CHAPTER 2. LITERATURE REVIEW

2.1 Section I: The Safety problem

2.1.1 Introduction

Travel by motor vehicles provides unprecedented degree of mobility, leading to continuous growth of traffic

As the number of motor vehicles and roadways miles and hence vehicles - miles of travel increase throughout the world, the population are more exposed to traffic accidents.

Highway safety is a world wide problem with over 500 million cars and trucks in use, and more than 500,000 people die each year in motor vehicles crashes, and about 15 million are injured [1].

In the United States, traffic fatalities account for more than 90 percent of transportation-related fatalities, and motor vehicles accidents are the leading cause of death for persons of ages from 5 to 29 years old (based on 1996) [2]. It is ranked third as the most significant cause of years of potential life lost, after Cardiac disease and cancer [3].

However, much progress has been made in reducing the number of deaths and serious injuries on nation's highway. In the United States, between 1966 and 1992 the number of vehicle miles traveled has increased from about one trillion to 2.1 trillion. Fortunately fatality rates have declined from 5 per 100 million vehicle- miles to less than 2 per 100 million vehicle- miles. In 1992, there were fewer than 40,000 fatalities on the nations highways, as opposed to 55,000 in the mid - 1970s[4].

2.1.2 Accident Statistics [2]

In 1998, the fatality rate per 100 million vehicle miles of travel remained at its historic low of 1.6, the same as in 1997 and down from 1.7, the rate from 1992 to 1996.

In 1998, 41,471 people were killed in the estimated 6,334,000 police-reported motor vehicle traffic crashes, 3,192,000 people were injured, and 4,269,000 crashes involved property damage only. Vehicle occupants accounted for 85.3 percent of traffic fatalities in 1998. The remaining 14.7 percent were pedestrians, pedal cyclists, and other non-occupants. Tables 2-1

and 2-2 provide overview fact sheets containing statistics on motor vehicle fatalities based on data from the Fatality Analysis Reporting System (FARS).

Table2-1: Motor vehicle occupants and non occupants killed and injured 1988-1998

Year	Occupants							Nonoccupants				Total
	Passenger Cars	Light Trucks	Large Trucks	Motor-cycles	Buses	Other/ Unknown	Total	Pedestrian	Pedalcyclist	Other	Total	
Killed												
1988	25,808	8,306	911	3,662	54	429	*39,170*	6,870	911	136	*7,917*	**47,087**
1989	25,063	8,551	858	3,141	50	424	*38,087*	6,556	832	107	*7,495*	**45,582**
1990	24,092	8,601	705	3,244	32	460	*37,134*	6,482	859	124	*7,465*	**44,599**
1991	22,385	8,391	661	2,806	31	466	*34,740*	5,801	843	124	*6,768*	**41,508**
1992	21,387	8,098	585	2,395	28	387	*32,880*	5,549	723	98	*6,370*	**39,250**
1993	21,566	8,511	605	2,449	18	425	*33,574*	5,649	816	111	*6,576*	**40,150**
1994	21,997	8,904	670	2,320	18	409	*34,318*	5,489	802	107	*6,398*	**40,716**
1995	22,423	9,568	648	2,227	33	392	*35,291*	5,584	833	109	*6,526*	**41,817**
1996	22,505	9,932	621	2,161	21	455	*35,695*	5,449	765	154	*6,368*	**42,065**
1997	22,199	10,249	723	2,116	18	420	*35,725*	5,321	814	153	*6,288*	**42,013**
1998	21,164	10,647	728	2,284	36	500	*35,359*	5,220	761	131	*6,112*	**41,471**
Injured												
1988	2,585,000	478,000	37,000	105,000	15,000	4,000	*3,224,000*	110,000	75,000	8,000	*192,000*	**3,416,000**
1989	2,431,000	511,000	43,000	83,000	15,000	5,000	*3,088,000*	112,000	73,000	11,000	*196,000*	**3,284,000**
1990	2,376,000	505,000	42,000	84,000	33,000	4,000	*3,044,000*	105,000	75,000	7,000	*187,000*	**3,231,000**
1991	2,235,000	563,000	28,000	80,000	21,000	4,000	*2,931,000*	88,000	67,000	11,000	*166,000*	**3,097,000**
1992	2,232,000	545,000	34,000	65,000	20,000	12,000	*2,908,000*	89,000	63,000	10,000	*162,000*	**3,070,000**
1993	2,265,000	601,000	32,000	59,000	17,000	4,000	*2,978,000*	94,000	68,000	9,000	*171,000*	**3,149,000**
1994	2,364,000	631,000	30,000	57,000	16,000	4,000	*3,102,000*	92,000	62,000	9,000	*164,000*	**3,266,000**
1995	2,469,000	722,000	30,000	57,000	19,000	4,000	*3,303,000*	86,000	67,000	10,000	*162,000*	**3,465,000**
1996	2,458,000	761,000	33,000	55,000	20,000	4,000	*3,332,000*	82,000	58,000	11,000	*151,000*	**3,483,000**
1997	2,341,000	755,000	31,000	53,000	17,000	6,000	*3,201,000*	77,000	58,000	11,000	*146,000*	**3,348,000**
1998	2,201,000	763,000	29,000	49,000	16,000	4,000	*3,061,000*	69,000	53,000	8,000	*131,000*	**3,192,000**

Table 2-2: Persons killed and injured and fatality and injury rates, 1988-1998

Year	Killed	Resident Population (Thousands)	Fatality Rate per 100,000 Population	Licensed Drivers (Thousands)	Fatality Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Fatality Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Fatality Rate per 100 Million VMT
Killed									
1988	47,087	244,499	19.26	162,854	28.91	177,455	26.53	2,026	2.3
1989	45,582	246,819	18.47	165,554	27.53	181,165	25.16	2,096	2.2
1990	44,599	249,440	17.88	167,015	26.70	184,275	24.20	2,144	2.1
1991	41,508	252,124	16.46	168,995	24.56	186,370	22.27	2,172	1.9
1992	39,250	255,002	15.39	173,125	22.67	184,938	21.22	2,247	1.7
1993	40,150	257,763	15.58	173,149	23.19	188,350	21.32	2,296	1.7
1994	40,716	260,292	15.64	175,403	23.21	192,497	21.15	2,358	1.7
1995	41,817	262,761	15.91	176,628	23.68	197,065	21.22	2,423	1.7
1996	42,065	265,179	15.86	179,539	23.43	201,626	20.86	2,486	1.7
1997	42,013	267,744	15.69	182,709	23.00	203,568	20.64	2,560	1.6
1998	41,471	270,299	15.34	*	*	*	*	2,619	1.6
Injured									
Year	Injured	Resident Population (Thousands)	Injury Rate per 100,000 Population	Licensed Drivers (Thousands)	Injury Rate per 100,000 Licensed Drivers	Registered Motor Vehicles (Thousands)	Injury Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Injury Rate per 100 Million VMT
1988	3,416,000	244,499	1,397	162,854	2,098	177,455	1,925	2,026	169
1989	3,284,000	246,819	1,330	165,554	1,984	181,165	1,813	2,096	157
1990	3,231,000	249,440	1,295	167,015	1,934	184,275	1,753	2,144	151
1991	3,097,000	252,124	1,228	168,995	1,833	186,370	1,662	2,172	143
1992	3,070,000	255,002	1,204	173,125	1,773	184,938	1,660	2,247	137
1993	3,149,000	257,763	1,222	173,149	1,819	188,350	1,672	2,296	137
1994	3,266,000	260,292	1,255	175,403	1,862	192,497	1,697	2,358	139
1995	3,465,000	262,761	1,319	176,628	1,962	197,065	1,758	2,423	143
1996	3,483,000	265,190	1,313	179,539	1,940	201,631	1,727	2,486	140
1997	3,348,000	267,744	1,250	182,709	1,832	203,568	1,645	2,560	131
1998	3,192,000	270,299	1,181	*	*	*	*	2,619	122

*Data not available.

Sources: Vehicle Miles of Travel and Licensed Drivers — Federal Highway Administration; Registered Vehicles — R.L. Polk & Co. and Federal Highway Administration; Population — U.S. Bureau of the Census.

2.1.3. Accidents in Virginia

Virginia's 1998 traffic safety record reveals 935 fatalities that constitute 13.77 per 100,000 populations, 15.91 per 100,000 registered vehicles and 1.3 per 100 million vehicle-miles traveled. These rates reflect good safety position when compared with U.S. 15.34,19.98 and 1.6 rates respectively. However, Virginia used to have higher fatality rates, which started to decrease from 2.9 fatality rate per 100MVMT in 1975, to 2.0 in 1985,and 1.8 in 1990, till 1.4 in 1997. [5]

2.1.4 Accidents in Rural Areas

Some 3.2 million miles of public roads serve rural America. Most rural communities depend heavily upon these vital arteries for commerce and entertainment as well as connectors to the nation Interstate system. A close review of statistical data for these roadways reveals that rural highways are experiencing a disproportionate amount of crashes and related trauma when compared to the urban system. In addition, Because on two-lane roads, higher speed head-on collisions - the deadliest of all crashes - are more common on rural highways than on urban freeways or rural interstate highways. These conclusions are supported by the following facts:

The Fatality Analysis Reporting System (FARS) uses the variable "Roadway Function Class" to identify rural and urban areas, as determined by the state highway departments and approved by the Federal Highway Administration. Although rural areas accounted for only 38 percent of total vehicle miles of travel in 1995, the fatality rate in those areas was 2.6 per 100 million vehicle miles traveled, compared with 1.1 in urban areas In 1996, crashes in rural areas accounted for 59 percent of total motor vehicle fatalities, and 56 percent of all the vehicles involved in fatal crashes were involved in crashes that occurred in rural areas. In 1996 also, 64 percent of total passenger vehicle occupant fatalities occurred in rural areas
In 1996, 46 percent of the sport utility vehicles involved in fatal crashes in rural areas experienced rollover--more than any other type of vehicle. Rollover rates for other vehicle types

involved in rural fatal crashes were 29 percent for pickups, 26 percent for vans, 21 percent for passenger cars, and 15 percent for large trucks. The rollover rates for vehicles in fatal crashes in urban areas were lower: 25 percent for sport utility vehicles, 15 percent for pickups, 11 percent for vans, 9 percent for passenger cars, and 8 percent for large trucks. [6]

NHTSA's National Center for Statistics and Analysis (NCSA) completed a study in 1996 comparing the characteristics of crashes the occurring in rural areas to the characteristics of crashes occurring in urban areas [7]. The study noted that while there are approximately 40% more fatal crashes and fatalities occurring in rural areas compared to urban areas, fewer vehicle miles traveled (VMT) occur in rural areas, resulting in higher fatality rates for rural areas for each year in the period studied.

It was noted also that rural fatal crashes compared to urban fatal crashes, have a larger proportion of crashes with:

- more than one fatality per crash;
- a truck involved;
- a vehicle rollover;
- severe vehicle damage;
- a head-on collision; and
- ejected persons.

In addition, the time for emergency medical services (EMS) to reach the fatal crash scene is longer in rural areas than in urban areas. Data also indicated that safety belt use was usually lower for hospitalized persons of rural crashes, and that crashes in rural areas are more severe: a person is as much as three times likely to suffer a fatality, when involved in a rural crash.

2.1.5. Crashes by Crash Type and Road Function [8]

The crash type and road function classifications are useful in identifying the impact of road function on the type of the collision and when estimating the benefits of certain ITS countermeasures such as crash avoidance systems. Table 2-3 shows a cross-tabulation of 1995 fatal crashes by crash type and road function. Tables 2-4 and 2-5 show 1995 injury crashes

classified by crash type and road function, respectively. Table 6 shows same year fatal crashes by weather conditions and crash type on rural roads.

Table 2-3: 1995 Fatal Crashes by Crash Type and Road Function

CRASH TYPE	RURAL				URBAN				TOTAL
	Freeway	Arterial	Other	Total	Freeway	Arterial	Other	Total	
Rear-end	225	407	201	833	382	363	87	832	**1665**
Head-on	186	2139	1495	3820	285	933	443	1661	**5481**
Angle	147	1706	1644	3497	558	2408	863	3829	**7326**
S-Swipe (same dir.)	43	39	29	111	108	47	16	171	**282**
S-Swipe (opp. dir.)	7	111	66	184	8	38	8	54	**238**
Single Veh. (off roadway)	1264	2592	5760	9616	1386	1868	1575	4829	**14,445**
Other/Unk	338	949	1855	3142	839	2513	1310	4662	**7804**
Total	**2210**	**7943**	**11,050**	**21,203**	**3566**	**8170**	**4302**	**16,038**	**37,241**

(Source: Extracted from FARS database)

Table2-4: 1995 Injury Crashes by Crash Type

CRASH TYPE	TOTAL
Rear-end	531,000
Head-on	58,000
Angle	782,000
S-Swipe (same dir.)	55,000
S-Swipe (opp. dir.)	13,000
Single Vehicle (off roadway)	422,000
Other/Unknown	305,000
Total	2,166,000

(Source: Extracted from GES database)

Table 2-5: 1995 injury crashes classified by road function

Road Function	Freeway	Arterial	Other	Total
Rural	53,000	232,000	332,000	617,000
Urban	253,000	895,000	401,000	1,549,000
Total	306,000	1,127,000	733,000	2,166,000

(Source: *Highway Statistics 1995*)

Table 2-6: 1995 Rural Fatal Crashes by weather Condition and Crash Type

Weather Condition	Rear-end	Head on	Angle	Side swipe (same dir.)	Side swipe (opp. dir.)	Single vehicle., off road	Other	Total
Normal	725	3,069	3,040	98	151	8,467	2,674	18,224
Rain	69	457	304	12	22	661	219	1,744
Sleet	3	45	15	0	2	33	11	109
Snow	15	247	60	1	4	137	46	510
Fog	18	72	62	0	2	131	46	391
Other/Unknown	3	30	16	0	3	167	25	225
Total	833	3,920	3,497	111	184	9,616	3,142	21,203

(Source: Extracted from FARS)

2.1.6. Economic Costs of Crashes

Economic cost components of crashes include productivity losses, property damage, medical costs, rehabilitation costs, travel delay, legal and court costs, emergency service costs, insurance administration costs, premature funeral costs and costs to employers.

A major study was conducted in 1994 by NHTSA about the economic costs of motor vehicle crashes. Significant findings on cost include [9]:

"The cost of motor vehicle crashes that occurred in 1994 was $150.5 billion, the equivalent of $580 for every person living in the United States, or 2.2 percent of this country's Gross Domestic Product GDP."

Each fatality resulted in lifetime economic costs to society of over $830,000. Over 85 percent of this cost is due to lost workplace and household productivity. The average cost for each critically injured survivor was $706,000 -- nearly as high as for a fatality. Medical costs and lost

productivity accounted for 84 percent of the cost for these Maximum Abbreviated Injury Scale (MAIS) level 5 injuries. Present and future medical costs due to injuries occurring in 1994 were $17 billion, representing 11 percent of total costs. However, medical costs accounted for 22 percent of non-fatal injury crash costs.

Lost market productivity totaled $42.4 billion, accounting for 28 percent of total costs, and lost household productivity totaled $12.3 billion, representing 8 percent of total costs. Because of their high incidence, crashes of vehicles that sustained only property damage were the most costly type of occurrence, totaling $38.9 billion and accounting for 26 percent of total motor vehicle crash costs. Property damage in all crashes (fatal and injury) as well as property-damage-only crashes totaled $52.1 billion and accounted for 35 percent of all costs, more than any other cost category. Figure 2-1 shows the breakdown of the economic cost of motor vehicle crashes in 1994.

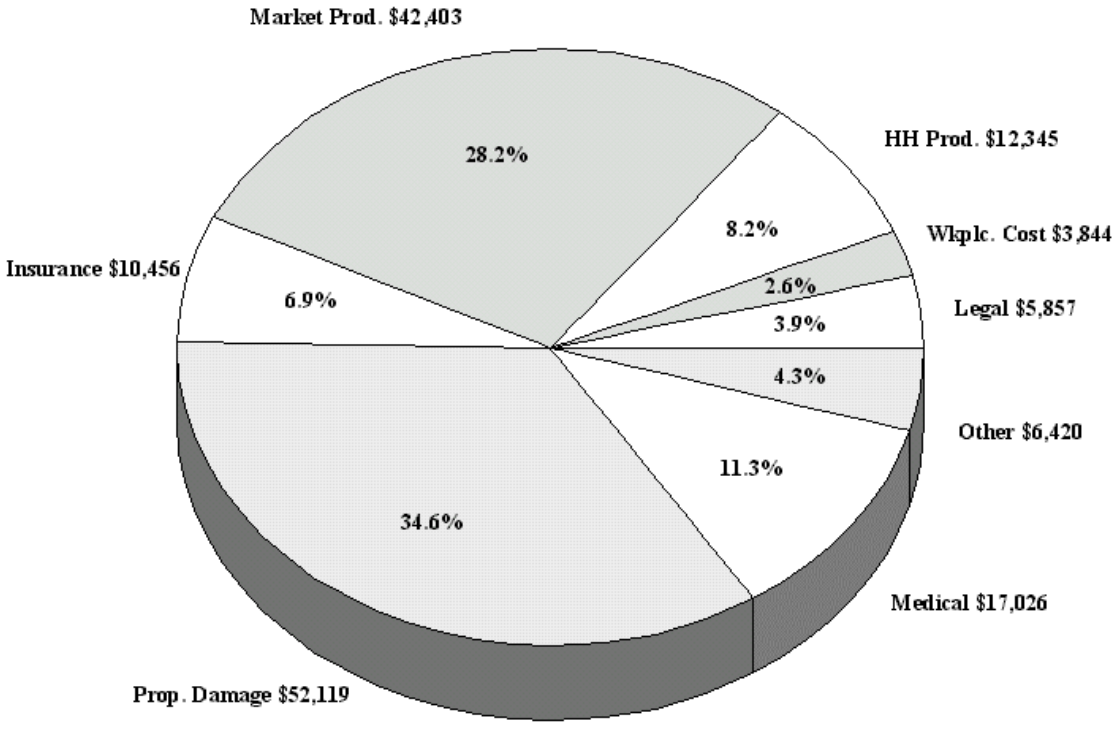

Figure 2-1: Economic Cost Breakdown Of Crashes (year 1994)

About 24 percent of medical care costs resulting from motor vehicle crashes are paid from public revenues, with Federal revenues accounting for 14 percent and states and localities 10 percent. Roughly 9 percent of all motor vehicle crash costs are paid from public revenues. Federal revenues account for 6 percent and states and localities paid for about 3 percent. Private insurers pick-up 55 percent while individual crash victims absorb about 29 percent. Overall, sources other than the individual crash victims pay about 70 percent of all motor vehicle crash costs, primarily through insurance premiums and taxes. Motor vehicle crash costs funded through public revenues cost taxpayers $13.8 billion in 1994, the equivalent of $144 in added taxes for each household in the United States.

Alcohol-involved crashes caused $45 billion or 30 percent of all economic costs, and 78 percent of these costs occurred in crashes where a driver or pedestrian was legally intoxicated (>= .10% Blood Alcohol Concentration BAC). Crashes in which police indicate that at least one driver was exceeding the legal speed limit or driving too fast for conditions cost $27.7 billion in 1994.

2.2 Section II: ITS and Safety

2.2.1 The need for new solutions to safety problem

An implicit objective of the transportation system is to minimize the risk of collision, yet maintaining a desired level of mobility. Traditionally, this has been done through improvements to the geometry or physical layout of the roadway. For example, smoothing horizontal and vertical curves and increasing stopping sight distance can make roads safer to drive on. Transportation has also been made safer through the implementation of various safety features on the roadway such as guardrails, traffic barriers and rumble strips.

Also, there have been safety features implemented in automobiles such as seatbelt, air bags and structure that have also improved the overall safety of highway travel. Traditional focus has been on **protecting** vehicle occupants [10]:

- Seatbelts save 10,000 lives each year and reduce fatalities and serious injuries by 50-70 percent
- Airbags, installed in one quarter of the cars on the road, save 500 lives each year
- Bumper and side-impact beam standards lessen the blow all together. Federal Motor Vehicle Safety Standard (FMVSS) 214, "Side Impact Protection" was amended in 1990 showed 23 percent fatality reduction in side impacts [11].

Recently the focus is moving toward **preventing** accidents all together: If we can prevent the crash from ever occurring, motor fatalities, injuries, property damage, and travel delays will not occur:

- Center-mounted tail lights
- Anti-lock brakes
- Day-time running lights
- Drinking age limits

Despite these efforts, fatalities, Injuries and accidents are too high. A new approach is needed to reduce the incidence and severity of highway crashes, particularly when the large share of

accidents is caused by driver error. This offers a compelling reason for investigating intelligent vehicle and highway technologies as a crash reduction measure.

2.2.2 Emerging ITS safety applications

The idea of the Intelligent Transportation Systems (ITS) – originally Intelligent Vehicle-highway Systems (IVHS) was born in the 1980's.It harnesses "new" technology to improve the safety, efficiency, and convenience of surface transportation, both for people and for goods. Recently, The Transportation Equity Act for the 21 century (TEA-21) passed by the congress in 1998 provides strong incentives to mainstream ITS into the transportation milieu [12].

In safety applications, a variety of ITS systems are oriented toward **reducing travel risk**. Some of these systems are oriented toward reducing crashes while others lessen the probability of a fatality should a crash occur:

A- ITS systems that **reduce the severity of crashes**, their consequences, or response times of emergency medical service are oriented toward lessening the probability of fatalities. In-vehicle collision notification systems, such as rural mayday systems, and incident detection technologies implemented on roadways reduce the time between the occurrence of an accident and the notification of emergency service providers. Traffic information and route guidance for emergency service providers reduce the time between accident occurrence and arrival of emergency services. Moreover, traffic management systems can be designed to give priority to emergency vehicles, further reducing their time of arrival.

B- With recent advances in information technology and telecommunications, ITS has emerged as another potential solution oriented toward reducing crashes. We may list the following:

- Traffic management systems limit the conflict of traffic streams thus reducing the likelihood of an accident. This can be accomplished through traffic control devices such as ramp meters or devices that encourage compliance to traffic laws such as video cameras.

- Traveler information systems improve safety by warning drivers of risk situations, and by reducing distractions from route finding and other navigation activities.
- Automation aids to commercial vehicle regulation and safety inspections improve safety enforcement, and thus reduce the probability of crashes and fatalities involving heavy trucks.
- Finally, advanced vehicle control systems reduce crash risk by taking limited or direct control of the vehicle in emergency situations to help avoid crashes.

Preventing accidents requires enhancing drivers' performance. Fortunately, a new set of sensing and communication technologies applications have emerged that can do this, such as:

Crash Warning Systems **-** Vehicle warns driver about collision hazards, stopped or slowing vehicles ahead, tailgating, running off the road, or vehicles in the "blind-spot". This gives the driver more time to respond or to avoid dangerous action.

Automated Travel Management **-** Traffic flow is enhanced using ramp metering, signal timing and lane control. Driver also receives information about the best route to take; this reduces congestion and results in safer driving conditions.

Vision Enhancement **-** Improves driver's vision of roadways at night and during inclement weather.

Video Enforcement **-** Video cameras detect speeding and drivers running red lights. This provides a strong incentive for drivers to obey traffic laws and avoid dangerous driving.

2.2.3 Benefits of Intelligent Transportation [10]

To estimate benefits, expected crash reduction rates were applied to crash problem sizes tabulated by NHTSA in Traffic Safety Facts 1995 where each ITS countermeasure applies only to certain crash situations. The expected crash reduction rates for infrastructure countermeasures were taken from a combination of field experience and analytical prediction. The expected crash reduction rates for in-vehicle crash reduction were taken from NHTSA publications.

The following tables summarize potential crash reduction benefits from ITS. Table 2-7 summarizes anticipated results from full implementation of infrastructure ITS countermeasures. Based on the subset of infrastructure-supported ITS services. 10% of injury crashes and 27% of fatal crashes could be avoided. Table 2-8 summarizes anticipated results from implementation of near-term, in-vehicle crash avoidance devices. The reduction in total number of crashes of 17% from full deployment of in-vehicle countermeasures predicted by NHTSA analysis includes a reduction of 16% in injury crashes and 9% of fatal crashes. Table 2-9 estimates total crash reduction benefits of ITS. Assuming that the target crashes for infrastructure and in-vehicle countermeasures overlap so that crash reduction totals are not fully additive, full deployment of ITS counter-measures could result in a reduction of 24% in injury crashes and 34% in fatal crashes.

The significant reduction in crashes from ITS countermeasures can be brought about only by the combination of ITS services, as represented in Figure 2-2. The implementation of these integrated services requires contribution from government as well as product developers and infrastructure providers.

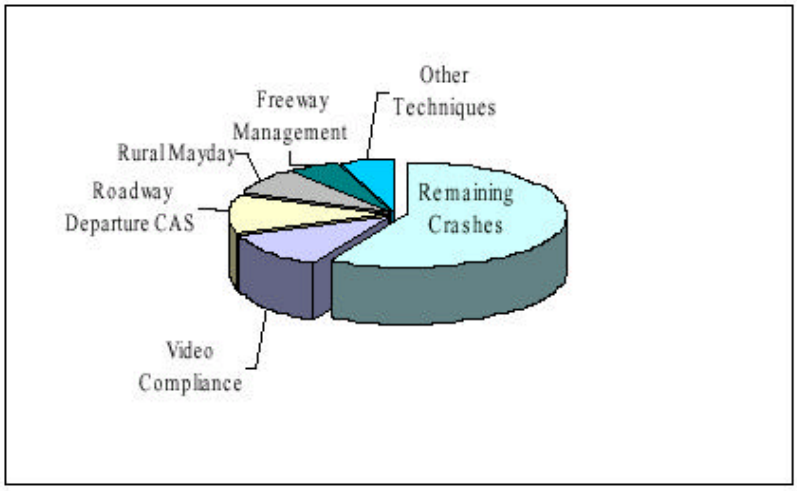

Figure 2-2: Contribution to Fatal Crash Reduction by ITS Countermeasure

Table 2-7: Infrastructure ITS Benefits Summary

Injury Crashes

Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Freeway Management	Urban Freeway	253,026	253,026	30%	75,908	3.25%
Video Compliance	All	2,334,623	583,656	20%	116,731	5.00%
Grade Crossing Compliance	Non-Freeway	2,028,738	1,837	90%	1,653	0.07%
Route Guidance	Urban Arterials	894,940	894,940	3%	26,848	1.15%
MCSAP/Inspections	All	2,334,623	97,000	22%	21,572	0.92%
Rural Mayday	All Rural	664,283	664,283	0%	0	0.00%
Total					242,712	10%

Fatal Crashes

Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Freeway Management	Urban Freeway	3,033	3,033	40%	1,213	3.26%
Video Compliance	All	37,221	9,305	50%	4,653	12.50%
Grade Crossing Compliance	Non-Freeway	31,966	626	90%	563	1.21%
Route Guidance	Urban Arterials	8,845	8,845	3%	265	0.71%
MCSAP/Inspections	All	37,221	3,858	22%	858	2.31%
Rural Mayday	All Rural	20,779	20,779	12%	2493	6.70%
Total					10,045	27%

Table 2-8: In-Vehicle ITS Benefits Summary

Injury Crashes

Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Rear End CAS	All	2,334,623	580,000	48%	278,400	11.92%
Lane Change/Merge CAS	All	2,334,623	12,500	37%	4,625	0.20%
Roadway Departure CAS	All	2,334,623	337,500	24%	81,000	3.47%
Total		2,334,623	930,000		364,025	16%

Fatal Crashes

Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Rear End CAS	All	37,221	1,055	48%	506	1.36%
Lane Change/Merge CAS	All	37,221	205	37%	76	0.20%
Roadway Departure CAS	All	37,221	12,118	24%	2,908	7.81%
Total		37,221	13,378		3,490	9%

Table 2-9: ITS Benefits Summary

Injury Crashes						
Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Freeway Management	Urban Freeway	253,026	253,056	30%	75,908	3.25%
Video Compliance	All	2,334,623	583,656	20%	116,731	5.00%
Grade Crossing Compliance	Non-Freeway	2,023,738	1,837	90%	1,653	0.07%
Route Guidance	Urban Arterials	894,940	894,940	3%	26,848	1.15%
MCSAP/Inspections	All	2,334,623	97,000	22%	21,572	0.92%
Rural Mayday	All Rural	664,283	664,283	0%	0	0.00%
Infrastructure Total					242,712	10.39%
Read End CAS	All	580,000	580,00	48%	278,400	11.92%
Lane Change/Merge CAS	All	12,500	12,500	37%	4,625	0.20%
Roadway Departure CAS	All	337,500	337,500	24%	81,000	3.47%
In-Vehicle Total					364,025	15.59%
Total					560,310	24%

Injury Crashes						
Countermeasure	Impacted Roadway	Roadway Crash Size	Target Crash Size	% Crash Impact	Crashes Avoided	% Crash Reduction
Freeway Management	Urban Freeway	3,033	3,033	40%	1,213	3.26%
Video Compliance	All	37,221	9,305	50%	4,653	12.50%
Grade Crossing Compliance	Non-Freeway	31,966	626	90%	563	1.51%
Route Guidance	Urban Arterials	8,845	8,845	3%	265	0.71%
MCSAP/Inspections	All	37,221	3,858	22%	858	2.31%
Rural Mayday	All Rural	20,779	20,779	12%	2493	6.70%
Infrastructure Total					10,045	26.99%
Read End CAS	All	37,221	1055	48%	506	1.36%
Lane Change/Merge CAS	All	37,221	205	37%	76	0.20%
Roadway Departure CAS	All	37,221	12,118	24%	2,908	7.81%
In-Vehicle Total					3,490	9.37%
Total					12,665	34%

In a separate study published in 1998 [13]**,** ITS countermeasures were separated into three areas:

1) Infrastructure-based ITS,
2) Vehicle-based ITS and,
3) Cooperative ITS.

Cooperative ITS includes those ITS applications that require elements to be added to both the infrastructure and the vehicle with significant interaction between them. For each ITS countermeasure below, related before-and-after studies are cited and estimates are given for crash reduction factors.

Table 2-10 below presents summary of the crash reduction factor for the various ITS countermeasures listed each with its appropriate ITS technology type, the types of traffic and crashes impacted. Note that infrastructure and cooperative based countermeasures impact all crash types for specific types of traffic, whereas vehicle-based countermeasures impact specific

crash types for all types of traffic. Finally, the crash reduction factors are listed with a relative level of confidence (high, medium or low). The confidence levels depend on the quantity and quality of data sources available.

Table 2-10: Summary of ITS Countermeasures Impact

ITS Technology Type	ITS Countermeasure	Traffic Impacted	Crash Type Impacted	Crash Reduction Factor	
				Value	Level of Confidence
Infrastructure-based	Ramp Metering	Urban Freeways	All	24%	H
	Incident Detection	Urban Freeways	All	18%	M
	Video Enforcement	Urban Arterials	All	20%	M
	Grade Crossing Enforcement	Railroad Crossings	All	78%	L
	RWIS (snow/ice)	Rural roads, inclement weather	All	40%	L
	RWIS (fog)	Rural roads, foggy conditions	All	85%	L
Vehicle-based	Rear-end CAS	All	Rear-end crashes	48%	M
	Lane change CAS	All	Lane change/merge crashes	37%	M
	Roadway Departure CAS	All	Single vehicle, run-off-road crashes	24%	M
Cooperative	In-Vehicle Navigation Systems	Urban Arterials	All	1%	L
	Emergency Response (Mayday)	Rural roads, fatal only	All	7%	M/L
	Intelligent Speed Control	Urban Freeways	All	20%	L

Table 2-11 shows the total fatal crash reduction of 9,572 fatal crashes or 25.7% from implementing ITS countermeasures after eliminating double counting between crash reduction estimates for infrastructure-based, cooperative and vehicle-based systems, whereas Table 2-12 shows the total injury crash reduction of 648,650 crashes or 29.9%.

Table 2-11: Total Fatal Crash Reduction from 100% ITS Deployment

ITS Type	1995 Fatal Crashes	Crashes Avoided	Total Crash Reduction
Infrastructure-based	37,241	4,163	11.2%
Cooperative	37,241	1,589	4.3%
Vehicle-based	37,241	3,820	10.3%
Total	**37,241**	**9.572**	**25.7%**

Table 2-12: Total Injury Crash Reduction from 100% ITS Deployment

ITS Area	1995 Injury Crashes	Crashes Avoided	% Crash Reduction
Infrastructure	2,166,000	312,280	14.4%
Cooperative	2,166,000	36,560	1.7%
In-vehicle	2,166,000	299,810	13.8%
Total	**2,166,000**	**648,650**	**29.9%**

2.3 Section III: Advanced Rural Transportation Systems (ARTS)

2.3.1 Definition and Historical Background

Rural ITS refers to that portion of the ITS program that focuses on travelers' and operators' needs in non-urbanized areas of the United States. As such, it involves interurban/interstate travel, small communities, rural counties, two-lane rural roads, and statewide and regional systems. Rural ITS infrastructure aims to improve the quality of life for rural residents and travelers by facilitating safer, more secure, available, and more efficient movement of people and goods in rural America [14].

In 1993, FHWA initiated a comprehensive study of rural applications of advanced traveler information systems (ATIS). The study produced a rural user needs assessment, a technology review, development of rural system concepts, and an activities assessment.

Based on this study, the ITS Joint Program Office formed a Rural Action Team in 1995 to develop a vision, strategic plan, and program plan for the ARTS program; the preliminary versions of these were completed in September 1996.

In addition, the Rural Action Team assessed the results of many operation tests of systems with rural applications, such as automated collision notification ("Mayday") systems, warnings at rail-highway grade crossing, and demand-responsive paratransit.

By 1997 there were 28 completed or ongoing operational tests, which dealt with rural issues in ATIS, ATMS, Mayday, and CVO [15].

2.3.2 Rural ITS user needs

ITS Architecture identified the following three separate transportation environments to aid in thinking about and analyzing the different needs and required focus:

1. Urban
2. Inter-Urban
3. Rural

Each has its own set of needs, priorities and concerns. However, U.S. DOT initiated an effort to develop and document a comprehensive list of rural ITS user needs. These needs could be used to identify rural travel requirements. Rural travel requirements will be identified to:

- define the Rural ITS Infrastructure;
- update the Rural ITS Program Plan; and
- provide input to the National ITS Architecture.

In fact, a Rural ITS Workshop was held on April 18, in McLean, Virginia, served as a forum for discussing traveler needs in rural areas. Stakeholders representing a wide variety of interests from 28 states were provided a draft list of rural user needs developed during previous efforts to review and critique. A finalized comprehensive list of user needs incorporating stakeholder comments received during the workshop was then prepared [16].

The conditions found in rural travel (including inter-urban travel through rural areas), the characteristics of the travelers, and the costs of maintaining the rural system all point to the need for a focused program for developing advanced technology solutions for transportation in rural America. Some of the attributes found in rural environments that make this need critical are [17]:

- Mix of users (rural and urban travelers);
- Secondary roads with less frequent maintenance, low volume primary and other state highway routes;
- Steep grades/blind corners/curves/few passing lanes;
- Large variance in travel speeds (frequent passing);
- Long distance travel;
- Fewer convenient detour options;
- Adverse road surface and weather conditions;
- Few navigational signs;
- Less existing infrastructure (per square mile);
- Light usage/large geographical areas impeding rapid emergency detection and response;

- More motor vehicle deaths with higher frequency of accidents/vehicle mile traveled and more severe accidents than found in urban areas;
- Recreational travelers needing traveler information services;
- Limited or non-existent public transportation services;
- Many, often uncoordinated, providers of transportation services to meet health and human services needs; and
- Very dispersed systems with high unit costs for service delivery, maintenance, and operations.

Actually it was a challenge to developing services that include the wide variety of conditions found in rural travel, and the costs of maintaining the rural transportation system. In fact, a Strategic Plan has been developed for the Advanced Rural Transportation Systems (ARTS) portion of the ITS Program by the Intelligent Transportation Systems Joint Program Office (JPO) created by The U.S. Department of Transportation.

ARTS Program Plan proposes five years (FY 97- FY 01) of USDOT projects and activities to advance the ARTS in partnership with other national, state and local public agencies, and with the private sector. Public sector activities will be focused on an ARTS infrastructure that will support various services to transportation providers and users. The ARTS will be fully coordinated with the national ITS through a common national architecture and standards. The ARTS will focus on rural needs and conditions, but will be interoperable with extensions of metropolitan ITS, and will be seamless for travelers and commercial vehicles [17].

2.3.3 ARTS Goals

The goals of the ARTS Program are closely tied to those of the overall ITS program. The five goals of the program are:

(1) Safety and security;

(2) Mobility, convenience and comfort;

(3) Efficiency,

(4) Economic vitality and productivity; and

(5) Environmental conservation.

Priority is given to those goals that will meet the more critical needs of travelers and transporters of goods in rural areas. Consequently, the primary goals of the ARTS program are **safety and efficient mobility**, versus those of urban systems, which are **congestion relief and increased throughput**.

2.3.4 Safety and Security

Improving safety and security is continually identified as a critical goal for rural transportation and ITS. Rural crashes tend to be more severe, and have longer response times. The characteristics of rural crashes mirror the diverse nature of the system, having a wide variety of causal factors. In some cases, trip fatigue takes its toll, while in other cases poor visibility or unsafe road conditions lead to crashes. ITS can play a major role in reducing the rate and frequency of crashes through a wide variety of safety advisory systems. ITS can also help reduce the consequences of the crashes once they occur by enabling emergency responders to reduce response time and provide improved care.

2.3.5 Safety and Security Strategic Objectives

1. Reduce the frequency of crashes (via pre-crash warning systems);
2. Reduce the rate of crashes (via pre-crash warning and advisory systems);
3. Reduce the severity and fatality level per incident from current levels (via improved response time and care); and
4. Reduce exposure to unsafe situations (e.g., getting lost, car breaking down, etc.) (via emergency notification system).

2.3.6 Critical Program Areas (CPA's)

Given the diversity of the rural transportation system, and the wide breadth of the program (i.e., encompassing a large number of needs of a large number of users), the ARTS program has been organized into seven Critical Program Areas (CPA's):

CPA 1 Traveler Safety and Security

CPA 2 Emergency Services

CPA 3 Tourism and Travel Information Services

CPA 4 Public Traveler/Mobility Services

CPA 5 Infrastructure Operations and Maintenance

CPA 6 Fleet Operations and Maintenance

CPA 7 Commercial Vehicle Operations

The clusters are not necessarily mutually exclusive and will overlap in their deployment in a specific region or rural setting. For example, services developed around a "safety information cluster" may also exist in the same area with services developed to meet the mobility needs. Similarly, clusters are ``fuzzy" and the boundary between two related clusters may be difficult to discern at times (e.g., infrastructure versus fleet operations and maintenance). Figure 2-3 shows the major conceptual overlaps between the clusters [17].

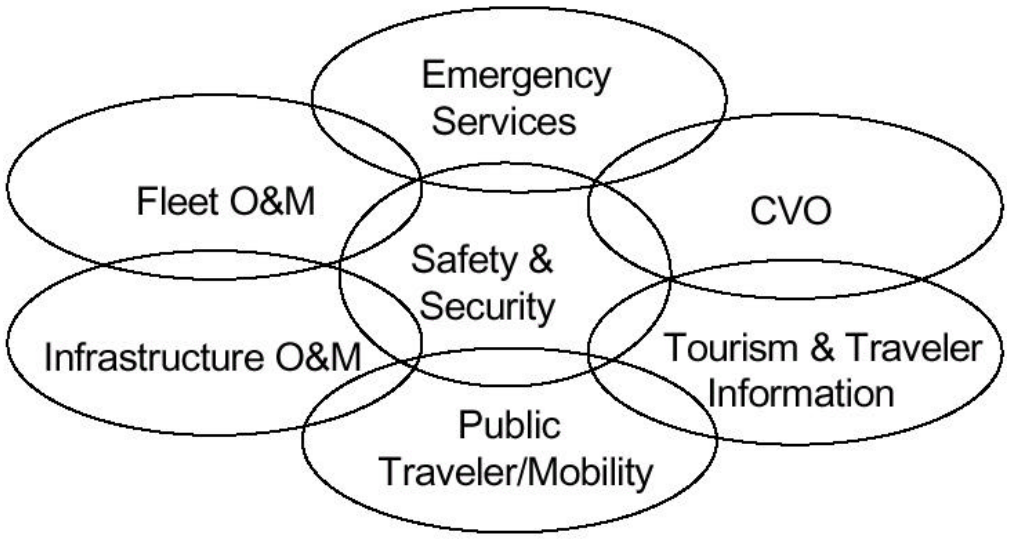

Figure 2-3: Conceptual Cluster Relationships

Actually each CPA had to be translated into applications capable to achieve the stated objectives in fulfilling its own specific needs. In fact, New York State Department of

Transportation, for instance succeeded in developing a compendium of systems, devices and strategies that can enhance safety, provide information, and make public transportation available to non-drivers in the small urban and rural areas throughout the State. This compendium is called the “Small Urban and Rural ITS Toolbox”. The “Toolbox” contains 30 unique “tools” shown in which define a list of state-of-the-art technologies currently available and appropriate for deployment to address mobility, capacity, information and safety problems and needs in the small urban and rural areas. A summary table (table 2-13) documents the contribution of each tool to the overall rural ITS infrastructure [18].

2.3.7 Traveler Safety and Security

Traveler safety and security is a central CPA while the rates and severity of accidents have been repeatedly identified as one of the most serious problems associated with rural transportation. Consequently, improving safety and security has been identified as a key cluster or critical program area.

The needs in this cluster center around improving the driver's ability to operate the vehicle in a safe and responsible way and in reducing the influence of other factors that may help cause an accident, such as, poor road conditions, visibility, etc. This cluster focuses on the prevention of accidents before they occur and in reducing the severity of the accident if it does take place.

Table 2-13: Contribution to Overall Rural ITS Infrastructure

Tools	FHWA Critical Program Areas: Traveler Safety and Security	Emergency Services	Tourism and Traveler Information Services	Public Traveler and Mobility Services	Infrastructure Operations and Maintenance	Fleet Operations and Maintenance
1. Incident Detection/Notification						
Information/Data Clearinghouse	X	X	X	X	X	X
Integrated Communication System	X	X	X	X	X	X
2. Traffic Management						
Automated Lane Indication	X			X	X	
CCTV for Incident Detection	X	X	X			
GIS Traffic Analysis	X		X		X	
Integrated Signal System	X				X	
Low-Cost Route Diversion System	X	X	X			
Variable Message Signs	X		X		X	
Vehicles as Traffic Probes	X		X	X	X	X
3. Safety						
Speed Warning System	X	X			X	
Smart Workzone System	X				X	
Automated Visibility Warning System	X				X	
Animal Warning System	X	X			X	
Portable Speed Warning System	X	X			X	
Dynamic In-Vehicle Alert System	X	X			X	X
4. Road/Weather Information Systems						
RWIS	X	X	X		X	X
Smart Plows/Agency Vehicle Monitoring	X	X		X		X
Automated Anti- /De-Icing Capabilities	X	X			X	X
5. Detection/Mayday Services						
Mayday System	X	X	X	X		
6. Transit						
Coordinate Rural Transit Service				X		

Tools	FHWA Critical Program Areas: Traveler Safety and Security	Emergency Services	Tourism and Traveler Information Services	Public Traveler and Mobility Services	Infrastructure Operations and Maintenance	Fleet Operations and Maintenance
7. Traveler/Tourist Information						
Highway Advisory Radio	X		X			
Traveler Information using Phones			X	X		
Interactive Kiosks			X	X		
Traveler Information on the Internet			X	X		
TIS via Personal Communication Devices			X	X		
Traffic Cable TV Channel			X	X		
8. Planning, Outreach and Delivery						
Integrated ITS Planning	X	X	X	X	X	X
Interagency ITS Coordinating Council	X	X	X	X	X	X
ITS Public Outreach and Education	X	X	X	X		

Specific action plans for identifying and applying a range of ITS technologies to each cluster has been developed. Some technologies being applied are closely related to technologies being used in urban settings; whereas, other are specified to rural settings. Some technologies and their applications for traveler safety and security cluster are outlined in table 2-14 [15].

Some of the advanced systems that may be explored and developed under this cluster are:

1. Wide area information dissemination systems (via radio, computer, TV, etc.) both pre-trip and en-route of safety information, such as weather and road conditions;
2. Site-specific safety advisories and warnings (e.g., the enhanced detector for hazard warning, visibility sensors, variable speed limits, collision avoidance, work zone detection/intrusion alarms, shoulder detection, etc.) to alert motorists of imminent problems;
3. Safety surveillance and monitoring (e.g., on transit vehicles (for malcontents and for ill riders), at park-and-ride lots, rest areas, etc.); and
4. In-Vehicle monitoring and detection systems including such items as driver monitoring (alertness, status), vision enhancement, perimeter detection, shoulder detection, etc.

Table 2-14: Technology System Applications

Program /Cluster Area	Technology Systems Applications
Traveler Safety and Security Technologies, such as wide-area nformation dissemination systems containing safety nformation, site specific safety advisories and warnings, and safety surveillance and monitoring, alert drivers to hazardous conditions and dangers.	*Railroad Crossing Warning System* is an active device to warn drivers of an oncoming train at unprotected grade railroad crossings. The train, equipped with a transmitter, sends a signal to vehicles approaching the grade crossing notifying the vehicle driver that a train is approaching. *Vehicle-Based Adaptive Safe Speed System* uses information on vehicle weight, vehicle type, roadway geometry, and road surface conditions to recommend a safe speed. Static and dynamic roadway data will be combined with vehicle data in an on-board processor to compute the safe speed. *Animal Warning System* will emit a high frequency signal or signals, audible to animals but not humans, to alert animals and divert them away from the roadway. The goal of this system is to warn animals which are large enough to cause an accident or damage a vehicle. *Work Zone Delay Advisory System* provides travelers with an active indication that delays actually exist at the work zone. The simplest type of system is a static sign with flashers which can be activated when there are delays. A second type uses speed sensors to determine approximate delay through the work zone and changeable message signs to transmit the information to travelers. A third type uses a passive automatic vehicle identification travel time monitoring system to more accurately determine delay at work zones. *Electronic Flare Warning System* is an in-vehicle device that transmits warning signals of advisory information to surrounding or approaching vehicles. The system is envisioned for use on slow moving construction and maintenance equipment, school buses, and emergency vehicles. The system could be applied to construction sites (e.g., lane closure and flagging operations). The approaching vehicle has an on-board device that receives the signal and issues an appropriate warning to the driver.

2.3.8 Expected Benefits of ARTS

The Rural Program is focusing on documenting the benefits of advanced traveler information, collision avoidance, and public transit systems in the rural context. Given the enormous needs of users of rural transportation systems, ARTS services are expected to create significant benefits, such as:

? Safety and security systems, in addition to, travel information services that will improve customer satisfaction or “peace of mind”.

? Faster response time to incidents and crashes that will not only save lives, but reduce medical costs.

? Sensors systems that will provide more accurate, reliable information to travelers and could reduce the occurrence of visibility-related multi-vehicle accidents in rural areas.
? In-vehicle communications and signing equipment that will improve safety along isolated stretches of road that are prone to hazardous weather conditions.
? Integrated road, traffic, transit, weather, and value-added traveler services that will improve real-time access to information on travel conditions by travelers thereby reducing delays.

2.3.9 Crash Reduction Benefits of ARTS

Rural applications that reduce crashes are either information systems (warning systems) or vehicle control systems (collision avoidance systems). Rural information systems inform travelers of potential hazards, which may pose a crash threat. Vehicle control systems are intended to reduce the probability of crashes. Crashes, such as those in roadway departures, are more prevalent in rural areas and are particular targets for rural applications of advanced vehicle control systems.

Collision warning devices and blind spot detectors are becoming available as commercial products. For example, Transport Besner Trucking Co. has installed an Eaton-Vorad collision warning device on 100% of its 170-truck fleet. Internal studies found that the combination of the device with a safety training program has reduced accidents by 33%. The Greyhound accident experience using an earlier model product yielded a reduction of 20% in a deployment equipping half of the fleet, which could extrapolate to a 40% reduction in accidents for full equipage [19].

Landstar Systems installed the Eaton-Vorad system on 40% of its owned fleet. Positive evaluation of the device by experienced drivers in a pilot test and the potential to decrease self-insurance losses lead to the decision to equip. Thirteen months later to the installation of the system in January of 1995, it was reported that no equipped power units have been involved in a rear-end collision.

The safety potential for other advanced traffic information system that warns commercial vehicles and other heavy vehicles of a potentially dangerous highway situation was being tested. The Dynamic Truck Speed Warning System for Long Downgrades has been installed in the Eisenhower Tunnel on I-70 west of Denver. This system warns drivers of safe truck speed at the start of the downgrade for normal operations based on truck weight.. Prior to the project, the state studied accident characteristics and discovered that 88% of the runaway trucks were out-of-state and that they entered runaway truck ramps at speeds of up to 110 mph. The system began operating during 1995. Observers report that trucks being instructed to slow frequently apply their brakes immediately.

Automated Highway System (AI-IS) related products can have safety benefits prior to full implementation of AHS segments. Based on data from Minnesota, 60% of rural freeway accidents are susceptible to reduction using lane keeping and collision avoidance technologies. These types of collisions include run-off-the-road, accounting for 34% of accidents, and animal hits. A reduction of 40% in these accidents could account for an annual reduction of 19,000 accidents including 190 fatal accidents nationally accounting for an estimated cost savings of $225 million [20].

Finally, a group has been convened by NHTSA to examine the expected benefits of collision avoidance systems. This working group examined the number of crashes that could be avoided using in- vehicle devices to aid in avoiding lane change/merge, rear end, and single-vehicle roadway departure crashes. Based on the best experimental data available, use of these devices could avoid a total of 1.1 million crashes annually [21].

2.3.10 Fatality Reduction Benefits of ARTS

In addition to the avoidance of difficult driving situations, rural transportation systems can reduce the consequences of crashes by means of emergency notification systems. Commercial systems are available that couple mobile telephone technology with satellite navigation.

According to analysis based on data from the Fatal Accident Reporting System, reduction of incident notification times on rural highways from the current average of 9.6 minutes to 4.4 minutes, corresponding to mayday devices working properly in 60% of rural crashes, would result in a reduction in fatalities of 7% annually, or a national total of 1727 [22].

2.4 Section IV: Crash Avoidance And Warning Systems

2.4.1 Introduction

One way that researchers frame the highway safety problem is to separate motor vehicle crashes into their pre- and post-crash phases. "**Crash avoidance**" is the term often used to describe improvements in vehicles, highway environments, and driver performance that can reduce the probability that a crash will occur. "Crash protection" and "**crashworthiness**" are terms that refer to improvements in vehicles and the highway environment that can reduce the severity of crashes—for instance, by protecting the vehicle's occupants and reducing the impact forces of the collision [23].

Crash (or collision) avoidance systems is one of the tools designed to help drivers better detect and quickly respond to impending collisions. Such countermeasures may include advanced technologies to alert drivers of impending collisions as well as enhancements to conventional systems, such as brakes, mirrors and lights.

Improvements in crash avoidance have proved far more difficult to attain, largely because the probability of a crash is affected by an array of complex and interacting factors involving the drivers, vehicles, and the highway environment. The human factor—the driver—is particularly important. Driver error and poor performance, caused by factors ranging from momentary distractions to driving rules intentional violations, are the main contributory causes of most highway crashes. Therefore, the development of such systems requires multi-discipline expertise and involvement of human factors engineers and psychologists in conjunction with mechanical engineers, and electrical engineers to plan, manage and conduct research to better understand vehicle technologies, driver performance, and driver behavior.

2.4.2 ITS and Degree of Automation

ITS encompasses several advanced driving features and concepts, ranging from obstacle detection and warning systems that are possible precursors of **partially automated** driving systems to **fully automated vehicles** traveling on instrumented highways.

Some automation features already are in use or in advanced stages of development, whereas others remain conceptual. Computer-aided antilock braking systems, an automated feature, have been in widespread use for several years. **Collision warning devices**, such as blind-spot detectors, have found niche applications in some commercial fleets. **Adaptive cruise control systems**, which include radar braking, may be introduced abroad within the next few years. It is worth noting here that when the term **"automation**" applies is a matter of debate because different advanced features offer not only different degrees of automation but different kinds. For instance, collision-warning systems may not automate vehicle controls but they do automate driver information acquisition [23].

2.4.3 Countermeasures Automation and Crash time-Intensity

To better understand the relationship between crash countermeasures type and the degree of automation (which reflects the degree of control), we may devise crash countermeasure concepts based on crash time-intensity curve as shown in figure 2-4 [24].

The first applicable countermeasure is to prevent the start of the hazardous maneuver by the use of a ***presence indicator.*** For proximity crash avoidance, for instance, such system might continuously sense other vehicles and provide an information display (visual, auditory, other) when a vehicle is present in an adjacent lane. Detection coverage over the full length of the Subject Vehicle (SV), on both sides, is needed since many proximity crashes involve vehicles outside the SV blind zone (i.e., side-by-side and rearward overlap cases). A design challenge of a presence indicator is to inform drivers of critical information at critical times in order to prevent the system from becoming a nuisance or an in-vehicle distraction source.

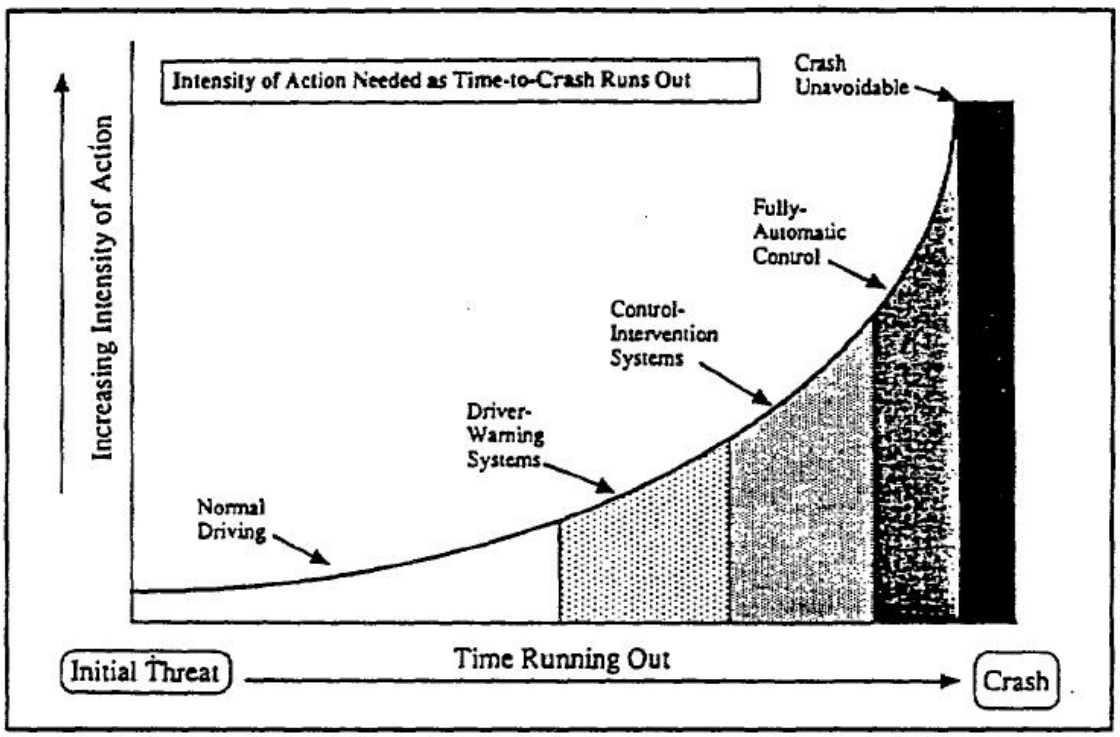

Figure 2-4: Time-Intensity Graph of Pre-Crash Avoidance Requirement

The second applicable countermeasure is a ***driver warning*** system. This would only be activated if a collision was imminent but with **enough time** that driver intervention alone is feasible for crash avoidance. Vehicle performance and IVHS system lags consume some of the available time to respond. In addition, a warning system implies some threshold condition for alarm.

Control-intervention systems are the third type of countermeasure concepts. This is an alternative (or possibly a supplement) to a collision warning system and would be activated beyond the point where driver warning alone is likely to be effective. In the event of a false alarm, the driver should be able to easily disengage the partial automatic controls.

Finally, *fully* ***automatic control*** systems are applicable if the time available to avoid a crash dictates that driver time delays must be near zero.

2.4.4 Warning Systems

For several years, the National Highway Traffic Safety Administration has sought to reduce highway accidents through effective and practical **in-vehicle** electronic driver aids and warning systems. Some innovations could monitor the driver's physiological condition, improve the driver's effective vision or otherwise alert the operator to potential hazards. However, other **highway-based** warning systems concepts have been tested and evaluated in many applications.

Actually the dramatic advances in sensing devices and computational power now offer a real possibility to develop in-vehicle and highway-based systems that can alert drivers to hazardous situations and impending collisions. In some other cases in-vehicle systems could even take temporary control of the vehicle to avoid a collision.

2.4.5 Highway-Based Collision Warning Systems Deployment Concepts

This section provides a brief description of some different deployment concepts [25]:

2.4.5.1 Friction/ice detection and warning systems

This system should consist of a sensor system to detect the condition of the pavement surface and an active warning sign to provide a speed advisory. The sensor system should be implemented so that it measures the condition of the roadway surface at the point where the vehicle is most likely to drive. A simple processor can then use the information about the condition of the pavement in combination with the known curvature, gradient, and dry-pavement friction coefficient to calculate an advisory speed. This speed would then be displayed on the active warning sign. It may also be necessary to have a separate speed advisory for trucks. The normal difference in speed limits between cars and trucks is 10 mph.

Another possible implementation of a friction /ice detection and warning system would be to include some type of vehicle speed detector. Then, after the system makes an estimation of what the safe speed should be, it can choose whether or not to illuminate a sign saying "SLOW

DOWN" based on the oncoming vehicle's speed. This would make it necessary to have a detector which measures speed, and thus adds to the complexity. However, radar sensors can detect both presence and speed, so it is possible that one radar could be used for both. Figure 2-5 [26] illustrates the deployment concept.

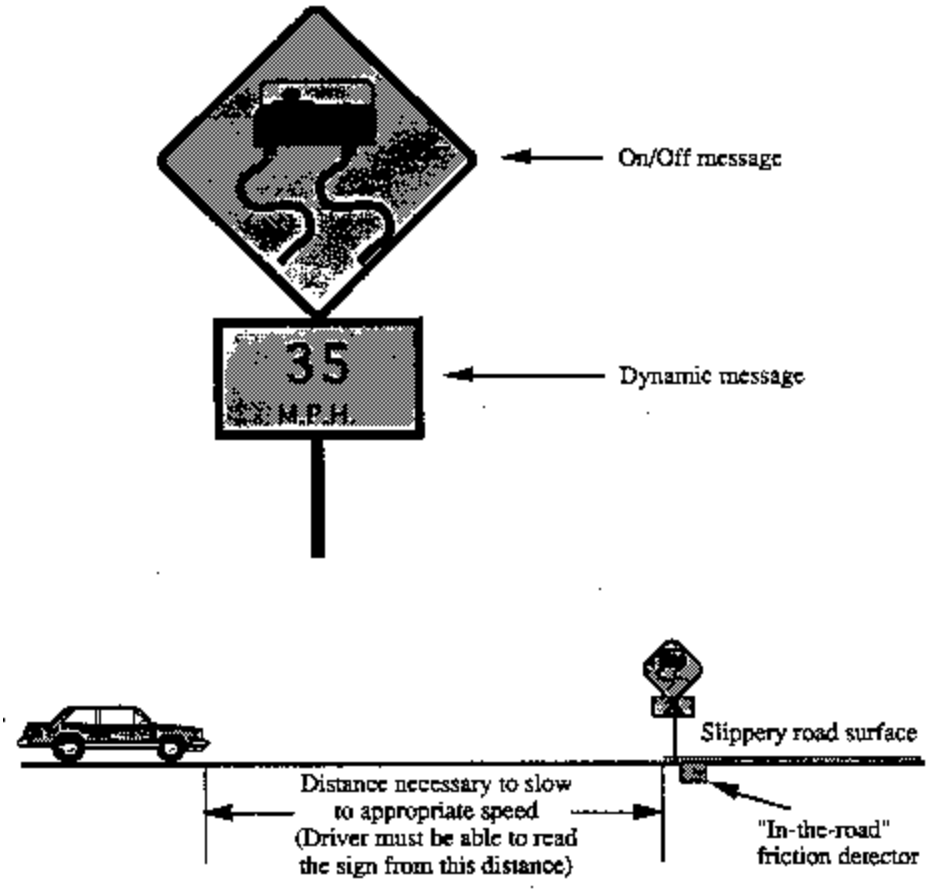

Figure 2-5: Road layout with an in-the-road friction detector

The major equipment for use in this countermeasure system is: pavement sensors to cover as much of the pavement as possible and an active warning sign. This assumes that the system has access to a complete weather information system of which the pavement sensors are only a small part. The following is a summary of the potential friction/ice detection systems:

2.4.5.2 Cooperative warning of the presence of oncoming vehicles on curves

A collision countermeasure system of this type is currently in operation in Japan. It has undergone extensive testing on a test track and has now been installed in actual portions of the highway. The name of the system is Guidelight. One of the Guidelight systems consists of a series of lights around the curve and an ultrasonic detector on each end of the curve. When a vehicle is detected, the lights are activated ahead of the vehicle at a rate dependent on the speed of the vehicle. The lights warn the driver of another vehicle entering the curve from the opposite direction that there is an oncoming vehicle. The ISO standard being developed for "cooperative warning of the presence of oncoming vehicles on curves" is based upon the Guidelight system, so Guidelight may become the standard collision countermeasure system for this type of warning [25]. Figure 2-6 shows an example of the Guidelight system [26].

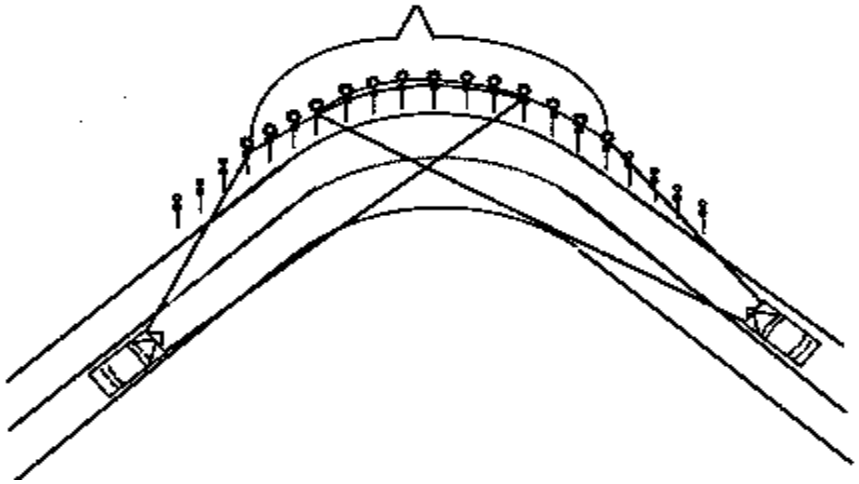

Figure 2-6: Schematic for Guidelight system on curves

Another possible collision countermeasure system proposed [26] would consist of a pair of warning signs which would be activated as soon as a vehicle enters the curve in order to warn vehicles traveling in the opposite direction. A possible active warning sign would have two flashing lights on top and depict a two-way traffic road (assuming there are only two lanes) with a car in the oncoming lane. Both the flashing lights and the representation of the car will flash

when the sign is activated. Figure 2-7 illustrates the deployment concept, and Figure 2-8 shows a possible active warning sign.

Minimum Sight distance (2 stopping sight distances)

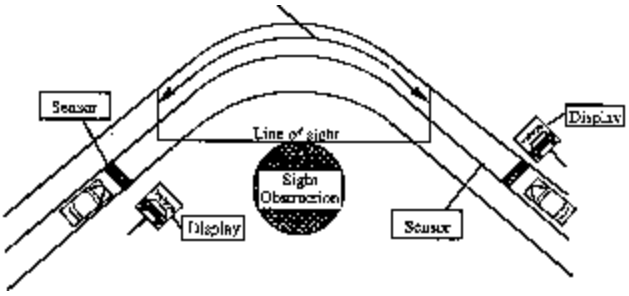

Figure2-7: Limited Sight Curve With a Single Sensor-Sign Pair

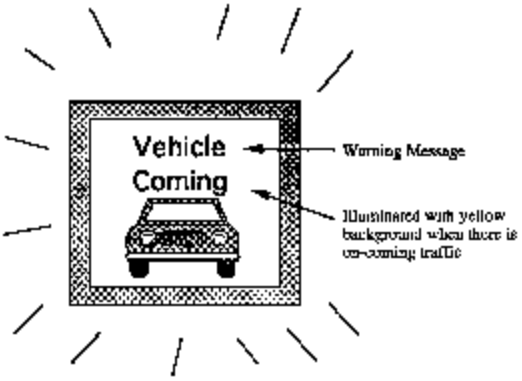

Figure2-8: Warning sign on a limited sight curve

The major equipment for this countermeasure system is: vehicle detectors and a series of lights if using the Guidelight system or at least 2 warning signs if using the system described above. The following are possible deployment concepts:

1. In the simplest system, there should be at least 2 sensors and 2 signs. The two sensors are used to detect a vehicle entering the curve, and the active warning signs are placed inside the curve. This prevents the case of both cars entering at the same time and then passing the signs before they are activated.
2. Another option is to have four warning signs, two at the entrances to the curve and two along the curve. One set of signs should be set a good distance ahead of the curve on either side, in

order to give the drivers enough advance warning that another car has entered the curve in the oncoming lane. The other set of signs should be set right within the curve so that cars that have passed the advance warning sign will still be notified if another car has just entered the curve.

2.4.5.3 Driver warning on a minor road in the presence of vehicles on a major road

This system is designed to enhance the driver's ability to assess the safety of entering an intersection on a major road from a minor road. There would need to be an active warning sign for the drivers on the minor road, and detectors to detect vehicles on the major road. A system of this type has already been implemented in Japan as part of the Guidelight program.
A basic system would have two active warning signs, one on each approach to the major road. The signs should indicate not only that a car is approaching on the major road, but also from which direction.

There will also need to be as many detectors as there are lanes on the major road, and they will need to be a sufficient distance away such that the warning can be given in an adequate amount of time. The signs should be visible to the car on the minor road until he actually makes the turn. Thus, if it is in the position of most stop signs, it may not be visible as the vehicle prepares to make a turn, so there is the possibility that a vehicle appears right after the driver has moved passed the sign. In Japan, in a "T" intersection, they have placed the sign across the road, so there is no possibility of not being able to see it because of preparation for a turn. That may well be the optimum placement.

The major equipment needed for this countermeasure system is: vehicle detectors for every lane on the major highway and at least one active warning sign. Figure 2-9 provides a detailed illustration of this deployment concept [26].

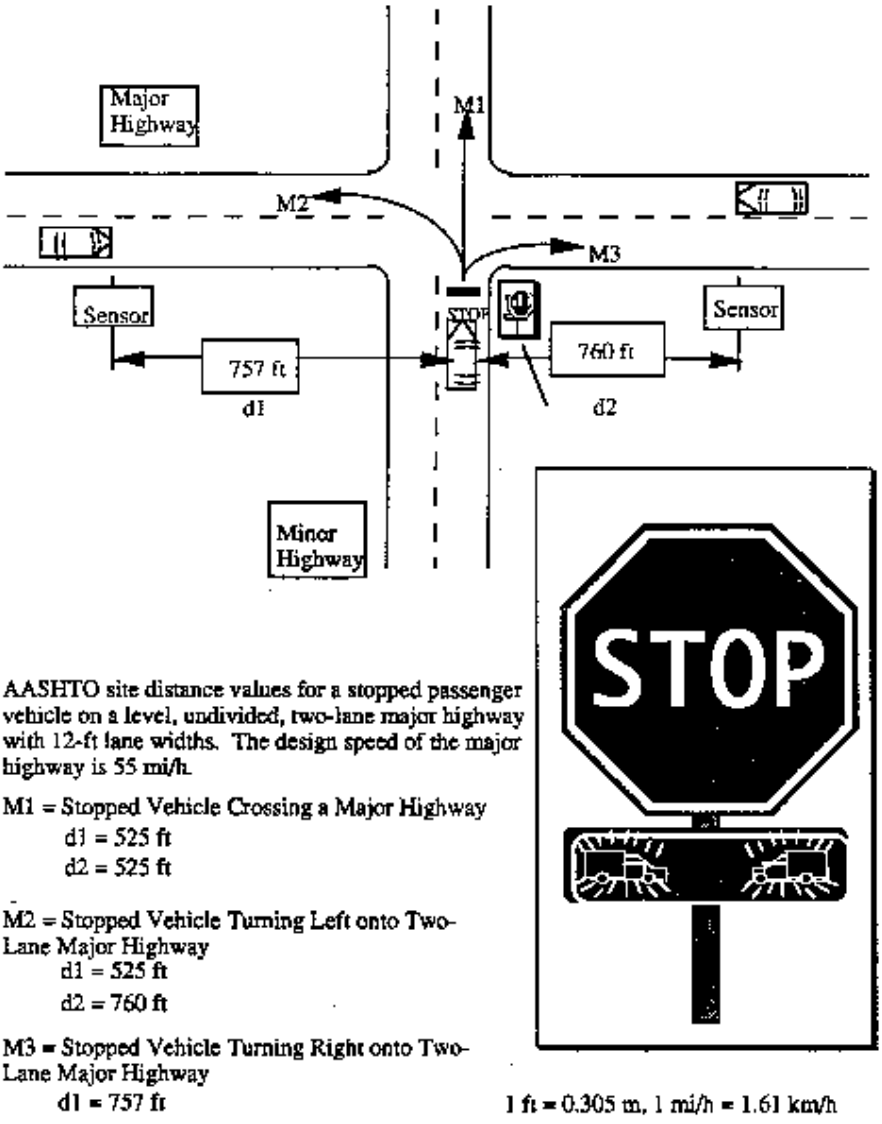

Figure2-9: Warning on a minor road of the presence of vehicles on a major road

2.4.5.4 Driver warning on a major road in the presence of vehicles on a minor road

This implementation will be similar to that for the previous collision countermeasure system except that it is the vehicles on the major road that will be warned. The detectors will need to be placed on the minor road sufficiently far back to provide adequate warning to the driver on the major road. If there is a stop sign at the intersection on the minor road, then a detector could probably be placed in the intersection and right before the stop sign. If there is only a yield sign,

it may be appropriate to place the vehicle detector farther back along the minor road. The sensors in the middle of the intersection should remain in either case.

The detectors will provide information as to whether there is a vehicle on any of the minor roads, and whether or not there is a vehicle in the middle of the intersection. The detector in the middle of the intersection needs to discriminate between cars crossing the intersection from the side road and cars crossing with the flow of traffic. A variety of sensor configurations can accomplish this. One radar sensor can detect directionality, and two piezoelectric sensors could also determine directionality. A smart controller would combine the information from all of the detectors to determine where the vehicle that has entered the intersection has come from. The major equipment needed for this countermeasure is: vehicle detectors to detect the vehicles on the side roads and in the intersection, and at least 2 warning signs. Figure 2-10 illustrates the deployment concept [26].

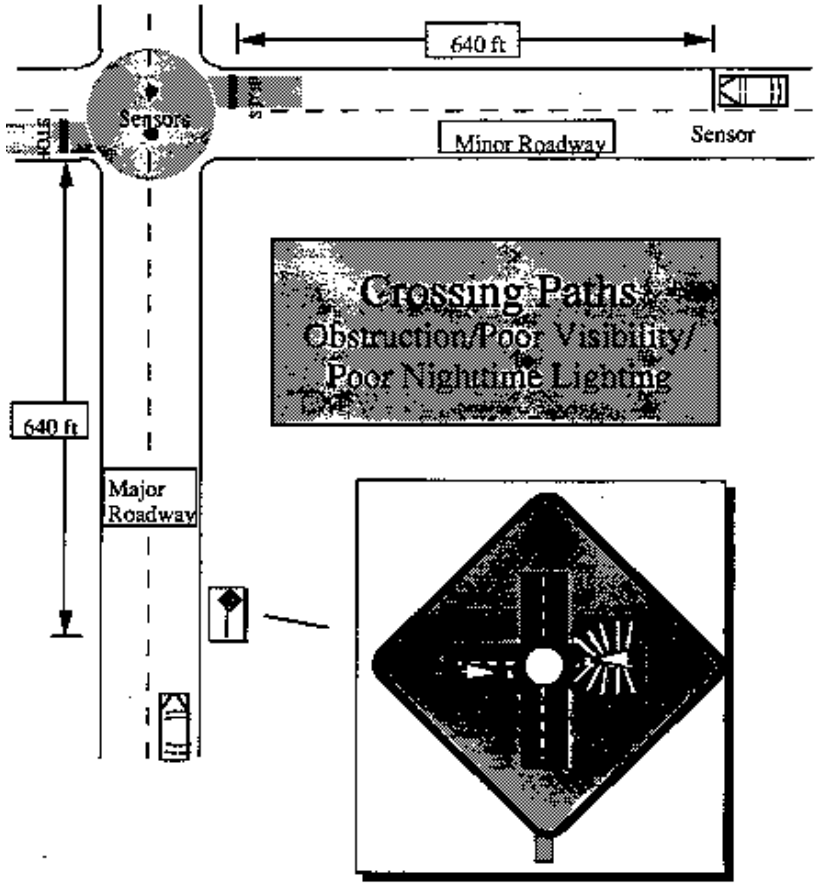

Figure2-10: Warning on a major road of the presence of vehicles on a minor road

2.4.5.5 Approaching vehicle warning for drivers making a left-hand turn and warning of vehicles turning left ahead

This system needs to perform multiple functions. First, it must identify that a vehicle is slowing down to make a left turn. It then needs to determine whether or not there is enough time to make the left turn based on the speed and location of oncoming traffic, and to activate an active warning sign appropriately.

The system must also activate a warning sign for vehicles following the driver making the left turn. An additional option is to have another sign to warn the oncoming traffic that a vehicle is making a left turn ahead. Sensors are needed to detect the acceleration of the vehicle that will be making the left turn, to detect the vehicle if it is still waiting to make a left turn, and to detect vehicles in the oncoming traffic lanes.

The most challenging aspect of this concept is to detect that a vehicle is slowing to turn left. Doppler radars can measure the range rate directly, whereas inductive loop detectors and spread-spectrum wideband sensors need to take multiple measurements and integrate them.

In an example multiple detector system for detecting the acceleration of a vehicle, a central controller would observe the timing between successive activations of the detectors. When the spacing increases above a certain threshold and indicates a predetermined amount of deceleration, the controller activates the left-turn ahead warning signal. The left-turn ahead signal will stay activated for a preset amount of time before turning off. If a speed threshold is used instead of an acceleration detector, the central controller should use memory of the most recent average speed so that the current speed can be checked against that. This would allow the system to adjust to changes in the flow of traffic. Figure 2-11 contains a schematic of a possible implementation of this deployment concept [26].

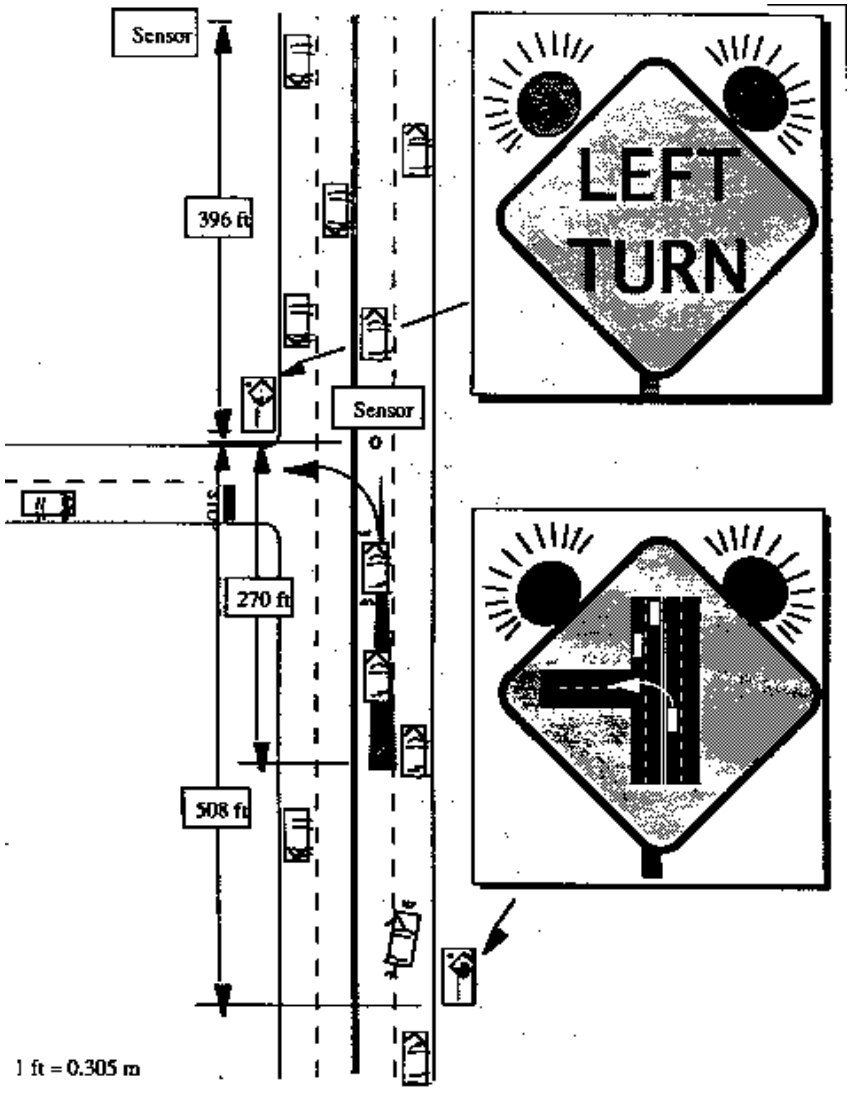

Figure 2-11: Approaching vehicle warning for driver making a left-hand turn and warning of vehicle turning left ahead

The major equipment needed for this collision countermeasure system is: vehicle detectors to calculate acceleration and presence of vehicle waiting to turn left, vehicle detectors for the traffic in the oncoming lanes, one controller, and four active warning signs.

The following are three potential implementations of this collision countermeasure system:

1. A series of sensors can be set up to measure the acceleration of the vehicle. If it is decelerating at a rate greater than some threshold, then the left turn-ahead sign can be activated. In addition, there should be another sensor in the area where the vehicle would be turning left. If

the sensor detects a stationary vehicle in this area, then it will also activate the left-turn ahead warning sign.

2. If congestion reaches high levels, then determining whether or not a car is slowing due to congestion or to make a left turn is more complicated. In this case, a sensor to detect slowing and a sensor to detect a stationary vehicle in the left turn position can be installed. The sensor, which triggers based on a deceleration level, can be deactivated in cases of heavy congestion, and so can the sensor which triggers on a stationary vehicle.

3. If there is a stop light ahead of the left turn area, the same setup that is in example 1 can be used, but the information about the phase of the stop light should be used when deciding whether or not a car is decelerating to make a left turn.

2.4.5.6 Weather Conditions Warning System

Some of these highway-based warning systems like Idaho storm warning system (SWS) has been installed and tested on I - 84 aiming at identifying low visibility events due to blowing dust/snow, and conveying this information to motorists via Variable message signs located throughout the highway. Real-time visibility / weather information is collected by sensing systems such as SCAN, HANDAR or LIDAR systems comprising visibility sensors (visible light and infrared light) and weather measurement sensors (wind speed and direction, air temperature, relative humidity and type and amount of precipitation). Figure 2-12 depicts the system algorithm [27].

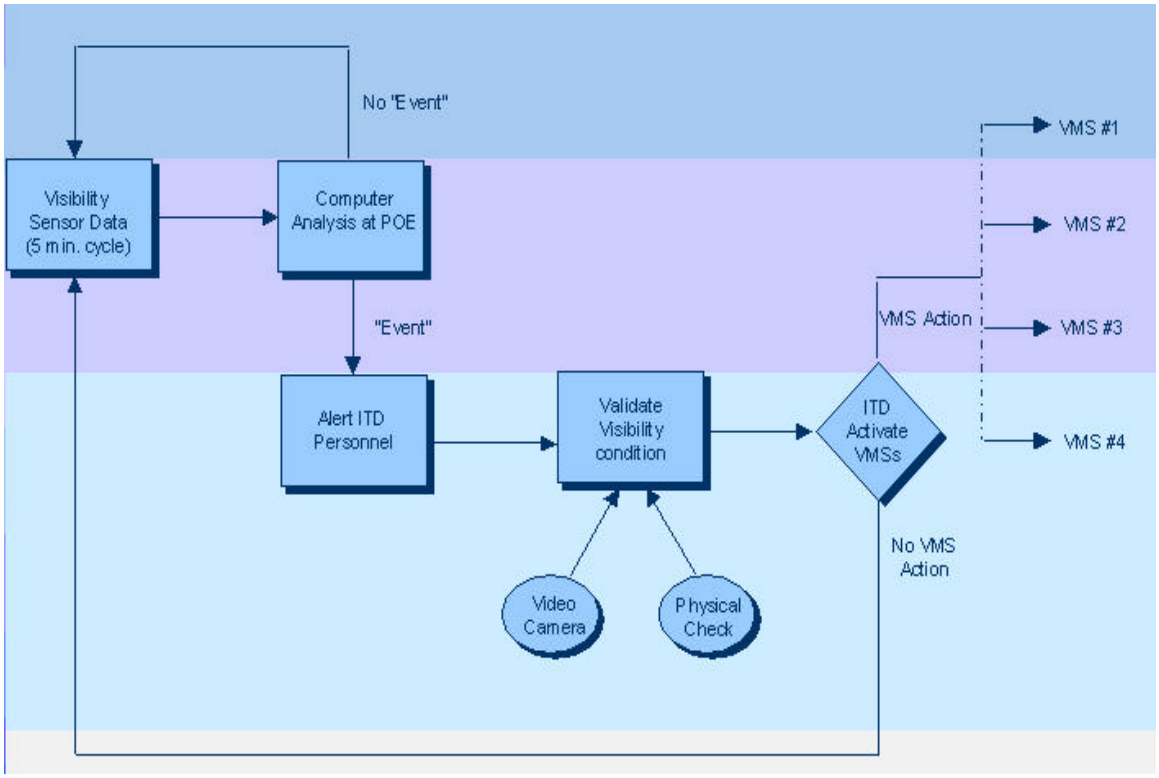

Figure2-12: Idaho Low visibility warning system function

2.5 Section V: In-Vehicle Collision Warning Systems

2.5.1 Introduction

Under the leadership of NHTSA, the National Automated Highway System Consortium (NAHSC), and the automotive industry, improved in-vehicle control devices are being developed for a variety of crash types such as rear-end, roadway departure, and intersection crashes, among others. This suggests that in-vehicle crash warning systems directed toward alleviating these various crashes could be of benefit for other crashes causes such as reduced visibility conditions, drowsiness or inattention of drivers as well.

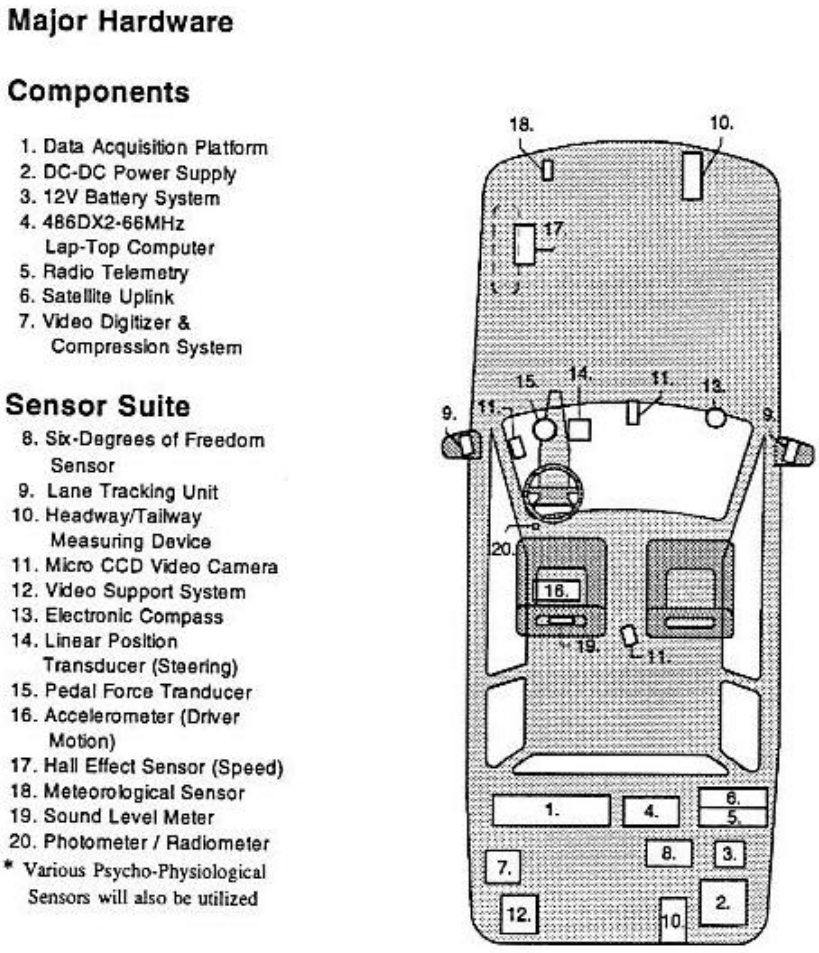

Figure 2-13: Portable Driver Performance Data Acquisition System for CAS Research (DASCAR)

Actually, the development of crash countermeasures requires innovative research tools and analytical techniques which are vital to understand, document, and evaluate vehicle-driver performance associated with different traffic, roadway and weather conditions. One of these tools is DASCAR, a portable instrumentation package and a set of analytical methods / tools which allow to collect real-world driver-vehicle performance data (figure 2-13) [28].

2.5.2 Hazard Scenarios

The ITS collision avoidance program is problem driven. Therefore, CASs requirement and the driver 's role in the various collision avoidance opportunities is determined by the "hazards scenarios". Actually hazard scenarios and their relative importance have been determined based on analysis of various accident databases. Figure 2-14 shows the distribution of the major crashes type. The three of the major safety problems are **rear-end**, **road departure** and **intersection collisions** that comprise nearly three fourths of all crashes in approximately equal proportions [28]. These crash types and others are the subject of research to understand system capability needed and driver role for effective collision avoidance support to drivers.

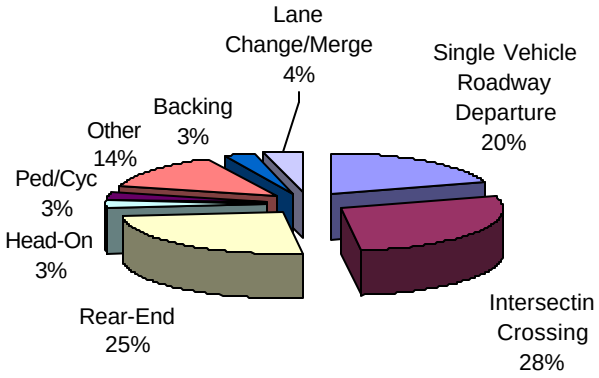

Figure 2-14: Distribution of Major Crashes types

- For rear-end crash avoidance, candidate systems include forward-looking radar or laser systems that present an in-vehicle warning if the driver is approaching a lead vehicle too closely.
- For roadway departure/drift-out-of-lane crash avoidance, laser-based lane sensors and machine vision systems could present a warning to the driver when the vehicle is leaving the lane.
- For intersection crash avoidance, vehicle-to-roadway communication or vehicle-to-vehicle communication systems may be appropriate.

Anyway, several in-vehicle warning and collision avoidance systems, including the above, are the subject of extensive research and development program led by NHTSA. That will be illustrated in details during the course of the following sections.

2.5.3 The Role of Driver In the CAS

The driver interface to crash warning systems may be auditory, visual, or tactile in nature. Visual displays typically consist of alphanumerics, symbols, colored lights, or icons (e.g., outline of a vehicle). Auditory displays are typically beeps that may be coded by pitch, intensity, duration, or waveform to convey information to the driver. Speech warnings are also a possibility. Tactile displays may provide warnings or cautions to the driver by forces provided from the system to the driver via the steering wheel or pedals. Note that none of these displays convey optical information about the driving situation. In this way, these systems do not help the driver "see" the hazard. Nevertheless, they may be useful for reduced visibility crash avoidance [29].
In general we must deal with the integration of the driver into CAS, defining his/her role relative to the system and specifying the human/machine interface to achieve performance goals. With CASs the driver's perception can be significantly augmented, and the issues become how to advise, alert and warn the driver of potential hazards in a manner consistent with obtaining appropriate driver response, and without causing undue annoyance, frustration or disregard. Figure 2-15 illustrates the general elements of a CAS and their interrelationship with the vehicle and driver [30].

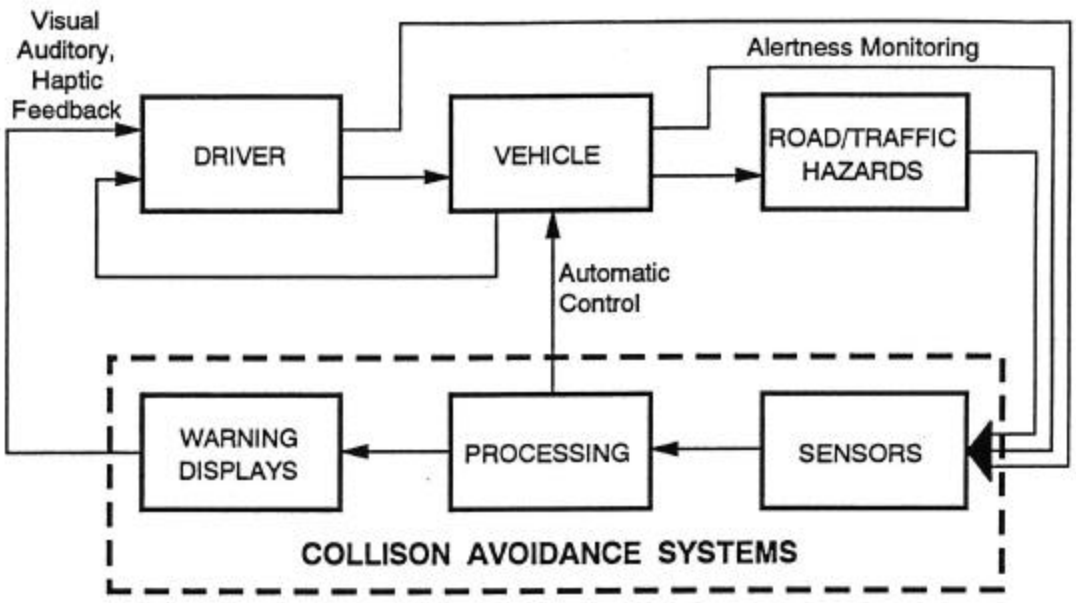

Figure2-15: Driver/Vehicle Interaction with CASs

Sensors provide data on potential accident conditions and processing cleans up and integrates the raw data of sensors (radar, video image, sonar, IR or laser) and optimizes the sensitivity of the incident detection and recognition process. Processing also provides commands to driver displays presented in visual, auditory and haptic (tactile or kinesthetic) formats.

The sensitivity of display feedback to potential accident conditions will be a key issue in system design. Processing sensitivity will interact with the rate of false alarm (artifact), and determine the conditions under which feedback is given to driver. The system could be designed to give the driver frequent feedback and generally extend his/her situational awareness (e.g., the presence of vehicles in the blind spot). At the other extreme, the system could be restricted to alarm warnings of high probability accidents (e.g., rapidly decreasing headway, incipient road departure). Issues here concern the nature of the display feedback, and whether it is intended to provide a general expansion of the driver's perception versus providing warning alarms of specific scenarios [30].

2.5.4 Federal Program

NHTSA established advanced collision avoidance and vehicle safety systems program that seeks to deepen understanding of the causes of collisions, identify and evaluate potential solutions, and work in partnership with industry to facilitate the development and deployment of effective collision avoidance products. This approach translates into a five-prong program:

(1) Research Tools and Knowledge Base;

(2) Identify Promising Crash Avoidance Opportunities;

(3) Demonstrate Proof-of-Concept;

(4) Facilitating Commercial Development;

(5) Accessing the Safety of Other ITS Systems.

Table 2-15 illustrates the detailed descriptions of each of these areas [31].

In addition, the program's research efforts (administered by NHTSA) are focused on:

(1) Collision avoidance systems;

(2) Automatic collision notification systems;

(3) Vision enhancement systems;

(4) Driver performance monitoring systems; and

(5) Research tools and knowledge base.

NHTSA crash avoidance research aims to develop a broad understanding of how advanced technology can be used to help avoid collisions. Consequently, the core research area is collision countermeasure systems and related systems to help enhance driver performance. To support analyses, development, testing and evaluation of these systems, NHTSA is developing a suite of research tools, including simulators, test vehicles, and data acquisition resources.

The objective of each research area is to help advance the capabilities, user acceptance, and benefits of collision avoidance systems. Capability refers to the technical performance of the systems and its components -- sensors, processors, and driver interface or controls. User acceptance addresses the interaction with the driver, including ease of use, desirability of the system, effects on driver performance, and affordability. The primary benefits are reductions in the number of collisions and their associated injuries and costs.

Table 2-15: Advanced Vehicle Collision Safety System: Five-Prong Program

Program Prong	Program Scope
Prong 1: Research Tools and Knowledge Base	The design of ITS crash avoidance systems requires a greatly enhanced and detailed understanding of how individuals drive and the characteristics and causes of accidents. As a result, NHTSA has developed a crash avoidance knowledge database of the major causes of crashes and pre-crash factors from real-world cases. In addition, NHTSA has created a portable on-board vehicle data gathering system -- the Data Acquisition System for Crash Avoidance (DASCAR) -- that can monitor and record vehicle performance and the driver's physical reactions.
Prong 2: Identify Promising Crash Avoidance Opportunities	Using its knowledge database, NHTSA has determined the factors that precede specific types of accidents. This understanding is being used to develop performance specifications for collision avoidance systems and to determine the benefits of deployed collision avoidance countermeasures.
Prong 3: Demonstrate Proof-of-Concept	A key program role is to demonstrate that advanced technology can practicably enhance the crash avoidance performance of motor vehicles. NHTSA's program includes the development of performance guidelines for crash avoidance technologies and field testing of prototypes This work builds upon the statistical and casual hardware and human factors needed to ensure that crash avoidance systems are safe and perform as required. The program has developed preliminary performance standards required for rear-end, road-departure, and land change/merge collision avoidance systems. In addition, the program has begun four operational field tests of intelligent cruise control and automated collision notification systems.
Prong 4: Facilitating Commercial Development	The ultimate objective of the crash avoidance program is to help the industry develop safe and effective products. Six cooperative agreements are now in place with industry for development and testing of systems addressing crash avoidance, applications to heavy commercial vehicles, lane-occupancy detection, and intelligent cruise control.
Prong 5: Accessing the Safety of Other ITS Systems	Other in-vehicle advanced transportation systems -- such as in-vehicle en-route guidance and information systems -- are coming on the market. NHTSA, working cooperatively with FHWA, is evaluating these systems to ensure that they are safe and do not distract the driver or overload the driver with information.

2.5.5 Collision Countermeasures Systems [32]

NHTSA is developing performance specifications for systems that could assist drivers in avoiding collisions. These performance specifications are technology-independent functional guidelines that define the relationship between specific safety problem areas, countermeasure performance requirements, and safety benefits. They provide the basis for conducting countermeasure design, prototyping, and test and evaluation activities.

2.5.5.1 Rear-End Collision Avoidance Program Area

Rear-end collision warning and control is considered a sub-service of the longitudinal collision avoidance service. These systems are primarily located on- vehicle, but could also be enhanced by equipment in the roadside or other vehicles, to prevent or decrease the severity of rear-end crashes.

These systems would, through driver notification and vehicle control, help avoid collisions with the rear-end of either a stationary or moving vehicle. These collisions are often associated with too short a headway with the vehicle in front. The driver maintains full longitudinal control of the vehicle until a dangerous condition, such as a stationary vehicle on the roadway ahead, is detected. Then the driver is warned, and if the driver does nothing, appropriate vehicle control actions to avoid the danger could be taken automatically.

There are three general categories of rear-end collision warning and control systems [33]:

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

So far, NHTSA project has developed performance requirements (both hardware and human factors) for advanced technologies to prevent or decrease the severity of rear-end crashes.

This involves the identification of requirements for major system components (or subsystems) such as candidate sensor, processor, driver warning/interface, and control elements. This project is oriented toward countermeasure systems that would be self-contained within the vehicle, although it does not exclude from consideration those countermeasures that may require, or be improved by auxiliary equipment installed on the roadside or in other vehicles. Limited capability systems involving intelligent cruise control capabilities are currently being tested in operational tests, and are expected to lead to validation/update of system performance specifications. Additional field and operational tests will be planned to test and evaluate full-capability rear-end CA systems [32].

2.5.5.2 Intersection Collision Avoidance Program Area

These systems are aimed at avoiding collisions at intersections and could be a combination of in-vehicle systems, infrastructure-based, or hybrid vehicle/infrastructure systems. It is a system that tracks the position and speed of vehicles within a defined area around an intersection and alerts vehicles when they are on a collision path. Sensors in the intersection will track the vehicles, processors with associated algorithms will compute the trajectories, and a communications system (beacon for example) will communicate with the vehicles. This application will provide drivers with the information necessary to take evasive action to avoid collisions [34].

This project has completed a thorough analysis of intersection collision problem size and causal factor analysis. Based upon the results of the causal analysis activity, simulation routines were utilized to evaluate the effectiveness of conceptual collision avoidance systems. Both in-vehicle systems, infrastructure-based systems, and hybrid vehicle/infrastructure systems are being studied. Performance requirements for system components have been examined and a preliminary set of performance specifications have been produced. Further efforts will involve the development of intersection CA system test bed and the refinement of system specification, prior to development of prototype systems for test and evaluation [32].

2.5.5.3 Road Departure Collision Avoidance Program Area

Sensor technologies could detect roadway or lane boundaries to keep vehicles from straying off the road .The systems alert the driver of the need for corrective actions.

This project has developed performance specifications for road departure countermeasure systems. In addition the project will develop two prototype systems and a testbed vehicle for system test and evaluation. Sensor technologies to support detection of roadway or lane boundaries are being examined while investigating potential approaches for prediction of imminent road departure.

2.5.5.4 Lane Change/Merge Collision Avoidance Program Area

These systems assist drivers in safely carrying out lane change, merging, and back maneuvers. This project is investigating the feasibility of equipping motor vehicles with countermeasure systems to assist drivers in safely carrying out lane change, merging, and backing maneuvers. The study considers the effectiveness, reliability, costs, and implementation practicability of such systems. Preliminary performance specifications as well as methodologies for estimating benefits of potential countermeasure systems have been developed.

2.5.5.5 Drowsy Driver Monitor Program Area

The initial focus of this program area is on the commercial trucking segment for four key reasons; the extensive night driving in commercial operations, the need to minimize fatigue-related accidents among paid drivers, the high cost of commercial vehicle accidents, and the relative affordability of such systems for high-value heavy trucks. Systems currently under consideration rely on sensing of two features of driver performance. One feature is lane tracking maintenance, i.e., how well the vehicle stays within lane demarcations. The other is eye and eyelid movements. Additional indicators of driver performance include steering wheel motions, head movement, and lateral acceleration. Figure 2-16 illustrates the schematic of in-vehicle drowsy driver warning system [28].

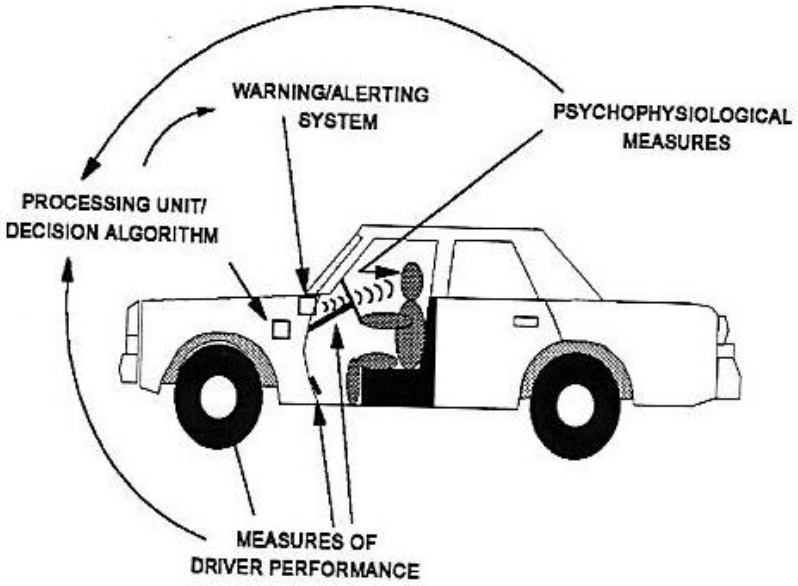

Figure 2-16: Vehicle-Based Drowsy Warning System Schematic

Technology may be able to provide earlier or more robust warnings of degraded driving status so as to preclude a drowsy driving-related crash. Drowsy driver detection algorithms and approaches have been a topic of considerable research in recent years. A key ingredient in the development of such algorithms is selection of an appropriate "criterion" measure for drowsiness. Of particular interest is the drowsy driver research program completed by Wierwille and his associates for NHTSA. This research focused on the development of a vehicle-based driver drowsiness detection system. This is a system of continuous, unobtrusive measurements of driving performance (e.g., steering wheel inputs, lanekeeping performance) and an algorithm to classify a driver as "drowsy" or "not drowsy". Such a detection system would eventually be integrated into a driver-system interface to present warning signals to the driver and possibly countermeasures to drowsiness as well (e.g., cool air, mint scent, seat shaker). During the course of research into drowsy driver detection algorithms, Wierwille and his associates conducted extensive studies in the driving simulator located at the Vehicle Analysis and Simulation Laboratory at the Virginia Polytechnic Institute and State University [35].

2.5.5.6 Driver Vision Enhancement Program Area

These motor vehicle-based systems could help drivers avoid collisions with other vehicles, pedestrians, and other objects on the road due to reduced visibility conditions (e.g., at night and during inclement weather).

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. Table 2-16 shows some of the possible reduced visibility crashes countermeasures [36].

Table 2-16: Possible Countermeasures for reduced Visibility Crashes

Category	Examples	General Characteristics
In-Vehicle Warning Systems	Headway detection systems, near object detection systems, lane position monitors.	Require sensors, processors, and driver display (but NOT an image of road scene). Provide overt alerts or warnings.
Roadway Information Systems	Variable Message Signs (VMS); Rumble Strips.	Do not require electronic sensors, in-vehicle processors, or displays. VMS provides information; rumble strips provide overt warning.
Direct Vision Enhancement Systems (DVES)	Improved Taillights; Ultraviolet Headlights; Polarized Headlights.	Do not require a detector, processor, or display. Driver's direct perception is enhanced. Do not provide overt warning.
imaging Vision Enhancement Systems (IVES)	Charge-Coupled Device (CCD) Cameras; Passive Far-infrared imaging; Active Millimeter-Wave Radar Imaging; Passive Millimeter-wave Imaging.	Do require sensor or detector, illumination (for active systems), processor, and in-vehicle video display or head-up display (HUD) that presents an image of the road scene. Do not provide overt warning signals.

The focus of this program is vehicle-based systems. Prototypes of driver vision enhancement systems exist and are currently being used to support a wide range of engineering tests and product development activities. Fundamental questions about the causal relationship between visibility and safety have not yet been answered. Moreover, key performance requirements and user acceptability of in-vehicle vision enhancement systems are not yet understood.

Heavy Vehicle Research [32]

These systems embrace a number of objectives, including a drowsy driver monitor, stabilizing heavy vehicles, collision warning, and improved braking performance.

2.5.5.7 Heavy Vehicle Stability Enhancement Systems Program Area

Two countermeasures have been identified by NHTSA to help reduce the incidence of heavy vehicle rollovers. The first is a Roll Stability Advisory System (RSA) that measures the rollover stability properties of a typical tractor-semitrailer as it is operated on the roadway and provides the driver with a graphical depiction of the vehicle's loading condition relative to it's rollover propensity. The RSA is intended to assist drivers in maintaining safe speeds on curves. The second countermeasure is a Rearward Amplification Suppression System (RAMS) that employs an active brake control system coupled with Electronic Brake System (EBS) technology. This system can selectively apply brakes to wheels to stabilize the vehicle and thus reduce the incidence of rear trailer rollover in double- and triple-trailer combination vehicles during crash avoidance steering maneuvers.

2.5.5.8 Heavy Truck Braking and Electronic Braking Systems

This is an ongoing research program aimed at improving the safety performance of heavy trucks. The research areas are as follows: the development of ABS performance measures for straight trucks and trailers, evaluation of SAE J1802 "Brake Block Effectiveness Rating Procedures", and evaluation of the performance and compatibility of truck tractors and trailers equipped with electronic brake systems (EBS).

2.5.5.9 Splash and Spray Suppression

In 1988, NHTSA terminated rulemaking requiring splash and spray suppression devices on large trucks. The agency determined at that time that there was no available technology demonstrated that would consistently reduce splash and spray to an extent that would improve visibility. The objective for this project is to identify and evaluate the technological advancements in heavy vehicle splash and spray suppression devices since the agency's last report to Congress in March 1994.

2.5.6 Traditional Areas of Collision Avoidance [32]

2.5.6.1 Rollover Program Area

The objective for this research is to develop an objective test procedure for determining the on-road, untripped rollover propensity of a vehicle make-model. Having such a test procedure will support either the implementation of a Federal Motor Vehicle Safety Standard to establish a minimum acceptable level for a vehicle's on-road, untripped rollover propensity, or the development of a consumer information program to reduce the incidence of on-road, untripped rollover. The test procedure will be developed to the level that it can be presented to the public in the form of a notice.

2.5.6.2 Anti-lock Brakes Program Area

Test track studies evaluating the effectiveness of ABS have shown it to be an advantageous safety device. For varying pavement conditions, ABS allows the driver to maintain steering control of the vehicle while braking even during extreme panic stop conditions. However, statistical analyses of real-world collision databases suggest that the introduction of ABS does not reduce the number of automobile crashes where it was thought ABS would have proved most effective. Crash studies show increased involvement of ABS-equipped vehicles in single-vehicle crashes and less involvement in multi-vehicle crashes. Specifically the increase has been in single-vehicle run-off-road crashes such as, rollovers or impacts with fixed objects. The

overall objective of this project is to determine why ABS does not appear to be effective in reducing all types of crashes.

2.5.6.3 Visibility Program Area

Convex and multi-radius rearview mirrors provide drivers a wider field of view as compared to flat mirrors. However, the driver may experience greater difficulty judging the distance and approaching speed of vehicles due to the reduced image size. The objective of this research is to measure the relative differences in driver performance when using the standard (planar) driver-side rear-view mirror and selected non-planar mirror types. Studies include the use of laboratory driving simulators and data collection of drivers experiences in Europe where these mirrors have been used.

2.5.7 Research Tools [32]

2.5.7.1 National Advanced Driving Simulator (NADS)

Simulators are considered essential to the efforts for understanding driver behavior and for testing of various situational, display, and control conditions rapidly without endangering the experimental subject. NHTSA is focusing on the development of a high fidelity, moving base simulator, to replicate the highway driving scenario. This will be a national research facility for human-in-the-loop, real-time vehicle driving simulation. With this facility, researchers will be able to present the antecedent events of a likely crash situation and then study the responses of research subjects (drivers) as well as the vehicle. Within the simulator these events can be presented in a precise and repeatable manner, efficiently, while providing complete safety to the human subjects.

2.5.7.2 Data Acquisition System for Crash Avoidance Research (DASCAR)

NHTSA has developed a portable instrumentation suite to support the collection of data on how drivers react to avoid collisions. The systems can monitor and record driver/vehicle and environmental parameters such as vehicle speed, lateral placement, eye glance, longitudinal and

lateral acceleration, etc. This instrumentation package is designed to be easily installed, and to operate in an unobtrusive manner to permit the collection of driver performance/behavior data on the road, in support of "naturalistic" field studies. The DASCAR systems will be used to assess the effectiveness of candidate ITS accident avoidance countermeasures and other driver information systems, address issues of design and safety consequences, develop a baseline/ normative driving database, characterize incidents/near misses and support implementation of other tools.

2.5.7.3 System for Assessing the Vehicle Motion Environment (SAVME)

This project is developing and validating a measurement system that can quantify the specific motions that vehicles exhibit as they move in traffic. In addition, the system will sense and record the location and motions of all other vehicles within the field of view relative to roadway boundaries and other features of the driving environment. In operation, the SAVME will gather information on successful collision avoidance maneuvers, including the reaction to other vehicles cutting in front, headway maintenance, typical lane changing trajectories, and response to inclement weather and other conditions which degrade visibility and performance.

2.5.7.4 Variable-Dynamics Test Vehicle (VDTV)

The VDTV is a test tool that will be used to establish safe performance envelopes for safety systems that will directly control vehicle motion. This vehicle will support the determination of the vehicles performance limits that would determine the performance envelopes of certain collision avoidance systems. It will also permit determination of how drivers react to various proposed ITS crash avoidance concepts and the effects of vehicle characteristics on control device effectiveness. The VDTV will also be used to validate NADS control algorithms.

2.5.7.5 Collision Avoidance Knowledge Base

The NHTSA research program has developed a safety-related database which continues to be updated and enhanced. This database comprises the collective knowledge developed by the NHTSA CA research program. A substantial effort has been accomplished in the research

(statistical analysis and case studies) of the major causes of crashes and in the understanding of pre-crash factors which contribute to the crash. This knowledge base provides the (causal analysis) background to identify crash mitigation approaches as well as the statistical basis for focusing NHTSA's program activities.

The knowledge base also includes initial performance specifications, benefit estimates, and development and test guidelines for crash avoidance concepts and/or products. Finally as program activities continue, the results of test and evaluation activities will produce data on system effectiveness, producibility, and market potential for the various CA systems/ products being investigated. The NHTSA research program has also developed a base of knowledge of the human factors that affect traffic safety. This database comprises the collective knowledge obtained by agency research to date, and continues to be updated and enhanced.

2.5.8 Long- Term Vision

Collision avoidance systems are a near-term reality with the continued application of knowledge and tools to assess their effectiveness, acceptability, and commercial viability.

Although much of the technology is not readily available to the buying public, the next phase of the NTHSA program aims to make effective systems available to car buyers as standard or optional equipment.

The program also expects to expand its focus from single crash avoidance technologies to integrating and combining elements of crash avoidance with broader ITS applications and the wider intelligent transportation infrastructure. As a result, the program will focus on overcoming technical challenges through field tests and other activities.

2.5.9 Proven Benefit

NHTSA estimates that 1.1 million or 17 % crashes could be prevented annually if all vehicles were equipped with just three of the primary ITS crash avoidance systems -- rear-end, roadway departure, and lane change/merge. By avoiding more than a million accidents, these

systems could save thousands of lives and $23 billion per year. Specific benefits are outlined in table 2-17 [31].

Table 2-17: Benefits Chart of Some Collision Avoidance Systems

Advanced Crash Avoidance Program/Element	Benefits
Rear-end Crash Avoidance Systems	• **ITS countermeasures could address over 1.5 million of the 1.7 million rear-end crashes that occur annually. NHTSA estimates that ITS driver warning systems would be effective in 49% of the rear end crashes, which would prevent 759,000 crashes annually.**
Road Departure Collision Avoidance Systems	• **ITS countermeasures apply to about 458,000 of the 1.2 million roadway departure crashes that occur annually. With an overall effectiveness of 65%, the systems could prevent 296,000 crashes annually.**
Lane Change/Merge Crash Avoidance Systems	• **ITS countermeasures apply to 192,000 of the approximately 200,000 lane change/merge crashes per year. The estimated effectiveness of the system is about 20% which could prevent about 39,000 accidents per year.**
Automatic Collision Notification Systems	• **Tests of on-board crash notification systems, simulated emergency calls have shown a decrease in time for medical help to arrive from 14 minutes to 8 minutes for urban crashes and from 21 minutes for out-of-town crashes. The 43% drop in response time corresponds to a 12% increase in the change of survival for an occupant involved in the crash. U.S. response times for fatal accidents average 10.1 minutes in urban areas and 19.6 minutes in rural areas.**

2.6 Section VI: Photo Camera Enforcement

2.6.1 Introduction

Enforcement the third of the triple Es Pillar for a successful implementation of transportation systems: Engineering, Education and Enforcement. Aggressive and reckless driving are the main reasons behind driving code violation which lead to sever crashes which turn to be sometimes a result of what could be considered as criminal (jailable) act.

According to a NHTSA survey on aggressive driving attitudes and behaviors (released at a conference held in January 1999 in collaboration with the FHWA about aggressive driving), more than 60 percent of drivers see unsafe driving by others, including speeding, as a major personal threat to themselves and their families. However, more than half admitted themselves to driving aggressively on occasion [37].

Although there is not one standard, accepted definition of aggressive driving, NHTSA currently defines it as "the operation of a motor vehicle in a manner that endangers or is likely to endanger persons or property". It can include a range of less serious offenses, such as reckless driving, and does not necessarily require willful and wanton disregard for the safety of others, according to NHTSA. Examples include speeding or driving too fast for conditions, improper lane changing, and improper passing.

Some common characteristics of the aggressive driver include the following [37]:

- They are high-risk drivers, more likely to drink and drive, speed, or drive unbelted.
- They run stop signs or other control signs in general, disobey red lights, speed, tailgate, weave in and out of traffic, pass on the right, make unsafe lane changes, flash their lights, blow their horns, or make hand and facial gestures.
- Their vehicle provides anonymity, allowing them to take out their frustrations on other drivers.
- Their frustration levels are high, concern for other motorists, low.

- They consider vehicles as objects and fail to consider the human element involved; therefore, they seldom consider the consequences of their actions.

NHTSA's aggressive driving work plan includes the development of innovative and effective countermeasures and enforcement strategies. Public information and education (PI&E) is another important component of these efforts.

Law enforcement as suggested by some researchers is witnessing downward trend, and Statistics show a dramatic decrease in traffic law enforcement. For instance, a Philadelphia study, which compared traffic data from 1975 to 1995, found that police issued many more traffic tickets in 1975 than they did 20 years later:

- In 1975, 16,000 speeding citations were issued, compared to 5,000 in 1995.
- In 1995, 71,255 traffic signal violations were cited; in 1975, there were only 20,514.

Moreover, in 1999 the city of Philadelphia was owed $334 million in unpaid traffic citations [38].

2.6.2 Applied Technology for Enforcement

Reinforcing law enforcement has many educational, legal, jurisdictional and technical aspects. The latter aspect falls in our scope of interest and consists of applying technology to further extend the capabilities of law enforcement. Some of technologies used to support enforcement are photo red light technology used for traffic light violations and cited laser technology, currently in use in Europe, for "following too closely". Both technologies have good possibilities if they are standardized nationally and accepted by the courts.

Actually photo red light enforcement camera is a proven technology that has achieved public acceptance and has been shown to reduce crashes. Photo enforcement was also successfully implemented for railroad crossing.

Radar speed display devices are other type of enforcement supporting technology that was found by some communities to have a calming effect in high-traffic speed areas and provide a good preventive measure.

Observation platforms such as aircraft, in-car video, and other equipment also aid the apprehension and prosecution of traffic violators who would otherwise be difficult to contact or to testify about. These vary in acceptability across the country, and must be accepted on a regional basis to be helpful [39].

2.6.3 Automated enforcement

Automated enforcement is defined as the "use of image capture technology to monitor and enforce traffic control laws, regulations, or restrictions. Where enabling legislation authorizes the use of automated enforcement, the image capture technology negates the need for a police officer to directly witness a traffic offense" [40].

For example, Figures 2-17 and 2-18 show pictures captured by an automated red light enforcement system in Howard County, Maryland [40]. Pictures such as these are used as evidence (in addition to other testimony if possible) to prosecute a traffic signal violation.

Automated enforcement could be used in many applications to reduce violations. Currently it applied with an emphasis on red light, speed limit, and rail-highway grade crossing enforcement. Other applications of automated enforcement could be with high- occupancy vehicle (HOV) and bus lanes, electronic toll collection (ETC) systems, and vehicle inspection and weigh-in-motion (WIM) stations.

2.6.4 Photo enforcement Technology

Usually, a photo detection system at intersections is composed of electromagnetic loops buried in the pavement, a terminal block that houses a microprocessor, and a camera (wet film, digital or video) atop a 15 +/- foot pole. When the signal turns red, the system becomes active and the camera takes pictures when cars enter the intersection.

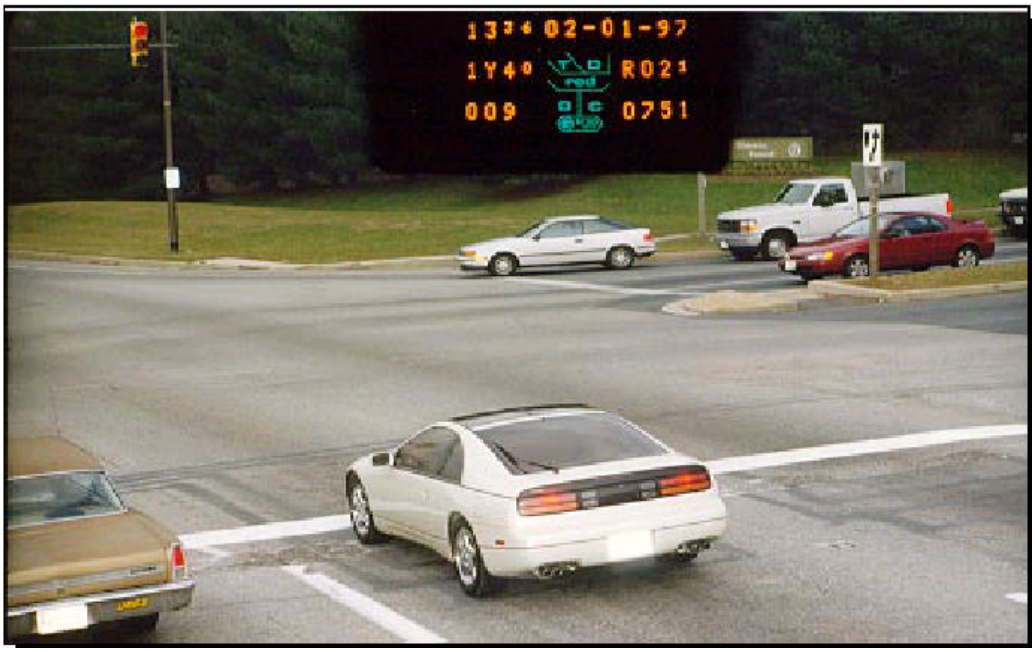

Figure 2-17: First Picture Taken By Automated Red Light Enforcement System

Figure2-18: Second Picture Taken By Automated Red Light Enforcement System

Photographs are taken of the rear of the car or both the front and rear ends. (If both the front and rear of a violating vehicle is to be photographed, two cameras will be used.) If large commercial vehicles are present on the road, front photographs are essential for identifying the owner of the truck.

Normally, the camera records the date, time of day, time elapsed since beginning of red signal and the speed of the vehicle. Upon review of the photographs and depending on state or local law requirements, tickets are issued by mail.

Passetti cited the following 10 requirements that automated enforcement systems should include [41]:

- The ability to capture, transmit, process, store and recover captured images so that data may be managed in an efficient manner;
- Sufficient resolution to satisfy court standards for the image-reading of vehicle license plates, clear detail of the vehicle, and identification of the vehicle operator (if necessary);
- The capability to prevent the spreading of overexposed portions of an image (anti-blooming) that may result from vehicle headlights or sunlight from highly reflective surfaces;
- Adequate differentiation of light to dark areas within an image to provide necessary details (also referred to as contrast latitude);
- The ability to provide blur-free images of moving vehicles;
- The ability to detect at varying levels of light;
- Image enhancement circuitry to eliminate major sensor defects such as bright or dark columns, which detract from the visible presentation of an image;
- Continuous read-out of images to support monitoring along with single frame capture capability for recognizing several successive vehicles committing a violation;
- The ability to be moved to different locations or to be mounted into a permanent position; and
- Components that are environmentally friendly.

Three camera types are generally used for red light enforcement [41]:

2.6.4.1 Wet film/35-mm

Industrial quality 35-mm camera (wet film) technology is the most common type used for photographing red light runners. Most automated enforcement systems equipped with 35-mm cameras produce black and white photographs, but some systems may produce color photographs. Although black and white photographs are less expensive than color photographs, it is often difficult to tell which light is illuminated on the traffic signal. Color photography can be used to eliminate any doubt as to whether the traffic signal is actually red.

Cameras are located in a special unit to protect them from the elements and vandalism and placed atop poles. Poles may be either hinged or contain specially designed “elevator" systems to allow access to the cameras. A notable quality of wet film systems is the need to have personnel visits every camera location, often on a daily basis, to retrieve exposed film and reload. The film is then transported for processing, developed, sent to a facility for review and then converted to a digital image.

Although vendors of automated enforcement technology will often claim that a single camera can enforce four through travel lanes, experience in New York and other areas has shown that reliable, accurate enforcement can only be performed on the first three travel lanes next to the red light camera. By having the loop detectors used only for the automated enforcement system, interference and conflicts with other detectors used for the traffic control system can be avoided.

When the traffic signal switches to the red phase, the camera used by the automated enforcement system becomes active (ready to take photographs). Vehicles traveling over the detectors while the camera is active signal the system to photograph the vehicle. A small period of time, referred to as a grace period, and a preset speed necessary to activate the system are usually allowed in order to differentiate between vehicles attempting to stop or turn right on red and vehicles that clearly are running the red light.

A common grace period is 3/10 of a second (though an international standard of 0.5 seconds exists) and a minimum speed necessary to activate the system ranges from 15 to 20 miles per hour.

When a vehicle running a red light activates the system, the camera takes at least two pictures. The first picture shows that the front of the vehicle is not in the intersection when the traffic signal is red. This picture must show the pavement marking defining the intersection (usually the stop bar or the crosswalk), the traffic signal displaying a red light, and the vehicle in question. The second picture then shows the vehicle in the intersection a short time later (0.5 to 1.5 seconds) (refer to figures 2-17 and 2-18). If driver identification is necessary, a third picture of the driver may be taken. From the pictures taken, the license plate will be magnified to allow for identification.

2.6.4.2 Digital

Digital cameras have the capability to produce higher resolution; more sharply detailed images of vehicles, and are equipped to prevent reflections or headlights from smearing the image. Photographs produced by digital cameras may be in color or black and white. The configuration of digital camera applications is very similar to the one described for applications using 35-mm cameras. As with 35-mm cameras, digital cameras are placed in protective housings atop poles. Sensors are placed in the pavement in the same manner as for 35-mm applications, with two sets of sensors per lane to detect vehicle presence and speeds. The cameras are wired to the signal controller and the loop sensors so when the signal turns red, the system becomes active. When a vehicle traveling over the allowed range of 15 to 20 miles per hour crosses the sensors, two pictures will be taken. Again, the first picture will be before the entrance to the intersection, usually the cross-walk or the stop bar, and the second picture will be a preset time later, usually 0.5 to 0.9 second later, with the vehicle in the intersection.

A major expected benefit of digital cameras is in easing the photo collection and accelerating the processing and distribution of notices of violation (tickets). This benefit is brought about because the captured image can be electronically transmitted directly to the review facility and immediately incorporated into a citation. In addition, digital cameras eliminate costs of such things as the film, processing, and the personnel required for daily film handling.

Hansen introduces a variety of issues associated with digital cameras. Very importantly, he questions how the courts will view digital violation images. Specifically, he points out the ease with which digital images can be tampered. In comparison with a wet film system, an original 35-mm slide and photo can be produced in court to support the veracity of the evidence. This back-up plan does not exist with digital images. The following suggestions are offered:

• When a digital image is transferred to a review facility, store a duplicate image at the camera site using a "tamper proof" data storage device.

• The storage media should, when full, be handled as evidence and viewed only in instances when the original is questioned.

• Maintain a documented chain of custody so that the court can be shown an image that has not been viewed by human eyes.

Other issues with digital cameras include the large file sizes for high-resolution photos. This in turn brings about slower and more costly file transfers. This could be especially cumbersome with multi-camera systems. Another issue is that some digital cameras are out of service while capturing an image. This could result in an inability to capture multiple violators i.e. the second or third violators going through the red signal.

2.6.4.3 Video

The use of video cameras and video processing technologies is receiving more attention for red light enforcement activities. Video cameras can be used to determine a vehicle's speed as it approaches the intersection, predict whether or not the vehicle will stop for the red light and then track the vehicle through the intersection and record a brief video sequence of the violation. Video images allow close-ups of both the front and rear license plates. Newer video cameras are digital, which allows real-time transmission of images and, like digital still cameras, reduced transport, handling and reproduction costs. Full video sequences can increase the number of detected violations for subsequent ticketing.

An advantage of a video system may be its ability to detect vehicle speed and predict whether or not a red light running violation will take place. With this prediction, it is possible to preempt the normal signal changes to create an all-red signal to prevent crossing traffic from entering the intersection when a collision is possible. Though this does not prevent the violation, it can help to mitigate the potential consequences of the violation. Additionally, video cameras can be used for non-enforcement activities such as traffic monitoring and surveillance, incident response, and crash reconstruction. If digital video cameras are used, the same concerns, i.e., lack of negatives and other non-tamperproof forms of evidence, etc.. apply as for the digital still cameras.

2.6.5 Effectiveness of Photo Enforcement

A report released on February 24, 2000 by the Federal Highway Administration shows that red light running violations decreased by as much as 60 percent at intersections where cameras automatically enforce the law. The report analyzed results of red light running camera programs in Los Angeles County; San Francisco; New York City; Howard County, Md.; and Polk County, Fla. "These results indicate once again that innovation and new technologies, such as cameras used to prevent red light running, can help improve safety" [42].

In New York City for example, at one red light camera installation it has been found in a before-after analysis that angles crashes have decreased by 60 to 70% after installation of the camera. Though the number of angle crashes has decreased, there has been an increase in less severe rear-end collisions in the same time frame. Total crashes, however, are down [43].

In a separate study evaluating the first six months of a pilot project in San Francisco showed that the number of red light runners at photo-enforced intersections dropped more than 42 percent. In another separate study in Oxnard, California, the Insurance Institute for Highway Safety also recorded a 42 percent reduction in red light violations. The Oxnard study included locations not equipped with cameras and found that there was a "spill over" effect at these locations as well [44].

Internationally, the decline in red light violation was estimated 55% in United Kingdom, 40% decline in Singapore and 32% in Victoria, Australia [42].

Meanwhile, some opponents of automated enforcement may question its overall effectiveness and it effectiveness versus other strategies. Automated enforcement of speed limits is perhaps the most debated area, since few will argue that running red lights or rail-highway grade crossings is an acceptable driving behavior. Some opponents disagree with the basic premise that speed kills. They assert that other factors are to be blamed in vehicle crashes and that all too often speed limits are set arbitrarily [45].