

Vehicle Technologies to Improve Performance and Safety

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1) Project Statement

A variety of on-board technologies are being added to motor vehicles to improve safety, monitor and regulate emissions, conserve energy, improve performance, and reduce travel time. For example:

- 1) Collision warning systems-Radar systems for detecting objects in the path of the vehicle that might not be visible to the driver.
- 2) Night vision systems which use infrared detectors to aid drivers in fog or in dark.
- 3) Warning and advice systems
 - a) Lane sensor which determines the position and heading of the vehicle in its lane.
 - b) Lane warning alerts the driver of an attempt to change lanes without signalling while in proximity to other vehicles.
- 4) Active vehicle control
 - a) Adaptive Cruise control which controls the spacing to the vehicle directly in front.
 - b) Lane Control which automatically keeps the vehicle in the centre of the lane.
 - c) Skid control which would automatically regain a stable condition when a skid occurs.
 - d) Co-operative headway control which would place vehicles in platoons and co-ordinate their spacing and speed.
- 5) Automatic collision notification system to detect any crash and report type, severity of crash and vehicle's final resting position.
- 6) On-board diagnostic systems (OBD) that monitor the function of emissions control systems and enable roadside officials to remotely and automatically detect vehicle out of compliance status.
- 7) Automatic vehicle identification or electronic toll collection which will automatically bill owners for tolls.
- 8) Cellular communications and computers to choose routing (e.g. screen displays that show routes).

This study will examine those on-board vehicle technologies ,which help to improve safety and reduce accident fatalities , injuries and property damage through emerging technologies like object detection, collision warning , and lane warning and advice .

2) Methodology

This study will examine on-board vehicle technologies in detail, documenting the current state of the technology (design specifications, functions carried out , costs, performance,etc.), expected improvements over the next ten to twenty years, current and anticipated applications, delivery systems (roles of public and private sectors, regulation, if any, etc.), market penetration, and other key issues raised. Specific tasks will include:

- 1) Literature review: conduct a detailed investigation of the literature, including journal articles, research reports, working papers, and trade magazine articles on the technologies and their applications.
- 2) Technology assessment: develop a typology of technologies and their applications, considering the objectives they address, their technical functions, implementation status. Evaluate the pros and cons of the technologies.
- 3) Incentives and disincentives for implementation: Identification of key issues involved in implementation of these technologies.

3.0) Introduction

Intelligent vehicle systems offer the potential to significantly improve safety and operational efficiency. “An “intelligent vehicle” may be defined as a vehicle that senses the environment and produces some automatic action or driver advisory”(Smith,2000). . There has been tremendous progress in vehicle safety in the past few decades. Improvements in seat belts, air bags, visibility and lighting have dramatically reduced road deaths in the USA. The fatality rate per 100 million vehicles miles travelled fell from 5.5 to 1.8 from mid 1960s to 1992.Recent developments include collision warning systems, adaptive cruise control, and infrared vision enhancement , all of which were announced as features in light vehicles in the U.S. market in the last year of the millennium. While these new technologies promise improvements in safety , the steady and high level of crashes in light vehicles each year indicates that the problem of safety remains critical.

Every year the NHTSA’s (National Highway Traffic Safety Administration’s) National Automotive Sampling System (NASS) conducts a sampling of police accident reports(PARS) for national estimates of the crash problem. The NASS selects about 48,000 PARs from across the nation to feed the General Estimates System(GES) of the NASS for crash count estimates. “In 1996 , the GES estimated the total number of passenger cars and light trucks involved in crashes to be 11.6 million while the total number of crashes was about 6.8 million ,giving a light vehicle share of over 94% of all vehicles involved ”(Smith,2000).

Accident data from the NHTSA shows that driving task errors caused 75.4% of all crashes in 1996. “According to data from the GES and the Fatal Accident Reports (FARS) databases , rear end collisions are the second largest category of collisions .They represent 23% of all collisions”(Wilson, 1997). Also 88% of all rear end collisions are caused by driver inattention and following too closely. NHTSA countermeasure effective modelling has found that “Headway detection systems can theoretically prevent approximately 37% to 74% of all police reported rear end crashes”(Knipling , 1993).

3.1) Primary Causes of Vehicular Crashes

A study conducted by NHTSA in conjunction with the Research and Special Programs Administration (RSPA)Volpe National Transportation Systems Centre(Volpe Centre) between 1991 and 1995 found the following distribution of primary causes of vehicular crashes(W. Najm et al, June 1995):

- 1) Driving Task Errors (75.4% of all crashes)
 - a) Driving recognition errors (43.6 % of all crashes); For instance:
 - i) Driver did not see the vehicle ahead due to inattention.
 - ii) Obstructed vision due to, intervening vehicles, road geometry and road appurtenances

- b) Driver decision error (23.3 % of all crashes); For example:
 - i) Driver misjudged gap/ speed to an approaching vehicle
 - ii) Tailgating /Unsafe passing
 - iii) Excessive speeding
 - c) Driver erratic action (8.5% of all crashes); For example
 - i) Driver intentionally ran the red light
 - ii) Failure to control vehicle
 - iii) Deliberate unsafe driving act
- 2) Driver Physiological State (14 % of all crashes)
 - a) *Drunk driver* (6 % of all crashes)
 - b) *Sleepy driver* (3.5% of all crashes)
 - c) *Ill driver* (4.5 % of all crashes)
 - 3) Vehicle defects (2.5 % of all crashes)
 - 4) Road surface (8.0%) due to surface being wet or due to snow, ice on the surface.
 - 5) Reduced visibility(0.1%).For instance due to glare.

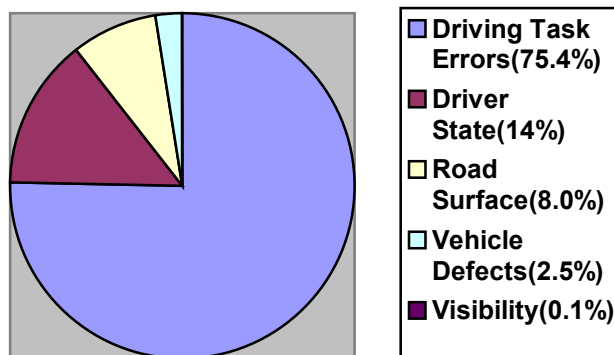


Fig 1: Primary Causal factors of Vehicular Crashes

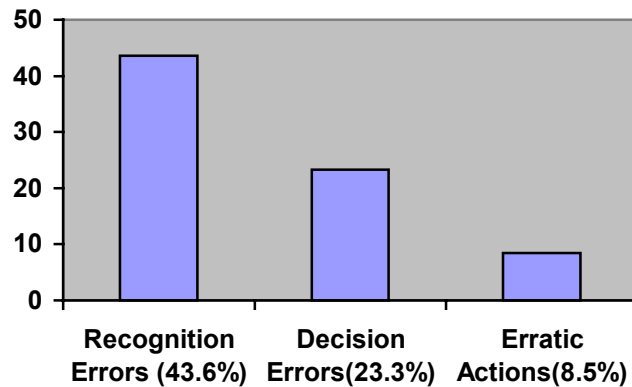


Fig 2 : Further Breakdown of driving task errors

3.2) Target Crashes

W. Najm et al. defined seven major crash types which were targeted for ITS technology applications:

- 1) Rear End (RE)- The front of the subject vehicle (SV) strikes the rear of a leading principal other vehicle (POV) , both travelling in the same lane.
- 2) Backing (BK) – The SV strikes, or is struck by , an obstacle while moving backwards. The obstacle can be another vehicle , or an object, animal or pedestrian.
- 3) Lane Change/Merge (LCM)- The SV driver attempts to change lanes and strikes , or is struck by, a vehicle in the adjacent lane.
- 4) Single Vehicle Roadway Departure (SVRD)- The SV leaves the roadway as a first harmful event. This crash type does not include roadway departures resulting from a collision with another vehicle.
- 5) Opposite direction (OD) : The SV collides with a POV traveling in the opposite direction. This impact results in a frontal impact or sideswipe.
- 6) Intersection crossing path (ICP): Three types of ICP crashes were identified :

- i) Signalized Intersection , Straight Crossing Path(SI/SCP) : The SV without a right of way strikes or is struck by , a POV with a right-of -way , both traveling through a signalized intersection in straight paths perpendicular to each other.
 - ii) Unsignalized intersection , Straight Crossing Path(UI/SCP): The SV without a right- of-way strikes or is struck by , a POV with right-of way while both are trying to pass in perpendicular directions straight through a unsignalized intersection (generally controlled by stop signs.
 - iii) Left Turn Across Path(LTAP) : The SV attempts to turn left at an intersection and strikes , or is struck by ,a POV traveling in the opposing traffic lanes.
- 7) Reduced visibility(RV) : This crash circumstance encompasses all crash types occurring in reduced visibility conditions that include non-daylight (dark, dark but lighted, dawn or dusk) or bad weather (rain, sleet, snow, fog, or smog).

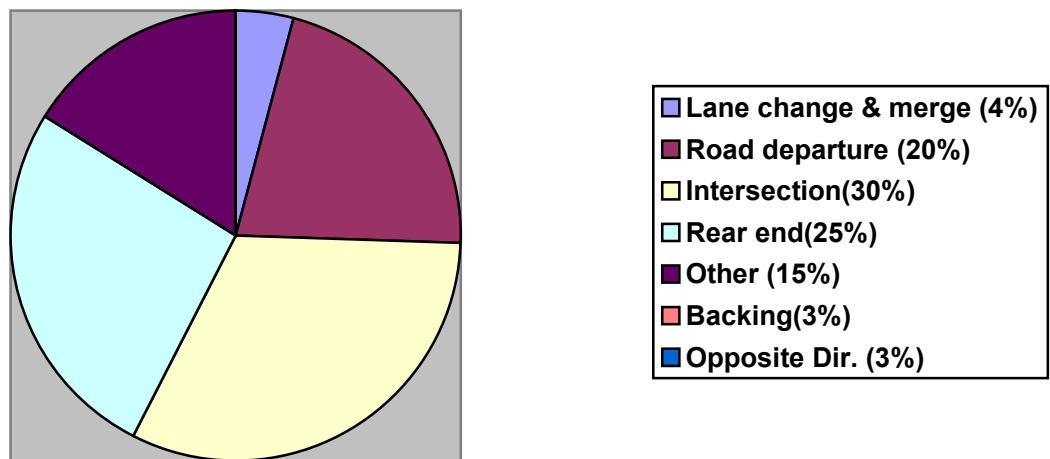


Fig 3 : Problem Areas Identified by the Intelligent Vehicle Initiative

Table 1: Target Crash Causes (causal factors for each crash type)

S.NO	Causal Factors	RE	BK	LCM	SVRD	OD	SI/SCP	UI/SCP	LTAP
1	Inattention	56.7	0.0	3.8	15.5	17.8	36.4	22.6	1.4
2	Looked-did not see	0.0	60.8	61.2	0.0	0.0	0.0	36.7	23.2
3	Obstructed vision	0.0	0.0	0.0	0.0	0.0	4.3	14.3	24.4
4	Tailgating/Unsafe passing	26.5	0.0	0.0	0.0	1.1	0.0	0.0	0.0
5	Misjudged gap/Velocity	0.4	0.0	29.9	0.0	5.9	0.0	12.2	30.0
6	Excessive speed	0.0	26.6	2.2	17.8	0.0	0.0	0.0	0.0
7	Tried to Beat Signal/POV	0.0	0.0	0.0	0.0	0.0	16.2	0.0	11.2
8	Failure to control vehicle	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
9	Evasive maneuver	0.0	0.0	2.6	13.7	18.6	0.0	0.0	0.0
10	Violation of signal/sign	0.0	0.0	0.0	0.0	0.0	23.2	3.4	7.4
11	Deliberate unsafe driving Act	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
12	Miscellaneous	1.1	0.1	0.0	0.0	1.0	5.9	0.0	1.7
13	Drunk	2.1	3.0	0.0	10.1	31.7	12.6	2.7	0.4
14	Asleep	0.0	1.9	0.0	11.8	0.0	0.0	0.0	0.0
15	ILL	9.6	0.0	0.0	3.5	1.1	0.0	0.0	0.0
16	Vehicle defects	1.2	5.7	0.3	5.3	4.5	1.6	0.0	0.0
17	Bad Roadway Surf. Conditions	2.3	0.0	0.0	20.2	18.3	0.0	7.0	0.0
18	Reduced visibility/Glare	0.1	0.0	0.0	0.0	0.0	0.0	1.1	0.1
19	Total %	100.0	100.0	100.0	100.1*	100.0	100.2*	100.0	99.8*
		* Rounding error							

4.0) Collision Warning Systems

The purpose of collision warning systems is to achieve reduction in accident fatalities , injuries and property damage through emerging technologies like object detection, collision warning and ultimately collision avoidance by accident prediction and automatic vehicle control.(braking , throttle adjustment , steering).

4.1) Technologies

There are a number of possible technologies for collision sensing:

1) Visible or infrared video cameras- tend to have good spatial resolution and are good for angle determination, object detection .However, the calculation of range and relative velocity is complex and the accuracy poor compared to active radar ranging systems. Also, performance is not good at night or in poor conditions.

2) Ultrasonic and infrared technologies have some possibilities for short range obstacle detection, for adjacent lane blind spot detection and rear looking warning systems but suffer from high pressure washing, weather and dirt susceptibility.

3) Laser and video systems can be used for long range detection but are not useful in adverse weather and the processing is very complex to eliminate false alarms. “A drawback of using LIDAR(Laser Radar) is that it becomes ineffective when they are facing the sun”(From personal communication with Xiqin Wang at PATH)

4) Microwave radar offers good range performance even in poor conditions. Microwave and millimetre-wave radar are characterised by their superior performance under adverse environmental conditions including rain, fog and road grime in comparison with laser light. Also, millimetre radar waves have a shorter wavelength than microwave ,so the antenna for narrowing and transmitting the radar beam can be made smaller in size , which facilitates easier vehicle installation.

Detection Performance of Radar

1) Inconsistencies between Radar Information and Required information – “The presence of a target is determined by detecting the reflected radar wave. However, even if a strong reflected wave is detected, the nature of the target is not certain. What is important is the magnitude of the impact at the time of the collision and a radar system does not always provide this information”(Fukuhara,1994)

2) Non detection and False Alarm-

- a) Errors or non detection can occur when the strength of the wave reflected back is so weak that it cannot be detected by the radar system.
- b) False detection can also occur due to noise or radar clutter i.e. unwanted reflection from roadside objects, cars in adjacent lanes or other objects besides the intended target.

Table 2: Technology and Performance Features (Woll,1998)

S.No	Technologies → Performance Feature	<i>Ultrasonic</i>	<i>Infrared</i>	<i>Laser</i>	<i>Video</i>	<i>Radar</i>
	CAPABILITIES					
1	Long Range Capability	●	⊖	○	○	○
2	Target Discrimination	●	●	⊖	○	○
3	Darkness Penetration	○	○	○	●	○
4	Adverse Weather Penetration	●	●	●	●	○
	COSTS					
5	Low Cost Hardware Possibility	○	○	⊖	●	○
6	Low Cost Signal Processing	○	○	○	●	○
	RELIABILITY					
7	Minimising False Alarms	●	●	⊖	⊖	○
8	Temperature Stability	●	⊖	○	○	○
9	Sensor Surface Dirt And Moisture Performance Effects	⊖	●	●	●	○

● Poor

⊖ Fair

○ Good

4.2) Forward Looking Collision Warning System Recommendations

Wilson has given a comprehensive review of performance guidelines for radar or forward-looking sensor. These guidelines are given for passenger car and mainly highway applications.

Some of the significant performance guidelines given by Wilson are as follows :

- 1) A forward- looking collision warning system must detect and warn the driver of all kinematics and dynamics of the host and lead vehicles especially, stopped vehicles in the forward path.
- 2) Acquisition Range – The forward looking sensor acquisition range should be $\geq 100\text{m}$. The minimum range at which the forward- looking sensor acquires targets should be 2 meters .The acquisition range is defined as the point at which a vehicle in the forward path has been detected reliably to permit tracking.
- 2) Horizontal Field -of- regard - The horizontal field of regard refers to the angle of view in the horizontal direction referenced to the longitudinal axis of the host vehicle. The collision warning sensor should have a minimum of ± 8 degrees horizontal field of regard. This is necessary to prevent crashes due to roadway curvature and horizontal field of view limitations. To minimize nuisance alarms from vehicles in adjacent traffic lanes , parked vehicles , roadway signs etc . , the horizontal resolution needs to be fine enough to discriminate vehicles in adjacent lanes , parked vehicles , roadway signs etc .
- 3) Vertical field of regard – The vertical field of regard refers to the angle of view in the vertical direction referenced to the longitudinal axis of the host vehicle. The driver vertical sensor should have a nominal $\pm 2.5^\circ$ to $\pm 3.5^\circ$ field of regard. The vertical field of regard should be large enough to overcome problems with the host and lead vehicles being on different roadway grades but not so large that overhead roadway objects present nuisance alarms.
- 4) Collision Warning methodology – The forward collision warning system must provide a suitable warning to the driver . At a minimum , an inattentive driver warning must be included. A following –too-closely warning is also recommended.
- 5) Driver warning time – The recommended system delay time is 300 milliseconds or less . System delay time is defined as the time required for the system to determine an object present in the forward path (acquisition) and warn the driver by changing the status of the warning indicator.
- 6) Atmospheric conditions – The driver warning system should function properly during varying environments such as rain, road spray , snow , fog .Also the system should be able

to detect when its sensing capability has degraded and inform the driver that it is not functioning properly.

- 7) Standard driver displays are desirable to prevent confusion while using systems from different manufacturers .

Table 3 : FCWS Recommendations

DESCRIPTION	RECOMMENDATION
Driver Display Type	Collision warning Display , Following too closely display .
Moving and stationary threats	Both
Acquisition Range	≥ 100 meters
Horizontal field of regard	± 8 degrees
Roadway Profile , Vertical field of regard	5.3 % grade , 6°
Atmospheric conditions	Clear , rain , snow
System Delay Time	≤ 300 milliseconds

4.3) Examples of Collision Warning Systems

1) FOREWARN system being developed by Delco

“Low cost radar sensors are integrated with components and systems already on production vehicles like vehicle sensors , ABS/TCS , braking systems , microprocessors , head up displays , and audio systems”(Schumacher et al,1996).The system warns the driver of an impending collision and does not take automatic control of the vehicle to avoid a collision.

An integrated collision warning system consists of four basic steps:-

- 1)Road Object Sensing
- 2)Collection of vehicle data
- 3)Data processing and threat assessment
- 4)Driver warning execution

The process of collision warning is as follows:

1) Radar sensors measure and report the position and relative velocity of objects in the rear and front of the vehicle. Sensors on the vehicle determine the vehicle's own speed, steering angle, brake status and gear position. Data from all sensors is combined to determine which of the vehicles are in the vehicle path. Both vehicles using the FOREWARN system incorporate radar sensors to detect objects in the front and rear of the vehicle. Since rear speeds are generally slow, the rear radar is designed to operate at ranges up to only 6m and to sense over a fixed azimuthal angle of approximately 45 degrees from the sensor location at the midpoint of the rear bumper. In the forward direction very long range and high azimuthal resolution sensors are required due to very high speeds, to distinguish between objects of varying sizes in adjacent lanes and to track these objects through curves and still identify the correct object in the path of the vehicle.

2) A collision avoidance microprocessor (CAP) evaluates all the road sensor and vehicle data and uses a threat assessment algorithm to identify and prioritise collision threats from road objects.

Range and time to collision is calculated as a function of relative speed and heading compared to typical driver behaviour involving average following headway and projected braking distances and times. Appropriate warning functions are enabled if the driver fails to brake or steer around objects.

“In the Lexus the threat assessment is based only on speed, steering angle gear and brake switch. The warning threshold are fixed in software and cannot be adjusted in realtime by the driver.” (Schumacher et al, 1996)

“In the Cadillac the CAP also monitors windshield wiper status, tire pressure, and the audio systems control” (Schumacher et al, 1996). The threat assessment algorithm uses this information to adjust the warning threshold range/time parameters. e.g. the warning distance is increased when the wipers are on. Similarly, if the tire pressure sensors report non-optimal tire pressure, the warning distance is adjusted to account for changes in stopping distance. The warning distance is also increased if the audio controls are being adjusted by the driver.

The CAP enables three driver warning functions:

- 1) Audio warnings given through the vehicle's audio system.
- 2) Visual warnings through head up displays on the front windshield for forward warning and on the rear windshield for rear warning.
- 3) Brake Pulse which uses the vehicle's traction control system.

Table 4 : FOREWARN Front/Rear Warning strategy (Schumacher et al ,1996)

Type	Forward Warning		Rear Warning	
	Caution	Emergency	>3m	<3m
Audio	Chime	Voice Brake! Brake! Brake!	Chime Slow Repetition	Chime Fast Repetition
Visual	Amber Triangle HUD*	Flashing red octagon on HUD	Slow Flashing Amber LED Rear Display	Fast Flashing red LED Rear display
Tactile	N/A	Brake pulse	N/A	N/A

*HUD –Head Up Displays were introduced on vehicles in 1988, head-up displays use a vehicle's windshield as an optical element to project virtual images in the direct field of vision of the driver.

2) The Eaton VORAD Collision Warning System

Radar System Operation - The Antenna Assembly which is located at the front of the vehicle and transmits and receives radar signals.

“The antenna coupler performs the function of sharing the antenna between the transmitter and receiver. The transmitter emits continuous wave radar energy at a frequency of 24.75 GHz with this frequency being slightly modified by the Modulator in order to extract target distance by the signal processor. This type of radar transmission is called FMCW which stands for Frequency Modulated Continuous Wave. The energy strikes vehicles and obstacles within the narrow beam and a portion of the transmitted radar energy is reflected back from each target to the antenna. This reflected energy is directed by the coupler to the receiver where the returned radar signal is compared with the transmitted signal. The frequency difference between the received signal and the transmitted signal is called Doppler frequency shift and is directly proportional to the relative speed between the target and the vehicle with the radar. Thus, this system is also called a Doppler radar system”(Woll,1998).

From the receiver, the signal is fed to the demodulator where the desired signal format is extracted. The signal processor then breaks down this complex signal consisting of

different frequency elements from all targets. The multi-target information is then fed to a powerful microprocessor which uses tracking algorithms to track targets and warning algorithms to predict hazardous situations and to issue warnings to the driver.

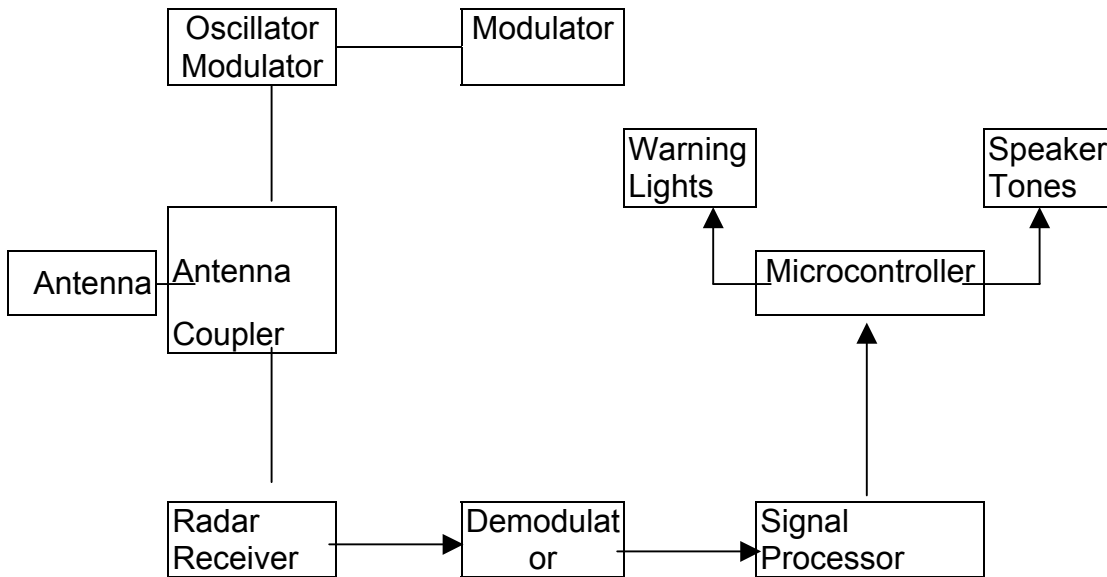


Fig 4 : Eaton Vorad Radar System Block Diagram

Components of the system

The Eaton VORAD Driver Reference manual describes the following components of the system.

- 1) Antenna assembly – The Antenna assembly is usually mounted in the center of the bumper. This insures that the radar beam is aimed directly in front of the vehicle. According to the Eaton VORAD website , “ The Antenna assembly can simultaneously monitor upto 20 objects within a 350 feet range , whether moving or stationary.
- 2) Central Processing Unit – The Central Processing Unit compiles information from the antenna assembly , engine control Unit , speedometer , optional side sensor , brake and turn signal circuits to produce audible and visible warnings.
The CPU can be located in a variety of places .Typical locations are on the vehicle firewall, underneath the dashboard , or behind the driver’s seat.
- 3) Driver Display Unit – The Driver Display Unit contains controls and indicators

related to system operation. The driver display unit system power up, speaker volume, range for vehicle warnings and headway thresholds for SmartCruise. Driver display unit indicator lights come on to indicate system power, system failure, SmartCruise enabled, and multiple stages of warning levels. The driver display unit also contains a small speaker that provides audible alert tones. The alert tones are sounded when the vehicle is closing on an object, and if an object is detected by the side sensor and the turn signal is activated for a lane change.

The driver display unit is mounted on top of or recessed in the dashboard in an area that is easily visible and accessible to the driver.

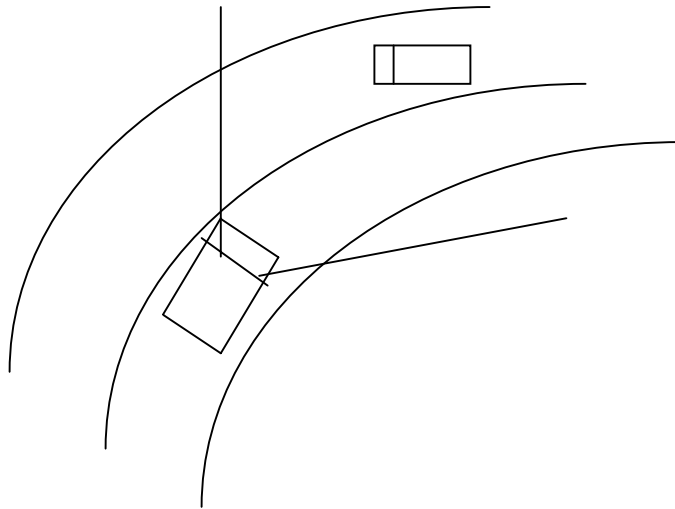
- 4) Side Sensor (Optional) – The side sensor is a radar device that senses objects from two to ten feet from the side of the vehicle in a blind spot area on either side of the vehicle. This information is provided to the Central Processing Unit for processing, lighting of appropriate indicator lamps, and sounding of alarms. Side sensors are generally mounted on the right side of the vehicle, at or near a blind spot area. The vehicle can be configured to have a side sensor on each side, left or right, or have two sensors located on the same side.
- 5) Side Sensor Display (Optional)- The Side Sensor Display contains red and yellow indicator lights. The yellow indicator light is on when there is no vehicle within the side sensor detection zone. When the side sensor detects an object, the red indicator light illuminates and the yellow indicator light goes off. The red light also illuminates when the sensor has failed.

Sometimes, in heavy rain conditions the side sensor is unable to detect objects.”(Eaton VORAD Driver Reference). This is due to particles of dirt which may block the sensor parts.

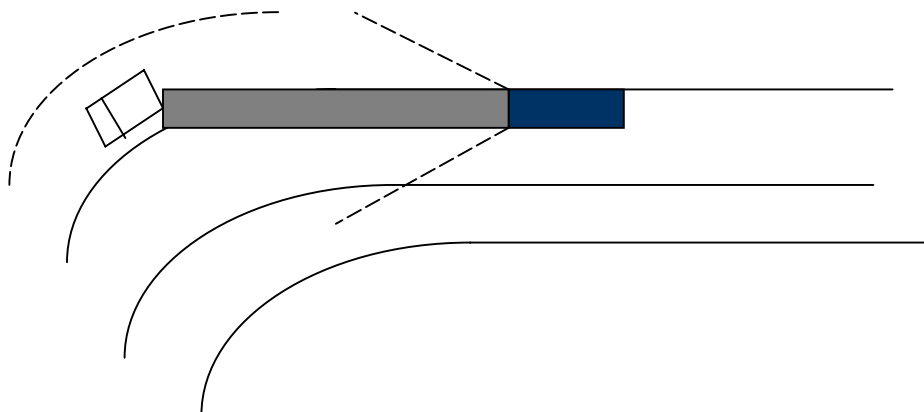
Limitations of the system

Certain kinds of road situations can effect the systems ability to detect objects. Curves, dips and hills on the road can affect detection. The radar system may sound a warning when it detects a vehicle in front of the radar even when the driver may be planning to turn away or stop prior to reaching the object. Examples of some special road situations are:

- 1) Detecting objects while vehicle is in a turn – Audible alarms will not sound with oncoming traffic during very sharp right or left turns of less than 750 feet radius.

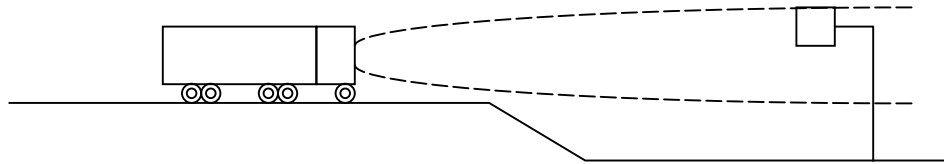


- 2) Detecting objects alongside an approaching curve – When approaching a curve warnings may sound and indicators may illuminate due to objects, such as a parked car on the side of the curved portion of the road in direct line of the radar beam.

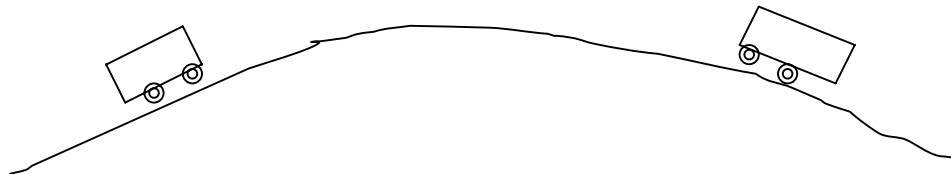


Parked Car Detected

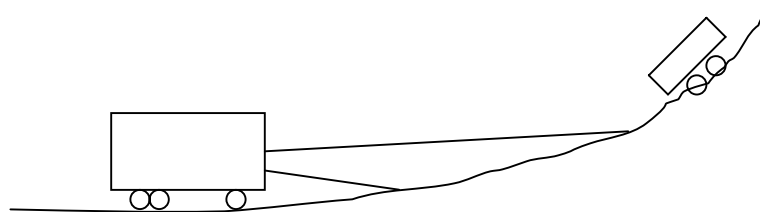
- 3) Detecting elevated objects -Some unusual road elevation angles may cause the system to detect overhead signs or passes.



- 4) Detecting vehicles on the other side of the hill - The system cannot detect vehicles on the other side of the hill. No alarm sounds until objects are within the field of the antenna.



- 5) Approach to a steep upward hill slope- The system cannot detect objects above its beam.



4.4) Cost and Current Applications of Collision Warning Systems

Collision Warning Systems are already on the market in the US and Japan. The major application for the technology so far has been detection of objects in a vehicle's blind spot. In the US school buses have been fitted with AC Delco's 'Forewarn' system to alert the driver of the presence of children in a blind spot. This system is also being made available for other heavy vehicles. These systems would also offer protection from 'side-swipe' type incidents. Current prices range from \$50 (for the radar) for the Siemens 'Sideminder' system, to the order of \$2,500 for an Eaton-VORAD radar based system. Complexity of the systems also differs greatly. Headway warning systems are currently available on heavy vehicles in Japan, with Isuzu, Mitsubishi, Hino, and Nissan with a price tag around \$5,000."

(www.dotrs.gov.au) October 9, 2000

Several several companies already are marketing collision warning systems. Engineers at Motorola, and Delco Electronics have developed systems that use radar to sense obstacles and provide an audible alert to the driver. One variation on the collision warning theme, a device called Parkpilot, uses ultrasonic sensors to help drivers avoid collisions during parking maneuvers. Developed by Robert Bosch Corp., Parkpilot will be available on selected European vehicles during the 1999 model year. More collision warning systems are expected to reach the market between 2000 and 2005.

(<http://www.manufacturing.net/magazine/dn/supplements/automotive/cars.htm>) *January 19, 1998*

The Forewarn system is being marketed by Delphi in the new Jaguars . Adaptive cruise control costs \$2,300 on a new Jaguar sold in England, pushing the price tag for the XKR coupe to \$101,585. A convertible with smart cruise control costs \$113,146. Mercedes buyers will be able to buy the smart cruise control plus a bumper-embedded radar sensor called Parktronic on premium S-Class models that will run from \$73,475 to \$81,625. Some Collision Avoidance Systems available in Japan are given in the following table:

Table 5 : Collision Avoidance Systems in Japan

S.No	Company	Model	Product name	Launch	Cost
1	Mitsubishi	Diamante	Pre-view Distance Control	Jul-95	\$3,660
2	Mitsubishi	Debonair	Distance Warning	Oct-92	\$5,990
3	Mitsubishi	truck & bus	Distance Warning	Jul-93	\$5,000
4	Hino	truck & bus	Safety Eye	May-92	\$4,500
5	Nissan Diesel	truck & bus	Traffic Eye	Dec-89	\$4,500
6	Isuzu	truck & bus	N/A	Dec-90	\$2,300
7	Toyota,	Estima, Hi-Ace,	Clearance Sonar	Aug-89	\$760
		Cresta , Chaser			
8	Nissan	Largo	Corner and back sonar	May-93	\$900
9	Honda	Odyssey	Corner and back sonar	Oct-94	\$760

(Source: www.itsa.org, September 98)

4.5) Safe Distance Calculation and Warning Activation

Brake reaction time is the interval between the instant that the driver recognises the existence of an object or hazard on the roadway ahead and the instant that the driver actually applies the brakes.

The following equation represents the minimum safe distance necessary between radar installed vehicles and the vehicle ahead if a collision is to be avoided. Vehicle 1 is the radar installed vehicle and vehicle 2 is the vehicle ahead.

$$D_s = V_1.T + (V_1^2/2\alpha_1) - (V_2^2/2\alpha_2)$$

D_s = minimum safe distance

V_1 = speed of vehicle 1

V_2 = speed of vehicle 2

T = driver reaction time

α_1 = decelerating capacity of vehicle 1

α_2 = decelerating capacity of vehicle 2

The decelerating capacity parameters in the equation above will depend not only on the vehicle models and their braking power, but also on the weight they are carrying and the road conditions, all of which are subject to variations. Consequently, the approximation $\alpha_1 = \alpha_2$ is used. The necessary reaction time T will also vary greatly from driver to driver depending upon the physical condition of the driver.

In some warning systems the driver can choose from different levels of reaction time depending upon how he or she is feeling and the surrounding traffic conditions.

When the processing unit detects that the actual distance has fallen below the minimum safe distance as calculated from the equation above, it activates an audio warning signal.

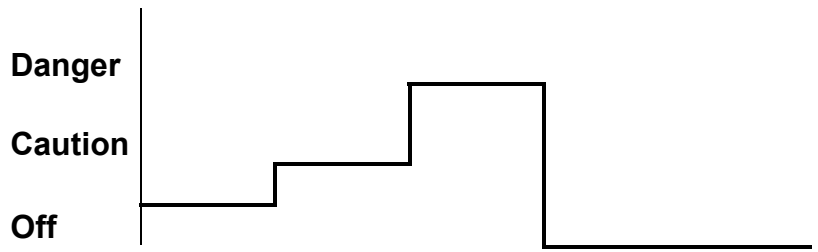
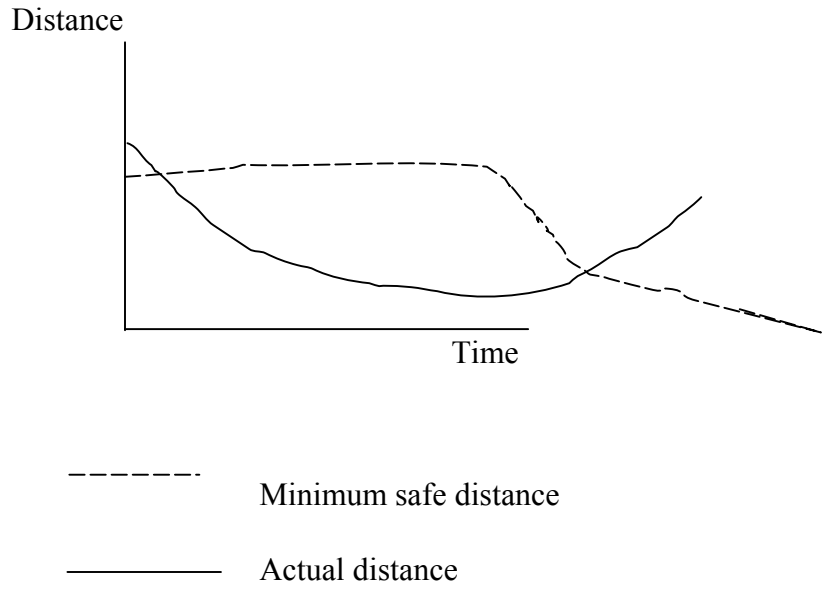


Fig 5 : Warning Sequence as Vehicles Approach each other

5.0) Adaptive Cruise Control

These systems called Intelligent Cruise Control extend the conventional cruise control by also enabling the driver to automatically follow a slow preceding vehicle.

The standard cruise control requires the driver to set the speed and engage the cruise gear. When overtaking a slower vehicle the driver often has to disengage the cruise control by applying the brakes or shutting off the cruise control. The driver has to re-engage cruise control when traffic clears. In dense traffic, repetitive engage-disengage activity makes cruise control unsuitable.

Adaptive cruise control places the radar system in the cruise control loop, allowing the radar system to control the speed of the vehicle to maintain a predetermined following distance from the vehicle ahead. The level of maximum braking varies among ACC systems, with an industry maximum of 3m/s^2 , or $0.3g$.

5.1) Fully MMIC 76GHz Radar for ACC

Recently a 76GHz FSK(Frequency Shift Keying) monopulse radar for ACC using MMIC (Monolithic Microwave Integrated Circuits) has been developed. The radar transmits two frequencies and measures the distance and relative speed of targets. The monopulse feature detects the azimuth angle of targets without a scanning mechanism.

The FSK monopulse 76GHz has three antennas, one transmit antenna and two receive antennas. These three antennas are mounted on one side of the MMIC module. The MMIC module employs four MMIC chips consisting of a 76GHz voltage controlled oscillator(VCO), a power amplifier, and two receivers.

By using FSK modulation and the monopulse feature, the radar can detect multiple targets simultaneously, continuously, and independently. Radar performance was evaluated and the radar could detect a passenger car at a distance of more than 140m.

5.2) Example of ACC

In July 1999, Nissan Motor Co., Ltd. announced the domestic release of the 41LV-Z model. The 41LV-Z was Japan's first production vehicle to feature an adaptive cruise control (ACC) system achieved with a braking control function with a millimeter-wave radar sensor.

The system measures the distance to a preceding vehicle and the relative velocity of the vehicles, based on information obtained by a millimeter-wave radar installed at the front of the host vehicle. Using that data, it automatically controls the host vehicle's speed by activating the throttle actuator or the brake actuators so as to maintain the set distance between the two vehicles. The millimeter-wave radar unit transmits a radio wave pulse and

computes the distance to a forward object from the time it takes for the reflected wave to be received. The relative velocity is calculated from the difference in frequency between the transmitted and reflected waves.

In the event a preceding vehicle decelerates or another vehicle cuts in front of the host vehicle so that the headway distance is shorter than the value set by the driver, the **ACC** system automatically closes the throttle valve to decelerate the host vehicle until it returns to the preset distance. When the situation necessitates even greater deceleration, the system also automatically applies the brakes. Once the headway distance becomes longer than the set distance, as a result of the preceding vehicle or the host vehicle changing lanes, for example, the **ACC** system automatically opens the throttle valve and gradually accelerates the host vehicle until the set distance is reached. It then acts again to maintain the desired headway distance to preceding traffic.

The driver can override the operation of the **ACC** system by braking or accelerating the vehicle manually. In this case, the control system is released and precedence is given to the driver's action.

5.3) Current Applications

ACC has been used in Japan since the mid-1990s, and was recently introduced by a few car makers in Europe. In July 1999, Nissan Motor Co., Ltd announced the domestic release of the 41LV-Z model, which has been newly added to the Cima lineup. The 41LV-Z was Japan's first production vehicle to feature an adaptive cruise control (**ACC**) system achieved with a braking control function with a millimeter-wave radar sensor. (www.itsa.org).

In Japan Subaru, in September 1999, unveiled a version of its Legacy wagon with Active Driving Assist. Besides adjusting cruising speed, it sounds an alarm if the car drifts out of its lane or enters a curve too fast. On the curve, it downshifts even before the driver starts braking. The ADA package adds \$5,099 to the Legacy's \$30,400 base price” (Tech review www.usatoday.com , July 21, 2000).

Nissan is scheduled to introduce ACC into the American market by next spring. Other car companies are expected to follow suit over the next two to three years.

Mercedes began selling adaptive cruise control on cars in Europe in 1999 . “Jaguar might introduce smart cruise control in the USA within two years. BMW is expected to introduce the feature in Europe in 2000.”(Tech review ,www.usatoday.com , Nov 23, 1999).

Toyota, Ford, Mercedes and Jaguar now offer "adaptive cruise control" on some vehicles. The technology tracks the car ahead, slowing down and speeding up automatically to maintain a safe distance in variable highway traffic.(Tech review ,www.usatoday.com , July 20 ,2000)

Adaptive Cruise Control, a Doppler radar-based system, is now available on select models of Volvo VN highway tractors.

6.0) Night Vision Systems



Fig 7 : Night Vision helps the driver detect objects long before the car's headlights would illuminate them.

The technology operates via an infrared sensor behind the center of the car's grille and can detect people, animals and moving vehicles on the road or at the side of the road well before a car's headlights, even high beams, can illuminate them. This is the same technology used by American troops during the Gulf War, to help get home safely.

The image of the person, animal or vehicle is then projected real-time onto a black-and-white, head-up display on the windshield in front of the driver. Objects emitting the most heat are whitest in the display, cooler ones are black.

6.1) Current applications and costs

1) Cadillac markets the thermal-imaging system, developed with Raytheon Systems Co., under the name "Night Vision." "It's a \$1,995 option on the Cadillac DeVille .

It operates via three main components. One is the camera mounted behind the grille of the car, which "sees" down the road. The second is the head-up display in the dashboard that projects what the camera sees onto the windshield in front of the driver.

The third are controls for the driver to position the head-up display on the windshield and adjust its intensity. A turn-off switch is included. The system turns on automatically when the

car is started as long as the DeVille's twilight sentinel system detects low-light conditions. A driver can't activate night vision during daylight.

2) A unique Active Night Vision system with infrared lasers that illuminates people, animals, road signs and road debris up to 500 feet ahead of the vehicle has been developed by DaimlerChrysler researchers in Ulm, Germany. (www.itsa.org , April 5, 2000)

Unlike currently available thermal imaging night vision systems, the DaimlerChrysler technology can see any object regardless of its temperature. For example, the DaimlerChrysler system could detect a tire on the road, lane markers or a fallen tree. It also illuminates the road ahead up to 500 feet without blinding the oncoming drivers; conventional high-beam headlights provide visibility of only 130 feet.

The system functions as follows: two laser headlights on the vehicle's front end illuminate the road by means of infrared light that is invisible to the human eye. A video camera records the reflected image, which then appears in black and white on a heads-up screen located directly in the driver's field of vision.

DaimlerChrysler's infrared Active Night Vision system could significantly reduce dangers associated with night driving, such as poor visibility and temporary "blindness" caused by oncoming headlights. Daimler Chrysler's Active Night Vision is an active system with its own light source and, unlike passive systems, not solely dependent on information resulting from the heat emitted by objects in the field of vision.

Researchers chose an infrared light source because such light is virtually invisible to the human eye, meaning it cannot blind drivers of oncoming vehicles. Its narrow spectral width also offers substantial benefits: preset optical filters are capable of reducing the blinding effects of oncoming headlights by a factor of 50 to 100, while still allowing the system's reflected laser light to pass through.

7.0) Key Issues involved in Implementation of Technologies

In recent years a lot of progress has been made in the research and development of object detection , collision warning and collision avoidance systems. Electronics technology has proven to be up to the task of developing these systems , but the implementation of these systems will depend on factors other than technology:

- 1) Cost - Cost Effectiveness is critical with automotive electronics systems , especially in the case of object detection , collision warning and avoidance systems. According to Ulke, “These technologies[millimeter wave radar, infrared laser, and image processing have been developed in the past with high effort , but without giving priority to the cost issues mandatory for automotive applications.” The clear objective was to develop these technologies for use in defense and airborne products (including space) first.

However, in recent years a number of automotive companies are trying to make these technologies available for use in the automobile with the reduction in prices of electronic components.

The heavy truck market represents the ideal industry for implementation , as costs resulting from collision represent a major drain on profits. Current prices of collision warning systems while high by consumer standards , are viable for the truck market. Also trucking companies are generally self insured and suffer costs averaging \$20,000 for even a minor accident and costs can easily exceed \$100,000 for a major accident: many users have reported substantial accident reductions quickly recovering their approximately \$2000 per unit investment.

- 2) Product liability This is always a concern when new products are involved, the fear of lawsuits has helped slow the introduction of adaptive cruise control in the USA, even as European drivers begin to use it. "There's a certain amount of 'Let's wait and see what happens in Europe,'" (Nick Ford, business development manager for adaptive cruise control systems at TRW Automotive Electronics, www.usatoday.com, Nov 23, 99). A mock trial held at the 44th Annual Meeting of the Human Factors and Ergonomics Society in San Diego,CA (2000) demonstrated how the plaintiff, the driver of a vehicle equipped with ACC can seek damages from the defendant , the manufacturer of the vehicle , for inappropriate design of the ACC that the driver alleges contributed to a motor vehicle collision in which she was involved. The underlying issue concerned the handover of control from the vehicle to the driver under conditions of partially automated driving.
- 3) Public acceptance According to Sayer, “Little substantive work has been focussed on the benefits of such systems [collision warning and avoidance systems] nor has the industry prepared the public with the proper expectation of the system’s performance.(Sayer,1996) For example , it is hard to predict how customers will respond to adaptive cruise control, since the product is so new. “But researchers say drivers who have used the technology in company tests share the same feeling: It's a stress-reliever.” (www.usatoday.com, Nov 23, 99).

- 4) Reliability -The biggest challenge with forward-looking collision-warning systems is false alarms. This can prove to be an annoyance to the driver. Research involving multiple sensors is being conducted by PATH for Transit Buses and by GM as part of the federal Intelligent Vehicle Initiative to reduce rear end collisions.

8.0) Future Research and Development -

In June 1999 the US Transportation Secretary announced a \$35 million joint research effort into vehicle crash warning systems by the U.S. Department of Transportation and General Motors Corp. The \$35 million Intelligent Vehicle Initiative (IVI) research project, which is the largest of its kind, will run for five years. It is the first IVI operational test under the Intelligent Transportation Systems (ITS) program, which was authorized by the Transportation Equity Act for the 21st Century (TEA-21).

The ITS project involves a 61 percent federal contribution, with the balance coming from GM and Delphi . The goal of the ITS Project is to measure the performance of the new collision warning systems. Also, the research will provide valuable information on driver acceptance of the technology. A primary partner in the field research is Delphi Delco Electronics Systems, which will provide expertise, along with GM, in adaptive cruise control, forward collision warning and driver interface. GM will also assemble the vehicles and lead the vehicle systems integration.

According to Roger Fruechte, director, Electrical and Controls Integration Lab, GM Research and Development Center: “Delphi Delco Electronics will provide vehicle-tracking algorithms. Delphi Chassis will provide the ACC brake system. Hughes Research Labs will provide some data fusion for the program because the project will be integrating a lot of different sensors and we need to have a good data- fusion algorithm. HE Microwave will provide the forward-looking radar. The University of Michigan Transportation Research Institute will conduct the test.”(www.itsa.org, September1999).

There are basically two objectives with this program. One is the development and integration of key technologies such as forward radar, forward vision, a mapping system, data fusion, etc., that can accelerate the introduction of a cohesive vehicle package that includes collision warning and adaptive cruise control functionality. Secondly, to assess the behavior of drivers and passengers, and determine their acceptance of a collision warning system through a comprehensive field operational test.

According to Roger Fruechte, “ The biggest challenge with forward-looking collision-warning systems is false alarms. We don't want that to be an annoyance to the driver. That's

why we are integrating multiple sensors, in order to further reduce nuisance alerts to the driver. We must remember that these systems are a driver's aid to reduce and mitigate rear-end collisions. They will not completely eliminate them.”

Testing conditions

All of the vehicles will be equipped with the same equipment. More than 100 private citizens from throughout Southeastern Michigan will be selected to drive 10 specially equipped vehicles equipped with Delphi Automotive Systems ACC, forward collision warning and driver interface technologies by mid-2001.

The test drivers will be recruited from licensed drivers in the area who meet a set of criteria that maximizes the chances of gathering good data without narrowing the breadth of the experiment. Then they will drive the vehicles, unsupervised, under real-world driving conditions. The University of Michigan Transportation Research Institute (UMTRI) would help screen, select and orient the drivers from across southeast Michigan, and then would perform data collection and analysis. According to Roger Fruechte, “ This will be the most comprehensive field operational test of automotive collision avoidance systems ever undertaken in the United States.”

Also, the US Department of Transportation (DOT) , Federal Transit Administration sponsored three projects as part of the intelligent vehicle initiative(IVI) , to reduce bus collisions. The Robotics Institute of Carnegie Mellon University is working on bus side collision warning. University of California , PATH program in partnership with California department of Transportation(Caltrans), San Mateo County Transit District(SamTrans) and Gillig Corporation is working on one of the other projects to develop and validate performance and technical requirement specifications for Bus Frontal Collision Warning Systems. Multiple sensors including two microwave radars, one laser radar, five ultrasonic sensors , four cameras, one GPS receiver are already installed on a SamTrans Transit bus to collect real life data.

According to Jim Misener at PATH , Collision Avoidance Systems is still a developing technology and a lot of money is being spent on research in this field.

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