Problem Area Descriptions

Motor Vehicle Crashes – Data Analysis and IVI Program Emphasis

U.S. Department of Transportation

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Motor Vehicle Crashes – Data Analyses and IVI Program Emphases

1. OVERVIEW

In general, the IVI program focuses on the more significant safety problem categories as indicated by statistical analyses of crash data. However, other factors were considered in setting program priorities and schedules. For some problem areas, the complexity of the countermeasure required an extended research and testing program. In other cases, promising crash countermeasures were ready to be tested in the field. Thus, in some cases, countermeasures to address smaller problem areas were selected for development because they were considered closer to deployment and could produce early benefits in terms of reduced crashes, injuries, and deaths. Additionally, the IVI Program includes countermeasures for platforms other than passenger cars. Platforms such as commercial vehicles, transit buses, and specialty vehicle have specific safety needs, offer unique opportunities to test and evaluate countermeasures, and are often early implementers of advanced technologies.

2. DATA ANALYSES OF MOTOR VEHICLE CRASHES

This section presents a brief summary of the analytic and research efforts that were conducted by U.S. DOT to characterize motor vehicle crash problems and analyze their causal factors and significance. During the early 1990s, the vehicle safety research efforts within NHTSA's Office of Collision Avoidance Research (OCAR) concentrated on a program "to facilitate the development and deployment of effective safety-related systems as part of the Department of Transportation Intelligent Vehicle Highway Systems program."[1] This program included a detailed analysis of vehicle crash statistics, causal analyses, and case studies.[2] These analyses were used to identify and classify the primary causal factors, to prioritize research activities, and to develop individual programs of research on crash countermeasures. The results of these analyses strongly influenced the program priorities and approaches within the current IVI Program. Additional analyses are underway to identify the safety-specific needs for transit and special vehicles operating on public roads.

2.1 Identification and Categorization of Motor Vehicle Crashes

Crash data from the Fatal Analysis Reporting System (FARS) and NHTSA's General Estimates System (GES) databases were analyzed to gain a detailed understanding of the nature and significance of factors contributing to crashes. Major crash categories and subcategories were identified through statistical analyses. Separate analyses of crash causal factors identified the predominant contributing factors for crashes. Based on these analytic efforts, and other research activities, seven problem area categories were identified where crash countermeasure systems could have potential benefits. Countermeasure development programs in each area focused on further analyzing crash scenarios to better understand causal factors and on developing and testing prototype countermeasure systems. An eighth category was subsequently added for new

[1] "Status Update of NHTSA's ITS Collision Avoidance Research Program." August Burgett, 1996.

[2] Report to Congress on the National Highway Traffic Safety Administration ITS Program, Program Progress During 1992-1996 and Strategic Plan for 1997-2002, dated January 1997.

features and technologies that are currently being installed in motor vehicles. These eight problem areas are:

Specific Crash Types	Driver Performance	Miscellaneous
• Rear-End Crashes	• Visibility	• Safety Impacting Devices
• Lane Change or Merge Crashes	• Driver Condition	
• Road Departure Crashes		
• Intersection Crashes		
• Vehicle Stability		

Motor vehicle crash causation is an illusive topic. Crashes usually have multiple causes. Available crash investigation data usually contain very little information on causation. Rather, the data describe the vehicles involved, the highway conditions at the crash scene and the characteristics of the involved drivers and whether they were cited for traffic violations. The severity of injuries, if any, also is noted.

Thus it is very difficult to ascertain the true "causes" of most motor vehicle crashes. The exceptions are those cases that involve severely impaired drivers such as those with high blood alcohol or drug concentrations. Given the absence of direct causation data, traffic safety analysts address crash causation tangentially by:

- Compiling and analyzing crash data to identify characteristics or circumstances that are over-represented in the crash population as compared to the overall driver, vehicle, or highway populations. This may include estimates of "exposure" to crashes and computing crash rates per unit of exposure, such as vehicle miles of travel.

- Conducting in-depth real-world crash investigations on a sample of crashes. These are conducted by trained investigators and attempt to document human, vehicle, and highway factors associated with the crash. Engineers and medical personnel may also be involved in reconstructing the crash event and occupant injuries.

- Compiling and analyzing non-crash data sources that may help identify safety-related problems such as roadside safety inspection data collected on trucks.

- Conducting engineering analyses of vehicle operator control dynamics.

- Conducting experimentation in a controlled laboratory or test track environment.

- Seeking out information from business owners that operate fleets of vehicles and determine their most important safety issues and problem areas (and why).

The results from the combination of these approaches lead to the identification of crash-reducing countermeasures and are highlighted in the following sections.

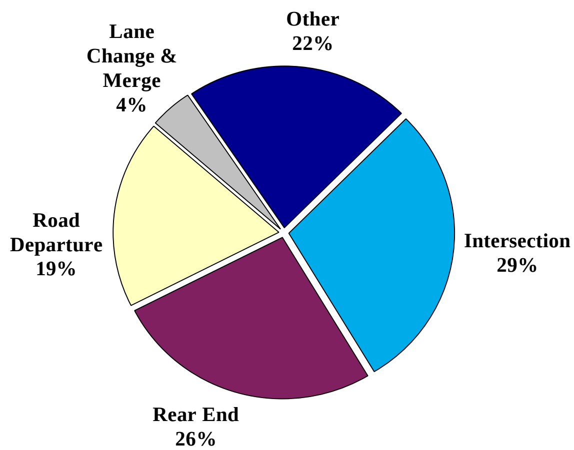
2.2 Causal Factor Analysis

Initial OCAR research focused on analyzing data regarding primary and associated causal factors in crashes, performing case studies and other research to develop a statistical view of these factors. Crash problem analyses included the review of individual cases, identification of relevant pre-crash circumstances, and preliminary assessment of potential intervention mechanisms. This work was conducted to provide the researchers with an increased understanding of the dynamics of the events that precede specific types of crashes. This knowledge was key to the development of performance specifications for collision avoidance systems and for predicting the potential benefits to be obtained from the specific collision avoidance countermeasure.

2.2.1 All Vehicles

Figure 2-1 shows the distribution of crash types for all highway vehicles, (based on 1994 GES data). The chart also identifies problem areas where the largest potential benefits could be obtained from the development and fielding of collision avoidance systems. As shown in the figure, the three largest crash types (rear-end, intersection, and road-departure) account for nearly 75 percent of all crashes. These findings provided the basis for establishing focused programs for each of these three types of crashes.

Figure 2-1. Distribution of Crash Types (1994 data)



Causal analyses identified a second category of crash countermeasure systems, namely those dealing with driver performance. Systems that enhance driver performance essentially cut across the various crash types and provide alternative approaches for reducing accident rates. Key contributing factors in motor vehicle crashes include reduced visibility, such as at night or in degraded weather conditions, and driver drowsiness. These factors occur across the spectrum of crash types shown in figure 2-1. The Volpe National Transportation Systems Center (VNTSC) supported NHTSA in performing a thorough review of collision data to determine collision causal factors for each crash type. A summary of the major causal factors for all collision types is shown in table 2-1.

Table 2-1. Causal Factor Distribution of Crashes
(Percent of total crashes, 1993 data)

Crash Type	Driver Task Errors			Driver Physiological State			Vehicle Defects	Road Surface	Visibility	*Total*
	Recogn. Error	Decision Error	Erratic Action	Drunk	Asleep	Ill				
RE	14.3	6.8	0.3	0.5	0.0	2.4	0.3	0.6	0.0	*25.2*
LCM	2.5	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	*3.9*
RD	3.2	3.6	3.2	2.1	2.4	0.7	1.1	4.1	0.0	*20.4*
SI/SCP	1.3	0.5	1.0	0.4	0.0	0.0	0.1	0.0	0.0	*3.3*
UI/SCP	4.3	0.7	0.2	0.2	0.0	0.0	0.0	0.4	0.1	*5.9*
LTAP	3.2	2.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	*6.6*
BK	1.8	0.8	0.1	0.1	0.1	0.0	0.2	0.0	0.0	*2.9*
OD	0.5	0.2	0.5	0.9	0.0	0.0	0.1	0.5	0.0	*2.8*
Total	*31.2*	*16.6*	*6.0*	*4.2*	*2.5*	*3.2*	*1.7*	*5.6*	*0.1*	*71.0*

Source: DOT HS 808 263
Note: Other intersection/crossing path crashes (14%) and miscellaneous other crashes (15%) not included in causal distribution but are part of total crashes.

KEY:	BK	Backing	RE	Rear end
	LCM	Lane change or merge	RD	Road departure
	LTAP	Left turn across path	SI/SCP	Signalized intersection, straight crossing path
	OD	Opposite direction	UI/SCP	Unsignalized intersection, straight crossing path

In 1996, NHTSA convened a Collision Avoidance System (CAS) Benefits Working Group that estimated the number of crashes that could be avoided in the United States with full deployment of rear end, road departure, and lane change and merge collision avoidance systems. These estimates were based on detailed analyses of crash scenarios and causal factors and the best empirical and analytical research available regarding operation of the collision avoidance systems. The Working Group determined the subset of crashes that could be address by countermeasure systems and also computed estimates of countermeasure effectiveness for the “relevant” subset of crash types. The results of this preliminary study are summarized in the following table. It must be emphasized that many estimates and assumptions were made to develop these results. The results must be considered preliminary in nature pending further research, refinement of potential countermeasure effectiveness estimates, and field experience.

Table 2-2. Crash Countermeasures – Estimated Deployment Benefits
(Numbers in Millions)

Crash Condition	Total Number of Crashes	Relevant Crashes Addressed by Countermeasures	Effectiveness Estimates for Relevant Crashes	Number of Crashes Reduced
Rear-End	1.66	1.55	51%	0.79
Lane Change/Merge	0.24	0.19	47%	0.09
Road Departure	1.24	0.46	65%	0.30
Total	**3.14**	**2.20**		**1.18**

2.2.2 Large Trucks

In 1997, approximately 444,000 large trucks were involved in crashes. Large trucks are defined as single-unit trucks and truck tractors with a gross vehicle or combination weight rating of more than 10,000 pounds. There were 4,871 large trucks involved in fatal crashes, an estimated 97,000 trucks in injury crashes, and an estimated 342,000 involved in property-damage only crashes.[3] Large trucks accounted for 3 percent of all registered vehicles, 7 percent of total vehicle miles traveled, 3 percent of all vehicles involved in injury and property-damage-only crashes, and 9 percent of all vehicles involved in fatal crashes in 1996.[4]

Table 2-3. Fatalities and Injuries in Crashes Involving Large Trucks

	Fatality Crashes	Percent of Total	Injury Crashes	Percent of Total
Occupants of Large Trucks	717	13	31,000	24
Single-Vehicle Crashes	*496*	*9*	*14,000*	*11*
Multiple-Vehicle Crashes	*221*	*4*	*17,000*	*13*
Occupants of Other Vehicle In Crashes Involving Large Trucks	4,189	78	99,000	75
Nonoccupants (pedestrians, pedalcyclists, etc)	449	8	2,000	2
Total	**5,355**	**100**	**133,000**	**100**

Source: 1997 FARS, GES

Of the 717 large truck occupants killed (shown in table 2-3), 496 in were killed in single-vehicle crashes and 221 in multiple vehicle crashes.[5]

Most of the fatal crashes involving large trucks involve multiple vehicles. In multiple vehicle crashes the driver of the other vehicle is cited by police in 80 percent of the cases compared to 28 percent for the truck driver. For single vehicle large truck crashes, 69 percent of the drivers had been cited (including “ran off roadway/out of traffic lane”, “driving too fast”, “inattentive”, and “drowsy/asleep” as the highest categories.)

3. REAR-END CRASHES

3.1 Data Analysis Results

A rear-end crash occurs when the front of a vehicle strikes the rear of a leading vehicle, in the roadway. Analysis of data from 1994, indicated approximately 1.66 million police-reported rear-end crashes.[6] These crashes accounted for over 920,000 injuries and 1,160 fatalities. As shown in figure 2-1, rear-end crashes accounted for approximately 26 percent of all crash types, making it one of the largest crash categories. NHTSA estimates that about 50 percent of these crashes

[3] Large Truck Crash Profile: The 1997 National Picture, FHWA, Office of Motor Carriers, September 1998

[4] Traffic Safety Facts 1997 – Large Trucks, NHTSA, National Center for Statistics and Analysis.

[5] Ibid.

[6] NHTSA, op. cit. footnote 2.

could be avoided by collision avoidance systems that could sense stopped or slower-moving vehicles in the forward lane.[7]

Table 3-1 shows the distribution of rear-end collisions over the range of possible dynamic situations.[8] These data indicate that a significant majority (approximately 91 percent) of the following vehicles were driving at constant speed when the collision occurred, implying that driver inattention to the driving task was a major causal factor for this collision type.

Table 3-1. Rear-End Crash Distribution by Dynamic Situation

Lead Vehicle	Involved Following Vehicle (percent):			*Total*
	Accelerating	Constant Speed	Decelerating	
Stopped	1	18	1	***20***
Constant Speed	2	7	0	***9***
Decelerating	0	14	3	***17***
Accelerating	0	2	0	***2***
Decelerating & Stopped	1	50	1	***52***
Total	***4***	***91***	***5***	***100***

Table 3-2 identifies the primary causal factors for rear-end collisions, based upon previously referenced NHTSA analyses. As shown, four factors were identified as the primary causes for approximately 92 percent of rear-end collisions. Based upon these findings countermeasure systems that could alert the driver to unsafe conditions became the focus of research in this area.

Table 3-2. Predominant Rear-End Crash Causal Factors

Crash Causal Factor	Distribution (Percent)
Inattention	41
Inattention/following too close	27
External Distraction	14
Internal Distraction	10
Other	8
Total	***100***

Rear-end collision avoidance systems (RECAS) monitor the forward path of the host vehicle, detect other vehicles and objects, and warn the driver if a collision is imminent. At present, the technology to provide effective rear-end collision avoidance systems is considered to be more mature (i.e., closer to commercial availability) than systems for some other collision types (e.g., intersection crashes). For example, some motor carriers have deployed rear-end collision avoidance systems on heavy trucks operating in revenue service.

3.2 Rear-End Collision Avoidance Program Area Accomplishments

Since 1993, rear-end collision avoidance has been actively studied by the NHTSA. Several research projects have been completed since that time. These include:

- Completed causal factor analysis for the crash problems.

[7] Preliminary Assessment of Crash Avoidance Systems Benefits, NHTSA Benefits Working Group, October 1996.

[8] DOT HS 808 561, IVHS Countermeasures for Rear-End Collisions, Task 1, Volume 1: Summary, Frontier Engineering, February, 1994.

- Completed operational tests of intelligent cruise control (ICC) systems. This activity provided an understanding of ICC system capabilities, user acceptance, and potential safety benefits. As stated earlier, ICC systems are considered an important technological stepping stone toward the development of full capability RECAS
- Completed preliminary system performance specifications. U.S. DOT has developed a basic understanding of system capability and potential benefits that could be achieved.
- Developed objective countermeasure test procedures. This effort updated and refined performance specifications and test metrics in preparation for the development and operational testing of prototype countermeasure capabilities over the next several years.
- Built an extensive human factors database for RECAS. This includes data on driver performance and driver-vehicle interface (DVI) issues (i.e., how and when to issue warnings).
- Initiated a joint research project on vehicle crash warning systems with GM and Dephi-Delco. This is a follow-on to the recently completed Automotive Collision Avoidance Systems (ACAS) program. The ACAS program focused on advancing individual subsystems by reducing the size and cost of radar components. The joint research project will develop and integrate key technologies to create a prototype forward collision warning system. The prototype system will be tested and evaluated under an extensive field operational test that will be conducted during the latter half of the 5-year project.

3.3 Continuing RECAS Program Area Activities

Previous studies have indicated that the use of multiple sensors can improve the ability of the countermeasure system to detect and to discriminate target objects in the host vehicle path from fixed objects alongside the road or in adjacent lanes. Combining the outputs of multiple sensor systems (or sensor fusion) is expected to aid in removing sensor clutter, caused by roadside objects such as signs and other highway structures. This issue will be addressed in more depth in follow-on projects within the IVI Program.

The centerpiece of continuing RECAS activities is a 5-year joint research program between the U. S. DOT and General Motors Corporation. This program will build on previous research to create prototype crash warning systems and conduct operational testing and evaluation, using licensed drivers under real world driving conditions. The prototype countermeasure system is expected to be equipped with multiple sensors (radar and optical), warning displays, map databases, and Global Positioning System receivers.

In addition to this joint research program, a number of related activities are planned to address outstanding RECAS capability and driver acceptance issues. These research plans include continuing human factors studies, detection/warning algorithm development, and benefits estimation efforts. Results of these supporting activities will be provided to the joint research program, and factored into the prototype development and evaluation efforts in that program.

4. INTERSECTION CRASHES

4.1 Data Analysis Results

Intersections are among the most dangerous locations on U.S. roads. Analysis of the 1994 GES data indicates that 29% of all police reported crashes were intersection crossing path related (see figure 2-1), that is, 1.85 million crashes.[9]

As part of a NHTSA-funded intersection collision avoidance system (ICAS) performance specification development project, Veridian Engineering conducted a detailed analysis of the intersection crash problem.[10] Veridian categorized four distinct configurations or scenarios C left turn across path, perpendicular path with entry with inadequate gap, perpendicular path with violation of traffic control, and premature intersection entry with violation of traffic control signal. Note: these scenarios do not completely correspond to the scenarios analyzed by VOLPE and summarized in Table 1-1 and therefore should not be directly compared. For each of the scenarios, specific characteristics associated with the traffic control device, driver response, intended maneuver, and causal factors were identified. The following table presents the distribution of crashes for each scenario.

Table 4-1: Distribution of Intersection Crash Scenarios

Crash Scenario	Percentage of Sample
No. 1 Left Turn across Path	23.8
No. 2 Perpendicular Path - Entry with Inadequate Gap	30.2
No. 3 Perpendicular Path - Violation of Traffic Control	43.9
No. 4 Premature Intersection Entry - Violation of Traffic Control – Signal	2.1

To identify appropriate crash countermeasures and predict their effectiveness, causal factors were analyzed for each of the scenarios presented in table 4-1. The causal factors that accounted for the highest percentage of crashes are presented in table 4-2.

[9] Data analyses by John A. Volpe National Transportation Systems Center.

[10] "Intersection Collision Avoidance Using ITS Countermeasures", Veridian Engineering, prepared for U.S. DOT, National Highway Traffic Safety Administration. Aug. 1999. DRAFT final report.

Table 4-2. Causal Factors by Crash Scenario
(Cells are marked with an X to indicate primary causal factors.)

Crash Scenario	**Causal Factors**					
	Looked, Did Not See	Attempted to Beat Vehicle	Vision Obstructed or Impaired	Driver Inattention	Deliberate Violation of Stop Sign	Deliberate Violation of Traffic Signal
No. 1. Left Turn across Path	X	X	X	X		
No. 2. Perpendicular Path – Entry with Inadequate gap	X		X	X		
No. 3. Perpendicular Path – Violation of Traffic Control				X	X	X
No. 4. Premature Intersection Entry – Violation of Traffic Control – Signal				X		

4.2 Intersection Collision Avoidance Program Area Accomplishments

Based on the data analyses summarized above, Veridian Engineering developed an ICAS testbed design. In keeping with the focus of developing systems that have a high likelihood of being implementable in the near term, the testbed design represents a first incremental step in solving the intersection collision problem. Along these lines, initial plans to include a signal-to-vehicle communication system were eliminated. Also, the original radar system design was complex, and a decision was made to use commercially available radar. While this represented a compromise solution, it allowed the development of a countermeasure at a reasonable cost.

The in-vehicle ICAS testbed included a threat detection system, the Geographical Information System/Global Positioning System (GIS/GPS), the driver vehicle interface, and the vehicle support system. The threat detection system utilized three Eaton VORAD millimeter wave radars to acquire data on vehicles approaching the intersection.

U.S. DOT also conducted a field test on an infrastructure-based ICAS concept.[11] The focus of this project was safety at unsignalized intersections. The system provided active warning signs, based upon loop detectors embedded in the roadway, for drivers at an unsignalized (two-way stop sign controlled) intersection with limited sight distance at a pilot location. Sensors embedded in the pavement detected the presence of vehicles waiting to enter the intersection (on the minor roadway), and measured the speed of approaching vehicles on the major roadway. The information was collected by a computer controller at the intersection that estimated the various vehicles arrival times and activated roadside warning signs accordingly.

Key accomplishments of these projects include:

- Developed performance metrics for an in-vehicle, autonomous system to warn drivers of potential intersection violation and targets on perpendicular paths

[11] "Vehicle-Behavioral Evaluation of the Collision Countermeasure System (CCS): Acclimation Phase Report", Raytheon Systems Company, prepared for U.S. DOT, Federal Highway Administration, December 1998.

- The in-vehicle ICAS system equipment was successfully integrated into a Ford Crown Victoria for testing and evaluation.
- The in-vehicle ICAS system was not capable of preventing all the collision scenarios presented in Table 3-1. The ICAS system was capable of dealing with intersection collision scenarios 1 and 2 as defined above, and part of scenario three, primarily for stop sign controlled intersections. The study results indicate that to obtain the additional coverage, information regarding the signal phase would be required.
- Visual, auditory, and haptic warnings were tested for the in-vehicle system.
- Linked map information and radars to reduce false alarms in the in-vehicle system
- For infrastructure-based ICAS, demonstrated positive driver safety behaviors at the test intersection where that system was deployed.

4.3 Continuing ICAS Program Area Initiatives

Future work on intersection collision avoidance will continue to seek vehicle-based solutions to this complex and difficult problem. However, there is a wide difference between the common pre-crash scenarios in the intersection crash population and their causal factors – this calls for different functionalities of the sub-parts of an intersection collision avoidance system. US DOT will conduct a more detailed systems study to explore next-step options to improve intersection safety. US DOT will coordinate near-term ICAS deployment options with state and local infrastructure deployment (e.g. photo enforcement as a synergic countermeasure for red-light running and the associated collisions avoided).

Additionally, US DOT plans to investigate infrastructure-based sensing to identify hazardous vehicle movements and possible pedestrian conflicts and interfaces with traffic control systems to recognize current phase and times to next phases. In general, new approaches to communicating with motorists will be considered, such as special communication systems to convey ICAS information to on-board intelligent vehicle ICAS.

5. LANE CHANGE AND MERGE CRASHES

5.1 Data Analysis Results

Lane change and merge (LCM) crashes accounted for approximately 244,000 crashes in the United States in 1994 (4 percent of all crashes) and resulted in 225 fatalities and many serious injuries.[12] They occur most often on metropolitan arterials and streets.

Table 5-1 lists the primary causal factors for LCM crashes. The data are based upon a case study review of crashes, conducted by NHTSA and VNTSC using data selected from the 1991-1993 GES and the Crashworthiness Data System (CDS).[13]

[12] NHTSA, op. cit., footnote 2.

[13] Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures, U. S. Department of Transportation, VNTSC, June 1995.

Table 5-1. Predominant LCM Crash Causal Factors

Crash Causal Factor	Distribution (Percent)
Looked/Did Not See	61
Misjudged Velocity/Gap	30
Inattention	4
Excessive Speed	2
Other	3
Total	***100***

LCM systems are expected to provide sensors and warning displays to help drivers become more aware of adjacent-lane vehicles prior to initiating lane change maneuvers. Such systems would alert the driver that an intended lane-change maneuver might be unsafe. The warning occurs during the decision phase of the lane change or before the driver initiates a lane change maneuver. This function requires sophisticated sensing and processing capabilities to determine the relative lateral position and velocity of vehicles in adjacent lanes during lane change and merge situations (i.e., merge area occupied, closing velocity too high-gap too small, etc.)

LCM crash countermeasures have focused on two specific crash scenarios. The first is the condition where a second vehicle occupies the space adjacent to the primary vehicle. In this instance there is little or nor longitudinal gap. The second scenario treats the condition where there is a longitudinal gap and substantial differential speed between the primary vehicle and the threat vehicle.

5.2 LCM Collision Avoidance Program Area Accomplishments

A performance specification project was initiated in 1993, with TRW evaluating enabling technologies, performing causal factors analysis, and test-bed development and testing. Both sonic and radar sensor technologies were evaluated. The study determined that radar systems are necessary to detect the presence and closing velocities of more distant vehicles (e.g., up to 100 feet behind equipped vehicle), especially over a range of lane geometries and weather situations.

Test bed fabrication and checkout has been completed. Prototype testing is underway, with emphasis on measuring system performance parameters, driver acceptance and usage patterns. The TRW testbed uses a scanning laser as the LCM sensor to measure driver behavior and evaluate countermeasure effectiveness. LCM countermeasure system performance specifications are being refined and will be published in 2000.

5.3 Continuing LCM Collision Avoidance Program Area Activities

The LCM program area is entering a second stage in problem definition where additional naturalistic driving data are being collected. This involves instrumenting vehicles to measure data on pre-crash events (as opposed to reconstructing such data from post-crash information). These data are necessary due to the lack of information on the timing of critical pre-crash events and opportunities for (countermeasure) intervention.

6. ROAD-DEPARTURE COLLISIONS

6.1 Data Analysis Results

A road-departure crash occurs when a vehicle leaves the roadway and is involved in a collision with another vehicle or other object, off the roadway. Analysis of crash data indicates that approximately 1.24 million police-reported crashes of this type occurred in 1994.[14] This number represents approximately 19 percent of the total crash problem and resulted in over 500,000 injuries and 13,000 fatalities.

There are many different causes of these types of crashes, including weather and visibility problems, driver impairment, and other improper driving behaviors. Due in part to these diverse causal factors, the development of effective countermeasure systems continues to present significant technical challenges.

Table 6-1 lists the primary causal factors for road-departure crashes. The data is based upon a case study review of crashes, conducted by NHTSA and the Volpe National Transportation Systems Center (VNTSC) using data selected from the 1991-1993 GES and CDS[15].

Table 6-1. Predominant Road Departure Crash Causal Factors

Crash Causal Factor	Distribution (Percent)
Impaired/Drowsy	25
Roadway Defects/Surface Conditions	20
Excessive Speed	18
Inattention	16
Evasive Maneuver	14
Other	7
Total	***100***

Two primary scenarios for road-departure crashes have been targeted for countermeasure development: lateral road excursions, in which the vehicle crosses roadway boundaries; and longitudinal crashes where the vehicle is traveling too fast to negotiate roadway geometry for the road surface conditions.

Countermeasure projects have focused on the development of systems to provide the driver with road-departure warnings. Because driver inattention and errors are key factors in these types of crashes, countermeasure development will be complemented by projects involving drowsy driver warning and vision enhancement systems. The lateral road departure countermeasure system is designed to prevent road departure crashes caused primarily by driver inattention or by the driver relinquishing steering control due to drowsiness. This countermeasure system would detect when the vehicle is about to depart from the road (lane) and would provide an appropriate warning. The system will either detect actual lane crossing or will attempt to predict an imminent lane boundary crossing based upon vehicle dynamics and road geometry.

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[14] NHTSA, op. cit., footnote 2.

[15] VNTSC, op. cit., footnote 10.

6.2 Road Departure Collision Avoidance Program Area Accomplishments

A project to develop and validate performance specifications for road departure countermeasure systems has been conducted by Carnegie-Mellon University (CMU) over the past 6 years. Project activities included a thorough analysis of the road-departure crash problem, development of countermeasure concepts, testing and evaluation of enabling technologies (including driver/vehicle interface options), and the development and refinement of system performance specifications. The final report for this project is currently drafted and will be published in late 1999.

The problem has two basic components; excessive speed for an upcoming curve – longitudinal road departure, and inadvertent road departure – lateral road departure. Several prototype systems have been developed and tested under real-world driving conditions for lateral road departure. The current version of a vision-based road-departure countermeasure system has undergone on-the-road testing. Updated performance specifications for this system will be published before the end of 1999. Algorithm development has focused on the ability to track lane geometry using vision-based sensors. Other concepts have been explored involving the use of map data base and navigation systems to enhance or augment the lane-tracking capability.

The longitudinal road departure countermeasure system will address crashes caused predominately by excessive speed on curved roadways. This system would detect when the vehicle is traveling too fast for the upcoming roadway conditions. It would utilize vehicle performance data in combination with information about pavement conditions and upcoming roadway geometry to determine the maximum safe speed for the vehicle.

Map database information is considered crucial to providing speed-related warnings for longitudinal road-departure scenarios. Requirements for a more detailed definition of road geometry in map databases have been developed and limited testing has been performed to validate the approach.

6.3 Continuing Road Departure CAS Program Area Activities

Additional data on lane-tracking sensor performance will be gained from the planned inclusion of optical lane-tracking equipment in the sensor suite for the GM and Delphi-Delco prototype rear-end collision countermeasure system headed for field operational tests. The sensor will augment forward looking radar sensors to support the identification of threats in the vehicle forward path.

A project aimed at the developing objective test criteria for road departure CAS systems will begin in FY 00. Two other projects are also planned: 1) a research project to establish a human factors data base for lateral road departure algorithm development and 2) a simulation study of commercial-off-the-shelf (COTS) speed/curve warning systems.

7. REDUCED VISIBILITY

7.1 Data Analysis Results

Approximately 43 percent of all crashes and 58 percent of fatal crashes occur at night or during other degraded visibility conditions, according to NHTSA accident statistics.[16,17] This interprets

[16] Ibid.

into roughly 2.8 million annual police-reported crashes, including 23,000 fatal crashes, where reduced visibility may have been a contributing factor.

A number of interrelated factors contribute to the high crash rate at night, including alcohol and fatigue as well as reduced visibility. Analyses of FARS data suggest that reduced visibility is also a major factor in nighttime collisions involving pedestrians and bicyclists. Furthermore, causal factor analyses indicate that driving task errors account for nearly 80 percent of the crashes (see table 2-1). Reduced visibility is a contributing element to this category. Note: reduced *atmospheric* visibility was the only visibility category identified separately in the study that produced table 2-1; reduced atmospheric visibility was the primary cause in less than one percent of the cases examined.

Driver vision enhancement systems help drivers when visibility is low by providing an augmented view of the forward scene. These systems fall into two broad categories: those that depend upon natural or infrastructure-based illumination; and those that depend on additional illumination from the vehicle. Infrastructure-based systems use reflective materials on pavement marking, road signs, and other fixed roadside objects to provide an enhanced view of the driving environment. On the other hand, vehicle-based systems use a suite of sensors and equipment to improve the view of the driving scene through an in-vehicle display. Research aimed at improving the illumination from headlights has also been conducted.

The focus of the IVI program (and this project area) is vehicle-based countermeasure systems. Prototypes of infrared (IR) driver vision enhancement systems exist and have undergone a wide range of engineering tests and product development activities. On-the-road testing has also been accomplished. Products have recently been introduced to the passenger vehicle market.

7.2 Vision Enhancement Program Area Accomplishments

Early efforts on vision enhancement included a Technology Reinvestment Program (TRP) project to investigate the feasibility of developing commercial products (system size, sensor cooling issues, form factor, cost reduction, etc.) from military vision enhancement systems. This study began in the early 1990s and was managed by VNTSC.

A NHTSA project was initiated in 1994 to investigate the feasibility of vehicle-based vision enhancement systems that would help drivers avoid collisions with vehicles, pedestrians, and other objects on the road, under conditions of reduced visibility. This project conducted a state-of-the-art review of relevant vision enhancement technologies. Subsequent efforts have addressed sensor capabilities, driver visual information needs for crash avoidance, and other driver performance issues. The study team conducted a preliminary assessments and field evaluations of an available night vision system and infrared vision enhancement prototypes from the U.S Army's Driver Vision Enhancement Program.

Other accomplishments include the completion of a pilot study that produced a human factors evaluation plan for infrared night vision enhancement systems.

7.3 Continuing Vision Enhancement Program Area Activities

The light vehicle manufacturers are beginning to offer vision enhancement systems as optional equipment on high-end vehicles. Equipment suppliers are also developing systems that could be installed in SUVs and light trucks on an aftermarket basis. Given current commercialization activities, future IVI program efforts for this area will be limited to the development of objective

[17] NHTSA, op. cit., footnote 2.

test procedures and evaluation criteria to measure the safety benefits of vision enhancement systems.

8. VEHICLE STABILITY

8.1 Data Analysis Results

Instability of a commercial vehicle may manifest itself as jackknifing, rollover, the inability of the driver to maintain directional control, or a combination of these results. Most incidents of heavy vehicle instability are triggered either by braking or rapid steering movements, but other causes may be wind gusts, road roughness, tire failure or simply cornering too fast for road conditions. Because they often result in rollover, heavy vehicle instability incidents are particularly serious in terms of potential for loss of life, injuries, property damage, and traffic tie-ups.[18]

Heavy truck rollover crashes are not frequent occurrences compared to the total number of highway crashes, but when rollover is present as a crash factor there is an increased likelihood of serious or fatal injury to the truck occupants. NHTSA data show that while rollovers are involved in 3 percent of all crashes for combination trucks, it was a factor in 13 percent of all fatal crashes of combination trucks (see table 2-3). When the truck is carrying hazardous materials, the consequences of the crash, in terms of injuries, deaths, and traffic congestion, are even greater.[19]

One option for reducing vehicle instability problems is to equip vehicles with systems that will enhance their stability on the road.[20] The advent of low-cost, high performance sensing/computing systems, coupled with the capability that now exists to analytically model detailed aspects of the vehicle dynamics associated with these type rollovers, make it possible to consider developing autonomous electronic computer-controlled on-board systems that could either warn or prompt drivers to take anticipatory corrective braking and/or steering maneuvers, or possibly initiate corrective control actions.[21] The efforts are concentrated on commercial motor vehicles. These vehicles are prone to stability problems due to their inherently high centers of gravity and (sometimes multiple) articulation points.[22]

8.2 Vehicle Stability Program Area Accomplishments

Efforts to date have focused on two countermeasures. The first, called a Roll Stability Advisor (RSA), is an in-cab device that indicates to a truck driver what the rollover threshold of the truck is, and how close to that threshold the truck is driving at any particular time. It is intended to inform the driver before a truck stability problem occurs so that driving adjustments can be made. The University of Michigan Transportation Research Institute (UMTRI) developed and tested a prototype RSA under a U.S. DOT-sponsored cooperative agreement. This system required complementary sensors and processors on both the tractor and trailer. Prior to the UMTRI effort, FHWA tested prototype infrastructure-based systems at three locations on the Capital Beltway.

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[18] U.S. DOT, Report to House and Senate Appropriations Committees on ITS Joint Program Office Intelligent Vehicle research Agenda 1999-2004, September 1999 (draft).

[19] NHTSA, op. cit., footnote 2.

[20] U.S. DOT, op. cit footnote 18.

[21] NHTSA, Heavy Vehicle Safety Research: A New Agenda for the 21st Century, June 1995.

[22] U.S. DOT, op. cit., footnote 18.

These systems measured the speed, weight, and height as a truck approached the highway off-ramp and flashed a warning sign if the data indicated that there was a risk of rollover. Key limitations of this approach are that it is geographically limited and does not directly sense vehicle stability.

The second countermeasure is an automated system to stabilize multiple-trailer combination trucks. The system will selectively apply brakes at individual wheels independently, without any driver action, to maintain or restore truck stability. This system is intended to suppress a combination truck's tendency to sometimes experience a phenomenon called rearward amplification, where each successive trailer in the combination experiences a more severe reaction to an initial steering input by the driver. Rearward amplification can result in the rearmost trailer rolling over, and possibly taking the rest of the combination with it. In order for this system to be implemented, the truck tractor and all its trailing units must be equipped with electronically controlled braking systems (ECBS).[23]

8.3 Continuing Vehicle Stability Program Area Activities

A limited field demonstration project will assess motor carrier driver and fleet experience with a rollover advisory system. This project combines technologies from three U.S. DOT projects: the two rollover countermeasure projects discussed above and the ALERT® on-board computer and display system developed for public safety vehicles. Trailers will be equipped with roll-stability sensors and drivers will be provided a visual display that will provide advice sufficiently in advance of a highway feature (ramp) to enable the driver to adjust speed appropriately. Infrastructure-based sensors will be deployed initially, with plans to move to a map database system to warn of risky off-ramps. This work is underway at the Oak Ridge National Laboratories.

UMTRI was recently awarded a contract to develop and demonstrate a trailer-based system to detect and suppress rearward amplification that can lead to rollover crashes. A previous system developed under a U.S. DOT-sponsored cooperative agreement required complementary sensors and processors on both the tractor and trailer. However, some industry sources have stated that deployment would be better served if there were a stand alone system for trailers.

Two projects have recently been awarded under the Generation 0 of the IVI that will address vehicle stability from the points of view of the vehicle and its interaction with the roadway.

9. DRIVER CONDITION WARNING

9.1 Data Analysis Results

Driver Condition Warning addresses a major concern of the commercial vehicle safety community and a significant causal factor in large truck crashes. At the National Truck and Bus Safety Summit in March 1995, sponsored by FHWA, participants identified driver fatigue as the top priority commercial vehicle safety issue. As part of a comprehensive over-the-road study on commercial vehicle fatigue and alertness completed in 1996, a summary of relevant literature found that driver drowsiness or fatigue is cited on police accident reports as a causal factor in a relatively small percentage of truck accidents. Researchers suggested, however, that the contribution of fatigue is likely to be underestimated in motor vehicle crashes. Police-cited

[23] Mitretek Systems, Large Truck Crash Characteristics and IVI Commercial Vehicle Projects, July 1999.

factors such as inattention, distraction, daydreaming, or looked but didn't see, that are cited instead of fatigue, may arise from a fatigued condition.

Table 9-1 presents estimated ranges for the percentage of large truck crashes that are fatigue related.[24]

Table 9-1. Estimated Range for Percentages of the Large Truck Crashes that are Fatigue-Related

Crash Type	All Large Trucks (Percent Fatigue Related)	Ave. Annual Crashes (1992-1997)	Range of Fatigue-Related Truck Crashes
All Police Reported Crashes	0.50% to 1.1%	392,000	1,960 to 4,312
All Fatal Crashes	2.8% to 6.1%	4,296	120 to 262
Fatal to Truck Occupant Only Crashes	15% to 33%	580	87 to 191
Fatal to Non-Truck Occupant Crashes	0.87% to 1.9%	3,666	32 to 70

As can be noted from the table, fatigue-related crashes become more significant for higher severity conditions. This is especially true for crashes where only the truck occupant was killed. For all truck crashes in this category, the fatigue-related percentage is 15 to 33 percent. The role of fatigue varies depending on the truck type. In this category, the fatigue-related percentage for single-unit trucks is 5.5 to 12 percent and for combination-unit trucks it is 18 to 40 percent.

Driver condition warning is aimed at developing technologies to monitor driver drowsiness and to warn the truck driver of potentially unsafe alertness problems. This program area is building upon previous work to develop a monitor that can detect driver drowsiness by direct and unobtrusive measures of eyelid closures. Research has shown that the onset of sleep is highly related to the percentage of eyelid closure time. Also, a real time, on-board device is being developed to inform drivers of their level of drowsiness.

9.2 Driver Condition Warning Program Area Accomplishments

Driver Alertness and Fatigue is a major area in U.S. DOToverall human factors (HF) research program, which includes Commercial Driver Training and Performance Management, Physical Qualifications, and Car and Truck Proximity Research. Recently completed projects include:[25]

- Effects of Operating Practices on Commercial Driver Alertness: This study examined the effects of physical activity on driver performance during extended work hours.
- Commercial Driver Fatigue, Alertness, and Countermeasures Survey: This study was an adjunct to the Driver Fatigue and Alertness Study to extend prior research and to collect additional data about CMV drivers and their job characteristics.
- Ocular Dynamics as Predictors of Driver Fatigue: This driving simulator-based study addressed the question of whether directed eye movements and other eye activities could be

[24] FHWA, Crash Problem Size Assessment Update: Large Truck Crashes Related Primarily to Driver Fatigue, January 1999.

[25] FHWA, Office of Motor Carrier and Highway Safety, Driver Alertness and Fatigue R&T Focus Area Summary, July 1999

monitored as "leading indicators" of fatigue. The results support the concept of early ocular indicators of fatigue.

- PERCLOS Technical Conference: A technical conference to discuss recent scientific validation findings regarding PERCLOS and other eye activity measures of alertness, and the status of efforts to develop in-vehicle sensors to continuously measure PERCLOS as an "alertometer."

9.3 Continuing Driver Condition Warning Program Area Activities

U.S. DOT Driver Alertness and Fatigue projects that are currently underway include:[26]

- Modeling of Driver Performance under Various Work/Rest Cycles: This project will gather data that will be used to improve and validate Sleep/Performance Prediction Models.
- Pilot Test of Technological Aids to Improved Fatigue Management: These pilot tests will include the actigraph, in-vehicle alertness monitoring, in vehicle "black box" performance monitoring, and a device which reduces backsteer and thereby reduces driver workload.
- Sleeper Berths and Driver fatigue: This 4-year study will determine the effects of sleeper berth use on driver alertness and driving performance.
- CMV crash Rates by Time of Day: This analytical study is accessing available crash data on CVM mileage exposure to determine the CMV crash data on CMV mileage exposure to determine the CVM crash involvement rate (per mile traveled) by time of day.
- Driver-Vehicle Interface for In-Vehicle Alertness Monitoring: This study will make recommendations regarding the optimal driver-vehicle design.

[26] Ibid.