivers respectively. For younger drivers test 1 had a mean BRT of 1.175 and 0.985 seconds for unalerted and alerted drivers respectively. It was found that BRT for test 2 was found to be 0.615 and .0780 seconds for older and younger drivers respectively.

Sivak et. al. (1982) completed an in-car study where the time to press a button from a leading car's brake lights was measured. Mean brake reaction times were found to be 0.73, 0.61, 0.78, 0.77, and 0.57 seconds for the overall mean, younger mean, older mean, female mean, and male mean respectively.

From these preceding studies, Sens et. al. (1989) concluded that as task complexity and degree of risk increases, reaction time increases. The review suggests that the current brake reaction time of 2.5 seconds is satisfactory because the value has been created using extreme brake reaction time cases.

Key Words: Brake Reaction Times

Name of Reviewer: Loren Stowe

Authors: Shefer, J., & Klensch, R. J.

Year: 1973

Title of Article/Report: Harmonic Radar Helps Autos Avoid Collisions: Lead Car Reflects Second Harmonic of Signal From Rear Car to Activate Warning and/or Braking System.

Journal: IEEE Spectrum

Issue: May

Pages: 38-45

Type of Article/Report: Lit review

System Studied: Automated Cruise Radar Brake

Application To Collision Intervention: Reducing false alarms collision warning systems through the use of a harmonic radar system. No mention of driver interface.

ABSTRACT: To reduce the problem of false alarms in collision warning systems, a harmonic radar system which receives the second harmonic of the transmitted frequency. This is accomplished by equipping the lead vehicle with a reflector which returns only the second harmonic thus greatly reducing the following problems: blinding--receiving transmitted signals from oncoming traffic; crosstalk interference--receiving the reflected signals from a car in an adjacent lane; and masking--receiving signals from a larger, but further away, target. Harmonic radar also allows for the possibility of "tagging" certain objects (wrong-way entrances, known hazards, etc.) to provide automatic braking in case of known hazards. An in depth description of the sensor is included.

Key Words: Blinding--receiving transmitted signals, crosstalk interference, masking.

Name of Reviewer: Stefan Hofmeyer

Authors: Sivak, M., Olson, P.L., and Farmer, K.M.

Year: 1982

Title of Article/Report: Radar-Measured Reaction Times of Unalerted Drivers to Brake Signals

Journal: Perceptual and Motor Skills

Volume: 55

Pages: 594

Type of Article/Report: Field Test

Independent Variables: Brake Light Configuration

Dependent Variables: Brake Reaction Time

Controls: Following Distance, Speed

Data Analysis Techniques: Mean, St. Deviation

System Studied: CHMSL

Type of Display: CHMSL

Application to collision intervention: Determine Brake Reaction Time

Subject Population: 1,644 Unsuspecting Subjects

ABSTRACT:

The goal of a study by Sivak et. al. (1982) was to find if high mounted brake light systems made a difference in perception reaction times. This was completed by observing a subject in a following car to see if their speed changed 3 seconds after break light initiation regardless of age and gender effects.

Data was collected at two speed ranges. The first speed range was from 32-40 km/hr with the subject car following 1 to 2 car lengths away. The second speed range was from 56-72km/hr with the subject car following 3-5 car lengths away. The lead car initiated brake lights for 3 seconds and car following the subject car recorded changes in speed with the use of Doppler radar.

1,644 data points were collected (one data point per subject). It was found that there was no significant difference between the HMSLs and the control group. The mean perception response time was found to be 1.21 seconds.

Key Words: Brake Reaction Time, CHMSL

Name of Reviewer: Stefan Hofmeyer

Authors: Sivak, M., Post, D.V., and Olson, P.L.

Year: 1981

Title of Article/Report: Driver Responses to High-Mounted Brake Lights in Actual Traffic

Journal: Human Factors

Volume: 23, Issue: 2

Pages: 231-235

Place Published:

Type of Article/Report: Field Test

Independent Variables: Brake Light Configuration

Dependent Variables: Brake Reaction Time

Controls: Time of Day, Headway

Data Analysis Techniques: Analysis of Variance, Pearson Test, Mean

System Studied: CHMSL

Type of Display: CHMSL

Application to collision intervention: brake reaction times.

Subject Population: 748 Unsuspectiong Drivers

ABSTRACT:

The goal of the Sivak et. al. (1981) study was to investigate an in-traffic brake reaction time and response probabilities of following drivers to conventional and CHMSL configurations. Brake reaction time was found by measuring the time between the initiation of brake lights and the initiation of the subjects brake lights within 4 seconds. Subjects included 748 unsuspecting drivers. Age and gender effects were not considered.

It was found that the was no significance between the control, CHMSL, and DHMSL. The brake reaction times were found to be 1.38, 1.39, and 1.30 seconds respectively. There was only significance in the percentage of subjects that braked, the fewest being in the control group.

Key Words: Brake Reaction Time, HMSL, CHMSL

Name of Reviewer: Stefan Hofmeyer

Authors: Snyder, H.L.

Year: 1976

Title of Article/Report: Braking Movement Time and Accelerator-Brake Separation

Journal: Human Factors

Volume: 18

Issue: 2

Pages: 201-204

Type of Article/Report: Experiment

Independent Variables: Lateral Separation, Vertical Separation

Dependent Variables: Movement Time

Controls:

Data Analysis Techniques: Analysis of Variance, Newman-Keuls Test

System Studied: None

Type of Display: None

Application to collision intervention: Design of accelerator-brake pedal separation

Subject Population: 7 Males, 2 Females

ABSTRACT:

Movement Times were obtained for nine adult drivers for three accelerator-brake pedal separations. The typical separation (6.35 cm laterally and 5.08 cm vertically) produced significantly longer movement times than did either a 10.16-cm or 15.24-cm lateral separation with no vertical separation.

Key Words: Braking Movement, Accelerator-Brake separation

Name of Reviewer: Anil Kumar Yenamandra

Authors: Stein, A.C., Ziedman, D., and Parseghian, Z.

Year: 1989

Title of Article/Report: Field Evaluation of a Nissan Laser Collision Avoidance System

Journal: DOT Report No. HS 807 417

Type of Article/Report: System Evaluation

Controls: Normal Driving

Data Analysis Techniques: System Studied:

Type of Display: Auditory, Visual

Application to collision intervention: Determines accuracy of collision warning systems under different conditions.

ABSTRACT:

This paper presents information on a laser based anti-collision system which signals the driver when the rate of approach is unsafe. The system has a maximum range of 100 meters and will function only when the subject vehicle travels at speeds greater than 15 mph. The driver interface of this system comprises of a visual range display and an auditory signal.

The qualitative tests comprised of 2016 miles of driving (30% highway, 20% arterial roads, the rest rural and residential roads). A total of 867 events were recorded in the trials. False alarms accounted for 712 events (caused by objects on the road, railing, vehicles changing lane in front of the driver, changes in the vehicle vertical slope), appropriate alarms 109 events and system misses 31.

The quantitative tests conducted showed that the range information provided by the system was accurate while the system gave greater warning distances as the closing rate decreased. There was no effect on the system performance due to rain or due to the influence of other similar collision warning systems. The number of false alarms increased during sunrise and sunset and there was a performance decrement when dust accumulated over the sensor.

Key Words: Collision Avoidance System, Collision Warning System

Name of Reviewer: Anil Kumar Yenamandra

Authors: Stein, A.C., Solomon, R.A., Ziedman, D.A.

Year: 1992

Title of Article/Report: Field Evaluation of the Radar Control Systems (RCS) Radar Anti-Collision Warning Systems

NHTSA Final Report

Type of Article/Report: System evaluation

System Studied: Collision Warning

Type of Display: Auditory and Visual

Application to collision intervention: Evaluates the performance of a collision warning system.

Subject Population: Undetermined

ABSTRACT:

The paper discusses a collision warning system that employs a pivoting microwave radar head with a range of 500 meters. The user interface offers a choice of settings for road type (highway, Normal), alarm onset (early, normal) and atmospheric condition (rain, normal).

The quantitative tests showed that the speed and closing rate information provided by the system was fairly good while the system did not provide any range information at high speed (> 60mph). There was no interference from other similar systems but the system performance was influenced by rain. The system could not detect pedestrians.

The qualitative tests were conducted over 2500 miles of actual roadway (50% interstate). A total of 573 events were recorded with 343 false alarms (due to freeway divider, stopped cars, signs on the road, objects on the median etc.), 185 appropriate alarms and 46 system misses (mainly due to the inability of the system to detect stopped vehicles in the front).

Key Words: Collision Warning System

Name of Reviewer: Timothy Brown

Authors:Summala, H.

Year: 1981

Title of Article/Report: Driver/Vehicle Steering Response Latencies

Journal: Human Factors

Volume: 23

Issue: 6

Pages: 683-692

Place Published: XX

Type of Article/Report: Field Test

Independent Variables: type of hazard

Dependent Variables: Lateral position of car, speed of subject car, angular deviation

System Studied: None

Type of Display: None

Application to collision intervention: Collision avoidance behavior advance warning time required

Subject Population: Unalerted drivers in free situation

ABSTRACT: This experiment investigated the driving maneuver to avoid an obstacle along side the road. Based upon the time readings measured the author recommends that drivers be given 3 seconds to respond to hazards.

Key Words: driver reaction time

Name of Reviewer: Stefan Hofmeyer

Authors: Summala, H., Leino, M., and Vierimaa, J.

Year: 1981

Title of Article/Report: Drivers' Steering Behavior When Meeting Another Car: The Case of Perceptual Tropism Revisited

Journal: Human Factors

Volume: 23

Issue: 2

Pages: 185-189

Place Published:

Type of Article/Report: Field Test

Independent Variables: XX

Dependent Variables: Lateral position

Controls: Road width

Data Analysis Techniques:

System Studied: None

Type of Display: None

Application to collision intervention: None

Subject Population:

ABSTRACT: This paper studied the behavior of cars approaching each other on a two lane road. Their lateral positions were measured and comparisons were made based upon the meeting instant. The author concluded that this behavior was based on attempting a corrective maneuver.

Key Words: Lateral position Correction-maneuver

Name of Reviewer: Timothy Brown

Authors: Akira Tachibana, Norio Fujiki, Masao Sakata, Masami Kiyoto and Toshihisa Fujiwara

Year: 1982

Title of Article/Report: Stereo Radar System for Automobile Collision Avoidance

Journal: Ninth International Technical Conference on Experimental Safety Vehicles

Pages: 909-917

Place Published: Kyoto, Japan

Type of Article/Report: Experiment Design rec.

For Empirical Studies:

Independent Variables: Radius of curvature(R) Offset(S) Object

Dependent Variables: Distance

Data Analysis Techniques: Plots

System Studied: Warning

Application to Collision Intervention: Use of a dual receiver pulse-Doppler radar collision warning system. Discriminating between impending collisions and objects that will safely pass by -- no driver interface.

Abstract: This paper discusses the use of a dual receiver and a phase difference to improve the detection of dangerous conditions. The study found that the phase difference effectively discriminates between dangerous conditions and conditions that are going to bypass the car.

Key Words: Phase difference Doppler radar Dual receivers

Name of Reviewer: Stefan Hofmeyer

Authors: Taoka, G.T.

Year: 1989

Title of Article/Report: Brake Reaction Times of Unalerted Drivers

Journal: ITE Journal

Volume: March

Pages: 19-21

Place Published:

Type of Article/Report: Lit review

Application to collision intervention: Determination of Brake Reaction Time.

ABSTRACT:

In a report by Taoka (1989), four brake reaction time studies were contrasted and a conclusion drawn. Three of these studies: Gazis et. al. (1960), Wortman et. al. (1983), and Chang et. al. (1985) measured BRT as the time of a yellow stoplight signal until the appearance of automotive brake lights. Brake reaction times for these three studies were 1.14, 1.30, and 1.30 seconds respectively. Taoka surmises that BRT should be viewed in a lognormal distribution.

The fourth study reviewed was Sivak et. al. (1982). This study measured time from the onset of a braking car to the initiation of brakes on a following car. Brake reaction time for this study was found to be 1.21 seconds. It was concluded by Taoka (1989) that a car following study was more indicative of BRT since there is a lag when braking for a yellow light.

Key Words: Brake Reaction Time

Name of Reviewer: Tim Brown

Authors: Tetsuo Teramoto, Keiji Fujimura and Yasuhiro Fujita

Year: 1989

Title of Article/Report: Study of Laser Radar

Journal: The Twelfth International Technical Conference on Experimental Safety Vehicles

Pages: 888-895

Type of Article/Report: Design rec.

System Studied: Warning Automated cruise Radar brake

Type of Display: Auditory

XX

Application to Collision Intervention: Alternate design for headway determination

Abstract: This paper covered one particular design configuration for determining headway. It also discussed reflection of the laser beam. The system configuration was included. Performance of this configuration can be improved. Subjects to be dealt with include stability, detection characteristics, and system control specifications for various features

Key Words: Pulsed laser Vehicle control

Name of Reviewer: Loren Stowe

Authors: Troll, W. C., Wong, R. E., and Wu, Y. K.

Year: 1978

Title of Article/Report: Results from a Collisions Avoidance Radar Braking System Investigation

Journal: SAE Report No. 740095

Pages: 1-11

Type of Article/Report: System evaluation.

Independent Variables:

Dependent Variables: false alarms, miss rates

Controls: System type

Data Analysis Techniques: The data were filtered to classify according to a common set of circumstances (effectively eliminating those where benefits seemed unlikely), sorting them according to system type, and placing them in one of three categories representing the confidence in accident prevention. To evaluate the compromises necessary to balance false alarms with missed targets, sensitivity analysis was performed using computer simulation.

System Studied: Radar Brake

Application To Collision Intervention: Accidents in the U.S. could be reduced by between 8 and 25% with a radar braking system. This system should have a automatic/ noncooperative configuration with anti-lock brakes.

ABSTRACT: Studies have shown that a automatic/noncooperative radar braking system may significantly reduce the number of accidents. One major problem with the implementation of such a system is target recognition, a key in reducing the number of false alarms. Six experimental systems were tested for radar cross section analysis, environmental analysis, operating environment in the vehicle, and performance analysis. These were tested on three types of radar: pulsed, diplex, and FM-CW. Cost-benefit analysis was determined through evaluation of accident data. The data were filtered to classify according to a common set of circumstances (effectively eliminating those where benefits seemed unlikely), sorting them according to system type, and placing them in one of three categories representing the confidence in accident prevention. Results showed that automatic/ noncooperative system may be most beneficial.

To evaluate the compromises necessary to balance false alarms with missed targets, sensitivity analysis was performed using computer simulation. The data

for the simulation was gathered using an existing automatic/noncooperative braking system equipped vehicle. The system included a 22.125 GHz signal radar which provided range and range rate information. Steering angle, vehicle speed, and road surface condition were also used by the system to determine stopping distance. For the test, three parameters were varied: 1.) radar detection cutoff range, 2.) antenna bandwidth, and 3.) activation delay. The first two parameters measured the geometric effects while the latter was used to show the influence of suppressing alarms from transient targets. More than 200 runs were made using combinations of four detection ranges, three bandwidths, and two activation delays. Data recorded included: signal presence, warning channel, brake command, vehicle speed, signal strength, range, range rate, and event. These data were analyzed to determine false alarm rate according to number, cause, magnitude/duration, and profile. To assess benefit, each system configuration's terminal state was measured to determine if the collision was avoided or, if not, the final velocity and the corresponding reduction of injury or fatality.

Results show that accidents in the U.S. could be reduced by between 8 and 25% with a radar braking system. This system should have a automatic/ noncooperative configuration with anti-lock brakes. Target discrimination is best achieved through restricting range and beam width to 150 feet and 2.5 degrees respectively. A longer range results in both a higher detection rate and false alarm rate. Reducing the system control based on steering wheel angle was effective in reducing the false alarms due to targets outside the vehicle path. False alarms due to scatter from heavy rain was significant. Vehicle speed was largely insignificant in as much at it could be tested. Activation delay seemed only successful in delaying a false alarm rather than eliminating it.

Key Words: Radar braking system, automatic/ noncooperative configuration with anti-lock brakes, radar detection cutoff range, antenna bandwidth, activation delay, target recognition, false alarms.

Name of Reviewer: Timothy Brown

Authors: Tsao, J.H.S., and Hall, R.W.

Year: 1993

Title of Article/Report: A Probabilistic Model and a Software Tool for AVCS Longitudinal Collision/Safety Analysis

Journal: California PATH Program

Volume: Working Paper UCB-ITS-PWP-92-3

Issue:

Pages: 1-22

Place Published:

Type of Article/Report: Model

System Studied: Automated Vehicles

Application to collision intervention: Type of automated cruise -- no driver interface.

ABSTRACT: This paper presents a probabilistic model of safety between two automated vehicles. A software tool is also introduced. Input parameters are the length of gap between the two vehicles, the common speed prior to failure, the reaction delay of the following vehicle, and deceleration rates. The paper uses these items to compare the safety of platooning and "free-agent "vehicle operation. The author contends that free-agent vehicle following can virtually avoid collisions while providing for a high freeway capacity comparable with that under the platooning rule.

Key Words: AVCS Collision speed distribution Platooning Free-agent

Name of Reviewer: Timothy Brown

Authors: Tumbas, N.S., Treat, J.R., and McDonald, S.T.

Year: 1978

Title of Article/Report: An Assessment of the Accident Avoidance and Severity Reduction Potential of Radar Warning, Radar Actuated, and Anti-lock Braking Systems

Journal: SAE Report No. 770266

Place Published:

Type of Article/Report: Data examination

System Studied: Warning Radar Brake

Type of Display: Auditory Visual Haptic Other

Application to collision intervention: None

ABSTRACT: This paper examined a group of 215 in-depth accident reports to study the benefits of anti-lock brakes, radar warning, and radar actuated brakes. The study examined what would have happened if one or more of the vehicles involved had been equipped with various combinations of these systems. It was found that anti-lock brakes would only have prevented one of the 215 accidents. The system that contained all three systems had some possibility of preventing 90 of the accidents.

Key Words: Anti-lock braking system Radar warning Radar actuated brakes

Name of Reviewer: Timothy Brown

Authors: Berthold Ulmer

Year: 1992

Title of Article/Report: Proceedings of the Intelligent Vehicles '92 Symposium

Pages: 36-41

Place Published: Detroit

Type of Article/Report: Field test

System Studied: Warning Automated cruise Radar brake

Application to Collision Intervention: Provide a alternative to laser and radar technology for the detection of obstacles. No driver interface mentioned

Abstract: This paper describes results of the autonomous Daimler-Benz test vehicle VITA. The basic structure of the vehicle is examined. The computer vision system is examined. On going research is also mentioned.

Key Words: Computer vision, lane tracking

Name of Reviewer: Stefan Hofmeyer

Authors: Wilson, F.R.

Year: 1987

Title of Article/Report: Measurement of Collision Avoidance Times

Journal: Proceedings of the Roads and Transportation Association of Canada

Volume: 1987

Pages: 41-64

Place Published:

Type of Article/Report: Field study

Dependent Variables: perception time, Brake Reaction Time

Controls: test course

Data Analysis Techniques: Analysis of Variance, Difference of Means, Chi-Square

System Studied: None

Type of Display: None

Application to collision intervention: Determine Brake Reaction Time

Subject Population: 10 Males and 10 Females Ages Less Than 35, 10 Males and 10 Females Ages Greater Than 35

ABSTRACT:

In a study by Wilson (1987), a driver's perception and reaction time were determined in a collision avoidance situation. Brake reaction time was defined as the combination of perception time and reaction time. Perception time was defined as the time which elapses from the instant an obstacle or dangerous situation appears in the path of a driver's vehicle, to the instant where the driver has recognized the conflict and has decided to take action. The reaction time was defined as the time required by a driver to complete a movement (i.e. apply braking). The perception time was measured from the target activation to the instant where the subject's foot was off of the accelerator pedal. Reaction time was measured as the time between releasing the accelerator and activating the brake pedal. The times were measured by electronic sensors and integrated with a computer.

The study included four subject groups, ten males and ten females below the age of 35 and ten males and ten females above the age of 35. The subjects were instructed to come to a complete stop in front of an obstacle that was triggered 40 meters in front of the car. The subjects were tested a maximum of five times.

It was found that male and female BRT was not significantly different and that older subjects had a marginally shorter reaction time, where younger subjects had a marginally shorter perception time. The average BRT was found to be 0.70 seconds and the average time when a subject passed the target was found to be 2.4 seconds. The average total perception, reaction, and vehicle response time was found to be 0.96 seconds.

In conclusion, the study by Wilson (1987) found that the standard of a 2.5 second BRT is conservative. This conclusion was derived from the analysis that a driver in the 99th percentile of the study would have a BRT of only 1.6 seconds.

Key Words: Brake Reaction Time