Working Paper:
Estimating the Potential Safety Benefits of Intelligent Transportation Systems

Benjamin B. McKeever
Mitretek Systems

November 1998

Σ

1. Report No. FHWA-XX-XX -XXX	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Working Paper: Estimating the Potential Safety Benefits of Intelligent Transportation Systems	5. Report Date November 1998
	6. Performing Organization Code
7. Author(s) Benjamin B. McKeever	8. Performing Organization Report No. 1998-17
9. Performing Organization Name and Address Mitretek Systems 600 Maryland Avenue SW, Suite 755 Washington, DC 20024	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-95-C-00040
12. Sponsoring Agency Name and Address Federal Highway Administration ITS Joint Program Office 400 Seventh Street, S.W. Washington, DC 20590	13. Type of Report and Period Covered 14. Sponsoring Agency Code HVH-1

15. Supplementary Notes

Sponsoring Agency Task Manager – Joseph I. Peters, Ph.D.

16. Abstract

The purpose of this working paper is to present estimates of potential safety benefits resulting from full implementation of Intelligent Transportation Systems (ITS) in the United States. These estimates were derived by integrating results from a number of different sources. In this paper, the safety benefits metrics used are reductions in fatal crashes and injury crashes.

The results presented here are not meant to be the final word on quantitative safety benefits, but only an estimate of what could possibly be achieved in the long run based on available evidence. As more empirical evidence on the safety benefits of ITS services and technologies becomes available over time, the results presented here can be revisited to refine these estimates.

17. Key Words Intelligent Transportation Systems, ITS, safety benefits, injury crashes, fatal crashes	18. Distribution Statement No restrictions. This document is available to the public from: National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 45	22. Price

Form DOT F 1700.7 **(8-72)** Reproduction of completed page authorized

EXECUTIVE SUMMARY

The purpose of this paper is to present estimates of potential safety benefits resulting from full implementation of Intelligent Transportation Systems (ITS) in the United States. These estimates were derived by integrating results from a number of different sources including field operational tests, model deployments and simulation studies. In this paper, the safety benefits metrics used are reductions in fatal crashes and injury crashes.

The estimates presented in this paper are based on an assumption of 100 percent market penetration of the ITS technologies or user services in an unspecified future time-frame. As such, they represent long run estimates of what can be achieved as ITS implementations take place. These simplifications were made to facilitate a first cut at obtaining an estimate for ITS safety benefits. Obtaining an estimate within a specific time context would require additional information regarding the current deployment of the various ITS technologies and assumptions about the projected annual growth of market penetration. In addition, assumptions have to be made about the impacts of ITS for less than 100% deployments, taking into account the complex interactions among users and non-users of ITS equipment and services.

We were able to develop estimated safety benefits at the national level for both fatal and injury crashes. These estimates, which were established at aggregate levels, are shown in the table below. These estimates represent the percent reduction in annual fatal and injury crashes with full ITS implementation relative to the no-ITS baseline.

Goal Area	Percentage Decrease
Fatal Crash Reduction	26%
Injury Crash Reduction	30%

It is clear that more empirical evidence would be desirable to support these estimated benefits. Good baseline data exists for fatal and injury crashes and is provided each year by the National Highway Traffic Safety Administration. However, many of the results regarding potential crash reductions resulting from ITS technologies are not empirically based. One reason for this is that many of the technologies, particularly vehicle-based technologies, have not yet been tested in the field. For example, the crash reduction rates from crash avoidance systems were determined using experimental data in conjunction with simple theoretical models rather than real world results [1].

The results presented here are not meant to be the final word on quantitative safety benefits, but only an estimate of what could possibly be achieved in the long run based on available evidence. As more empirical evidence on the safety benefits of ITS services and technologies becomes available over time, the results presented here can be revisited to refine these estimates.

TABLE OF CONTENTS

Section 1: Introduction

The purpose of this paper is to present estimates of potential safety benefits resulting from full implementation of Intelligent Transportation Systems (ITS) in the United States. These estimates were derived by integrating results from a number of different sources. In this paper, the safety benefits metrics used are reductions in fatal crashes and injury crashes.

The results presented here are not meant to be the final word on quantitative safety benefits, but only an estimate of what could possibly be achieved in the long run based on available evidence. As more empirical evidence on the safety benefits of ITS services and technologies becomes available over time, the results presented here can be revisited to refine these estimates.

ITS utilizes a variety of different computer, communication, and surveillance technologies to improve safety and efficiency in transportation. These technologies, deployed in ITS systems, are expected to yield a wide range of benefits. The ITS Joint Program Office (ITS/JPO) of the Federal Highway Administration has identified a limited number of benefit areas and measures on which to focus its evaluation resources. This collection of measures, given the name "A Few Good Measures," includes two measures that relate to safety: fatalities and crashes. Data on total crashes in the United States tends to be spotty. Consequently, this report will focus on crashes resulting in a fatality or personal injury for which data collection is more orderly.

1.1 Background

Crashes and fatalities are an inevitable, although undesirable, transportation outcome. In 1995, 37,241 fatal crashes resulted in 41,798 deaths. Additionally, in the same year 2,166,000 injury crashes resulted in 3,386,000 injuries. These numbers are down significantly from previous years but they still pose a major problem.

An implicit objective of the transportation system is to minimize this risk for some desired level of mobility. Historically, this has been done through improvements to the geometry or physical layout of the roadway. For instance, 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. Finally, there have been safety features implemented in automobiles such air bags and anti-lock brakes that have also improved the overall safety of highway travel. Even with these recent safety improvements, there is still more that needs to be done.

With recent advances and in information technology and telecommunications, ITS has emerged as another potential solution to the problem of transportation safety. 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. Among the ITS systems oriented toward reducing crashes, 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.

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.

1.2 Organization of Report

The rest of this report presents the background, methodology and results of an effort to quantify the potential safety benefits of ITS. Section 2 details the highway safety problem in the United States by giving various crash type sizes for different road types and conditions. Section 3 provides a literature review of the estimated safety benefits of different ITS countermeasures. Next, section 4 presents the methodology and major assumptions that were used to quantify the safety benefits of ITS. Section 5 uses the data presented in sections 2 and 3 to calculate a rolled up estimate of the impact of ITS on fatal crashes under the assumption of 100% market penetration. Section 6 does the same for injury crashes. Finally, section 7 provides conclusions and recommendations.

Section 2: Statement of Problem

Traffic accidents constitute a major threat to public health and have been classified as a crisis by the US Center for Disease Control. In 1995 alone, there were over 6.6 million police-reported motor vehicles crashes. Of these crashes, roughly a third or 2,166,000 were injury crashes and less than 1 percent or 37,241 were fatal crashes [2].

The United States Department of Transportation (USDOT) collects statistics on fatal and non-fatal crashes. These statistics are stored in two data systems designed and developed by the National Highway Traffic Safety Administration (NHTSA). The first of these systems, the Fatality Analysis Reporting System (FARS), is probably the better known of the two sources. Established in 1975, FARS contains data on all fatal crashes occurring in the United States. The second source, the General Estimates System (GES) contains data from a nationally representative sample of police-reported crashes of varying severity, including those that result in death, injury, or property damage. For this study, FARS was used to derive fatal crash numbers and GES was used to derive injury crash numbers. The most recent year for which accident data was available when this study began was 1995; therefore, the estimates in this study are based on 1995 crash data.

The relative size of the crash problem in the United States can be described from a number of perspectives, which give indications of methods to approach improving safety. Crashes can be classified by crash type (e.g. rear-end, head-on, etc.), road function (e.g. rural interstate, urban arterial, etc.), vehicle type, weather conditions, or any number of ways. By breaking crashes down in this manner, one can better estimate the impact of certain ITS countermeasures that are targeted towards specific crash populations.

2.1 Crashes by Crash Type and Road Function

Table 2-1 shows a cross-tabulation of 1995 fatal crashes by crash type and road function. Tables 2-2 and 2-3 show 1995 injury crashes classified by crash type and road function, respectively. A cross-tabulation of injury crashes by crash type and road function was not feasible since the GES database does not contain a data field for road function. Table 2-3 was extracted from *Highway Statistics 1995* [3].

The crash type and road function classifications are useful when estimating the benefits of certain ITS countermeasures such as crash avoidance systems or freeway management systems. For example, we know that freeway management systems will most likely impact crash rates on urban freeways so this classification gives us a more accurate crash size on which to base our crash reduction estimate. The same is true for crash avoidance systems which have applications for reducing rear-end, lane change and roadway departure crashes. Rear-end and roadway departure crashes can be taken from tables 2-1 and 2-2 directly. However, lane change/merge crashes must be estimated using sideswipe/same direction type crashes. Of course, not all sideswipe/same direction crashes are caused by lane changes or merges and some lane change/merge crashes result in angle collisions. Nevertheless, sideswipe/same direction crashes provide a good estimate for crashes involving lane changes or merges. Therefore, this report will use sideswipe/same direction type crashes to estimate the target crash size for lane change/merge crash avoidance systems (CAS).

Table 2-1: 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)

Table 2-2: 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 2-3: 1995 Injury Crashes 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*)

2.2 Crashes by Vehicle Type

Crashes can also be classified by vehicle type. This is helpful when one wants to estimate the potential safety benefits of implementing ITS for commercial vehicle operations or transit vehicles. Table 2-4 shows the 1995 distribution of vehicles involved in both fatal and injury crashes by vehicle type. Note that in 1995 there were 4,472 trucks involved in fatal crashes and 83,000 trucks involved in injury crashes. This data is presented as a count of vehicles involved in crashes. In order to be consistent with the rest of the study, this data needs to be expressed as a crash count. According to the Office of Motor Carriers, in 1995 there were 4,198 fatal crashes and approximately 78,000 injury crashes involving at least one truck [4].

Table 2-4: 1995 Vehicles Involved in Crashes by Vehicle Type and Severity

Vehicle Type	Vehicle Counts	
	Fatal Crashes	Injury Crashes
Passenger Vehicles	49,086	3,843,000
Trucks (4500kg<GVWR)	4,472	83,000
Buses	271	14,000
Motorcycles	2,268	50,000
Other	427	5,000
Total	*56,524*	*3,995,000*

(Source: *Traffic Safety Facts 1995*)

2.3 Crashes by Relation to Junction

Crashes can also be classified by where they occur in relation to junctions in the roadway. This is helpful when one wants to estimate the potential safety benefits of junction related ITS countermeasures such as advanced traffic signal control or ITS for railroad crossings. Table 2-5 shows the 1995 distribution of fatal crashes cross classified by relation to junction and crash type. Similarly, table 2-6 shows the 1995 distribution of injury crashes cross classified by relation to junction and crash type. Note that in 1995 there were 2,746 fatal crashes and 466,000 injury crashes that occurred at signalized intersections. Also, there were 390 fatal crashes and 4,000 injury crashes that occurred at railroad crossings.

Table 2-5: 1995 Fatal Crashes by Relation to Junction and Crash Type

Relation to Junction	Rear-end	Head on	Angle	Side swipe (same dir.)	Side swipe (opp. dir.)	Single vehicle., off road	Other	Total
Non-Junction	1,171	5,046	1,329	242	223	12,076	6,545	26,632
Intersection w/ traffic signal	176	59	1,746	8	2	488	267	2,746
Intersection w/ out traffic signal	189	305	3,773	10	9	958	492	5,736
Driveway, Alley Access, etc.	60	27	345	3	0	246	57	738
Entrance/Exit Ramp	26	9	62	4	1	286	63	451
Rail Grade Crossing	1	1	0	0	0	0	388	390
Other/Unknown	16	34	71	15	3	391	52	548
Total	1,665	5,481	7,326	282	238	14,445	7,804	37,241

(Source: Extracted from FARS)

Table 2-6: 1995 Injury Crashes by Relation to Junction and Crash Type

Relation to Junction	Rear-end	Head on	Angle	Side swipe (same dir.)	Side swipe (opp. dir.)	Single vehicle., off road	Other	Total
Non-Junction	257,000	25,000	93,000	38,000	8,000	294,000	187,000	902,000
Intersection w/ traffic signal	121,000	13,000	268,000	3,000	1,000	42,000	18,000	466,000
Intersection w/ out traffic signal	104,000	17,000	280,000	5,000	2,000	51,000	79,000	545,000
Driveway, Alley Access, etc.	28,000	1,000	121,000	2,000	0	23,000	13,000	188,000
Entrance/Exit Ramp	11,000	0	3,000	1,000	0	9,000	4,000	28,000
Rail Grade Crossing	1,000	0	0	0	0	0	3,000	4,000
Other/Unknown	9,000	2,000	12,000	6,000	2,000	17,000	3,000	33,000
Total	531,000	58,000	782,000	55,000	13,000	422,000	305,000	2,166,000

(Source: Extracted from GES)

2.4 Crashes by Weather and Road Surface Conditions

Finally, crashes can also be classified by weather or road surface conditions. This is useful when estimating the potential safety benefits of road weather information systems (RWIS). Table 2-7 shows the fatal crashes occurring on rural roads in 1995 cross classified by road surface condition and crash type. Table 2-8 shows the same for 1995 injury crashes. Table 2-9 shows the fatal crashes occurring on rural roads in 1995 cross classified by weather condition and crash type. Table 2-10 shows the same for injury crashes. It should be noted that in 1995, 987 fatal crashes and 47,000 injury crashes occurred on rural roads when the pavement was snowy or icy. Also, 391 fatal crashes and 6,000 injury crashes occurred on rural roads during foggy conditions.

Table 2-7: 1995 Rural Fatal Crashes by Road Surface Condition and Crash Type

Road Condition	Rear-end	Head on	Angle	Side swipe (same dir.)	Side swipe (opp. dir.)	Single vehicle., off road	Other	Total
Dry	703	2,797	2,877	94	149	8,039	2,509	17,168
Wet	100	697	504	15	27	1,135	378	2,856
Snow/Ice	27	415	106	1	2	327	109	987
Other/Unknown.	3	11	10	1	7	115	45	192
Total	833	3,920	3,497	111	184	9,616	3,142	21,203

(Source: Extracted from FARS)

Table 2-8: 1995 Rural Injury Crashes by Road Surface Condition and Crash Type

Road Condition	Rear-end	Head on	Angle	Side swipe (same dir.)	Side swipe (opp. dir.)	Single vehicle., off road	Other	Total
Dry	65,000	13,000	138,000	3,000	3,000	160,000	55,000	437,000
Wet	19,000	6,000	34,000	1,000	1,000	43,000	16,000	120,000
Snow/Ice	3,000	3,000	8,000	1,000	1,0000	21,000	10,000	47,000
Other/Unknown	2,000	1,000	2,000	0	0	6,000	5,000	13,000
Total	90,000	22,000	182,000	5,000	5,000	232,000	82,000	617,000

(Source: Extracted from GES)

Table 2-9: 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)

Table 2-10: 1995 Rural Injury 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	69,000	16,000	152,000	4,000	5,000	186,000	63,000	493,000
Rain	15,000	4,000	21,000	1,000	0	29,000	13,000	83,000
Sleet	0	0	1,000	0	0	1,000	0	2,000
Snow	3,000	2,000	6,000	0	0	9,000	5,000	25,000
Fog	1,000	0	1,000	0	0	3,000	1,000	6,000
Other/Unknown	2,000	0	1,000	0	0	4,000	1,000	8,000
Total	90,000	22,000	182,000	5,000	5,000	232,000	82,000	617,000

(Source: Extracted from GES)

Section 3: ITS Countermeasures

Intelligent Transportation Systems (ITS) offer tools to address transportation safety on several fronts, including automating control of the vehicle, mitigating circumstances that contribute to crashes, and responding more quickly to crashes when they do occur. The systems that perform these tasks can be classified according to the type of technology being used. This report separates ITS countermeasures 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. This categorization is based on the primary market segments for purchasing ITS countermeasures and can be useful for understanding differences in potential safety benefits within and between them. The rest of this section discusses the various ITS countermeasures that fall under each of these areas and how these countermeasures will improve safety. This section also indicates the types of traffic and crashes that are most likely to be impacted by each ITS countermeasure.

For each ITS countermeasure below, related studies are cited and estimates are given for crash reduction factors. It should be noted that most of these studies are before-and-after studies, which is not always the best method for establishing crash reduction factors [5]. One reason for this is the regression to the mean effect. This happens because in general, sites with a high number of crashes in recent years are chosen as study test sites. Since crashes are a highly random event, there is a tendency for the number of crashes in subsequent years to be lower and closer to the true mean. A second drawback to the before-and-after method is that these studies do not use control variables to see if there are other factors that could have affected accident rates besides the ITS countermeasure. In spite of the limitations, these studies provide the best available estimates for crash reduction factors. As such, they will be used in this paper to estimate the potential safety benefits of ITS.

This study pulls together information from estimates previously identified and supported in the literature or research reports. It should be noted that the ITS countermeasures mentioned below are not the only ITS countermeasures that influence safety. There may be other ITS countermeasures with safety impacts that either have yet to be studied or have yet to be implemented. This issue will be discussed further in section 7.

3.1 Infrastructure-based Systems

The infrastructure-based ITS countermeasures and their related benefits are discussed below. Infrastructure-based Intelligent Transportation Systems that have proven safety benefits include:

- freeway management systems (ramp meters),
- incident detection systems,
- video enforcement (speed cameras, red light cameras),

- traffic signal control,
- advanced warning systems,
- railroad crossing systems, and
- road weather information systems.

3.1.1 Freeway Management Systems

Freeway 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 variable message signs. Figure 3-1 shows an entrance ramp meter during rush hour. There are a number of case studies in the existing literature documenting the benefits of ramp metering. From a 1995 FHWA report that summarizes the results of these case studies, accident rates were reduced by 24-50% on the freeways where ramp meters were implemented [6]. It should be noted that this accident rate reduction was relevant for the entire section of freeway under study, not just the merge areas and included all types of accidents. Using the lower end of the crash reduction range (24%) as a conservative estimate and realizing that ramp metering will primarily be implemented on urban freeways, we can estimate the reduction in fatal and injury crashes.

Figure 3-1: Entrance Ramp Meter

3.1.2 Incident Detection and Management Systems

Incident detection systems can improve safety on highways by providing motorists with warnings of incidents ahead, thus reducing the likelihood of secondary crashes. Also, by expediting the removal of accidents from the roadway, incident detection systems can further enhance highway safety.

An ongoing study of an Automatic Incident Detection (AID) System on the M1 motorway in the United Kingdom is finding promising safety benefits from incident detection systems [7]. The AID system in the study uses inductive loops in the roadway surface to detect the presence of stationary or slow moving traffic. When these conditions are detected, an advisory 50-mph speed limit sign is set upstream to warn approaching vehicles of traffic problems ahead. At the same time, the local police department is alerted of the location of the incident. A before-after analysis using seven years of accident data showed that total injury accidents were reduced by 18% for the years when the AID system was operating. Since incident detection systems are most likely to be implemented on urban freeways, we can expect them to result in an 18% reduction in injury and fatal crashes on urban freeways.

3.1.3 Video Enforcement Systems

There are also a number of case studies in the existing literature documenting the safety benefits of video enforcement either in the form of speed cameras or red light cameras. Speed cameras combine the use of radar technology or road sensors and 35mm-film technology to enforce speed limits on urban arterials or freeways. A study of speed cameras installed in London has shown that speed cameras led to a 20% reduction in injury crashes and a 50% reduction in fatal and serious crashes on major arterials [8]. In Australia, speed cameras were installed at over 800 fixed speed detection sites in New South Wales and various sites on urban arterials in Victoria. Accidents there decreased by 22% and 30% respectively [9]. The speed cameras can also be used in conjunction with mandatory speed limit signals. The “controlled motorway” study performed on the M25 in England combined speed cameras with mandatory speed limit signals. Early results from this study showed a 30% reduction in injury crashes [10]. From the studies mentioned above, one can conservatively assume that speed cameras have the potential to reduce crashes on urban arterials or urban freeways by at least 20%.

Red light cameras photograph vehicles as they are travelling through red lights at intersections. A recent United States study reports that a number of cities saw a 20%-30% reduction in traffic signal violations when cameras were installed at intersections [11]. Assuming that the reduction in violations at signalized intersections correlates one-to-one with the reduction in crashes at intersections, we could expect about a 20% reduction in the number of crashes at signalized intersections when using red light cameras. Since signalized intersections are usually located on urban arterials, this crash reduction complements the 20% crash reduction on urban arterials due to speed cameras, which was mentioned in the previous paragraph. For the sake of simplicity, we will assume that the combination of speed enforcement and traffic signal enforcement using video will lead to a 20% reduction in both injury and fatal crashes on urban arterials.

Speed cameras also have the potential to reduce crashes on urban freeways but this technology performs a similar function to that of adaptive speed control (see section 3.3). Since speed cameras and adaptive speed control both target speed-related crashes on urban freeways, this study will only apply the 20% crash reduction factor from video enforcement to urban arterials. The impact on urban freeways will be treated in section 3.3.3.

3.1.4 Traffic Signal Control Systems

Adaptive traffic signal control projects such as the Sydney Coordinated Adaptive Traffic System (SCATS) have shown the potential to reduce crashes at intersections. As part of the FAST-TRAC project in Michigan, intersections equipped with SCATS showed an 18% reduction in total accidents one year after implementation [12]. Unfortunately, many of the intersections equipped with SCATS in this project also had protected left turns added, which is not an ITS improvement. Therefore, since it is impossible to tell whether the FAST-TRAC accident reduction is due to SCATS or the protected left turns, this paper will not include adaptive signal control in its calculation of ITS safety benefits.

3.1.5 Advanced Warning Systems

Advanced on-road motorist information systems that warn commercial vehicles and other heavy trucks of potentially dangerous highway situations have had success in reducing truck crashes on highways [13]. Two specific systems that have the potential to significantly reduce truck crashes are the Ramp Rollover Warning System (RRWS) and the Down Grade Warning System (DGWS). The first of these systems, the RRWS, alerts truck drivers to slow down when maximum safe speeds are exceeded at exit and entry ramps. Since being implemented in 1993, the system has resulted in a 100% reduction in rollover crashes at all three implementation sites on the Washington D.C. Capital Beltway. DGWS integrate weigh-in-motion and variable message signs to advise drivers of the safe decent speed prior to a mountain grade. The first prototype DGWS, shown in figure 3-2, is installed on I-70 in Colorado. A preliminary review of the accidents and runaway truck ramp use for the past two years indicate a 13% decrease in the number of crashes resulting from excessive truck speed and a 24% decrease in the overall use of truck runaway ramps.

Until the two ongoing studies mentioned above are completed, these countermeasures will not be considered in the calculation of a national estimate for ITS safety benefits. Also, the target crash size for each of these applications is very small (less than 1% of all fatal and injury crashes in 1995) so leaving these countermeasures out of our estimate will have a negligible effect on the overall injury and fatal crash reduction resulting from ITS.

Figure 3-2 Down Grade Warning System installed in Colorado

3.1.6 Railroad Crossing Enforcement Systems

Another ITS countermeasure that impacts safety is railroad crossing enforcement systems. These systems work in much the same way as the red light cameras described in section 3.1.2. The system consists of a typical railroad-crossing signal and gate and a camera installed at the crossing for the purpose of enforcing compliance with the signal. The camera takes a picture of any vehicle that illegally crosses the intersection. Figure 3-3 shows a picture of a grade rail crossing which is being monitored by an enforcement system. Field trials have shown that these devices may be useful in improving safety. In limited trials in Los Angeles, grade crossing enforcement systems have cut the violation rate by 78%-92% [14]. Assuming that the reduction in violation rate at grade crossings correlates one-to-one with a reduction of crashes at grade crossings, we can estimate safety benefits of these systems. Using the lower end of this range as a conservative estimate, this countermeasure has the potential to reduce all crashes at railroad crossings by 78%.

Figure 3-3: Grade Rail Crossing

3.1.7 Road Weather Information Systems

Traveler information systems linking remote weather sensors with variable message signs or in-vehicle devices improve safety by warning drivers of changes in road conditions or by implementing speed control. A European study found that weather-monitoring systems were successful in reducing vehicle speeds by 10% and accident rates by more than 30% during inclement conditions [15]. Furthermore, fatal and injury crashes were reduced by more than 40% during inclement conditions. Therefore, a 40% crash reduction factor will be assigned to fatal and injury crashes occurring on rural roads during inclement conditions (i.e. snow or ice on the road surface).

The same European study found that weather-monitoring systems equipped with visibility sensors linked to variable message signs can reduce accidents by as much as 85% on foggy days [15]. Thus, an 85% crash reduction factor will be assigned to all types of crashes occurring on rural roads under poor visibility conditions.

3.2 Vehicle-based Systems

The vehicle-based ITS countermeasures that impact safety and their related benefits are now discussed. The vehicle-based countermeasures presented in this paper include three types of crash avoidance systems (CAS): rear-end CAS, lane change/merge CAS, and roadway departure CAS. These are by no means the only vehicle-based applications available but they represent the only ones that have undergone a rigorous safety benefits estimation process. Other vehicle-based technologies that could improve safety that are not addressed in this paper include night vision and driver monitoring.

Crash avoidance systems reduce crash risk by taking limited or direct control of the vehicle in emergency situations to help avoid crashes. According to the General Estimates System (GES), rear-end, single vehicle road departure, and lane change/merge crashes account for about 44% of all police-reported crashes in 1995. Improved vehicle control devices to mitigate these types of crashes are being developed under the leadership of NHTSA and the automotive industry.

In a 1996 study, NHTSA uses the best available estimates of CAS performance and driver response to derive estimates of crash reduction factors for three types of crash avoidance systems [1]. These systems address three major crash types: 1) rear-end collisions, 2) lane change/merge crash types and 3) single vehicle, road departures. While potential safety benefits are expected in these areas, field experience upon which to base such estimates is not available. Therefore, NHTSA convened a task force to develop safety benefits estimation methodologies and applied them to these crash avoidance systems. The 1996 NHTSA study presents the findings of the group.

A word of caution, since NHTSA crash reduction estimates for all three types of CAS were based on all police reported crashes, it is possible that the impact of CAS on fatal crash reduction may be less. The reason for this is that the alcohol involvement rate is considerably higher for fatal crashes and crash avoidance systems are less likely to be as effective if the driver has been drinking. However, since no fatal crash reduction estimates are available for CAS, this report will use the NHTSA estimates for calculating both injury and fatal crash reduction. The NHTSA estimates are now given.

3.2.1 Rear-end CAS

Rear-end crash driver warning systems are intended to monitor the forward path and velocity of a host vehicle relative to a lead vehicle and provide appropriate warnings. According to the NHTSA study, about 48% of all rear-end crashes can be avoided using these warning systems [1].

3.2.2 Lane change/merge CAS

Lane change/merge crash avoidance systems monitor position and relative velocity of vehicles in adjacent lanes and advise the driver of unsafe lane changing conditions. According to the NHTSA study, these systems can reduce lane change/merge crashes by about 37% [1].

3.2.3 Road Departure CAS

Road departure systems sense when a vehicle is traveling too fast for operating conditions or is on a path that will lead to road departure. According to the NHTSA study, these systems can result in a 24% decrease in single vehicle, run off the road type fatal crashes [1].

3.3 Cooperative Systems

The cooperative ITS countermeasures that impact safety and their related benefits are discussed below. Cooperative ITS countermeasures include those ITS applications that require elements to be added to both the infrastructure and the vehicle with significant interaction between them. This categorization is based on the primary market segments for purchasing ITS countermeasures and can be useful for understanding differences in potential safety benefits within and between them. The cooperative ITS countermeasures presented here include in-vehicle navigation systems, emergency mayday systems, intelligent speed control systems, and ITS for CVO and transit operations.

3.3.1 In-vehicle Navigation Systems

In-vehicle navigation systems combine real time traffic information with in-vehicle digital map displays to provide travelers with dynamic route guidance. This is expected to improve safety by reducing distractions from the driving task caused by route finding and other navigation activities. Results from the TravTek simulation study indicated an overall reduction in crash risk of about 1% for motorists using dynamic navigation devices [16]. The relevant crash population for in-vehicle navigation systems will be those occurring on urban arterials since that is where most navigation tasks are needed. Thus, this report will assume that in-vehicle navigation systems reduce all types of crashes on urban arterials by 1%.

3.3.2 Emergency Mayday Systems

Emergency services are another area of rural ITS that affects safety. A number of initiatives have been developed to facilitate the means of calling for assistance. Vehicles have been fitted with the latest “emergency call system” utilizing satellite Global Positioning Systems and digital road maps. These systems are often referred to as rural mayday systems. By reducing the response time of emergency vehicles, these systems can reduce the likelihood of a fatality occurring after a crash. A European study has shown rural mayday systems to result in a 43% reduction in response time and a corresponding increase in casualty survival rate of 7-12% [15]. In 1995, the mean time between accident occurrence in rural areas and notification of emergency medical services was 7.6 minutes in the United States. Based on a statistical study conducted across 48 states [17], if accident notification time is cut in half, we can expect about a 7% reduction in rural fatalities assuming a 100% market penetration of rural mayday devices. Therefore, a 7% crash reduction factor will be assigned to all fatal crashes occurring on rural roads. The total number of crashes would remain unchanged since only the severity of the crashes is affected. We assume that injury accidents would also remain unchanged even though there may be a slight increase from more potentially fatal crashes becoming injury crashes. For this study, we will assume this increase is negligible compared to the total number of injury crashes.

3.3.3 Intelligent Speed Control Systems

Much research is being performed in Europe in the area of intelligent speed control. One such application, external vehicle speed control (EVSC), has already been tested in England and has shown promising results[18]. In this application, the variable speed limit is determined in a traffic control center and relayed to the vehicles via roadside beacons. Depending on the level of speed control desired, this information can either be presented to the driver as advisable travel speed or be used to automatically control the speed of the vehicle.

The study calculated the potential crash reduction resulting from the EVSC system for various scenarios based on early test results. When the automated EVSC application is used, injury crashes can be reduced by 20 to 35 percent. Intelligent Speed Control countermeasures will primarily target crashes occurring on urban freeways since that is where the technology is most likely to be effective. Therefore, taking the lower end of these estimates to be conservative, we can expect a 20 percent reduction in injury and fatal crashes on urban freeways due to intelligent speed control.

3.3.4 ITS for CVO and Transit

A variety of ITS technologies concerned with commercial vehicle operations (CVO) and transit are expected to have an impact on safety. The CVO technologies include commercial vehicle electronic clearance for the automated checking of weight, safety status, and credentials, on-board safety monitoring systems, automated roadside safety inspections, and hazardous material incident notification. Transit ITS applications include automatic vehicle location (AVL) and route planning tools for managing fleets and advanced monitoring and maintenance systems. These ITS applications are generally cooperative in nature, but some may be infrastructure or vehicle based. Currently, there is no solid data on the safety benefits of these countermeasures; thus, ITS for CVO and transit are not taken into account in the calculation of ITS safety benefits. However, a more specific fleet analysis could be performed for commercial vehicles and transit vehicles later, when benefits data becomes available.

3.4 Summary of ITS Countermeasures and Confidence Levels

Table 3-1 below presents a summary of the ITS countermeasures discussed in this section. Each countermeasure is listed with its appropriate ITS technology type. The types of traffic and crashes impacted by each safety countermeasure are also listed. 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. For example, the estimate for the ramp metering crash reduction factor has a high level of confidence, since there have been seven before-and-after studies performed in the United States with resulting crash reduction factors ranging from 24 to 50 percent. Conversely, the grade crossing enforcement crash reduction factor has a low level of confidence, since it is assumed that the percent reduction in these types of crashes is directly proportional to the percent reduction in grade crossing violations. Also, the grade crossing estimate is based on just one study of a limited number of sites in one metropolitan area. Only one crash reduction factor is considered to have a high level of confidence; the remaining are judged to have medium to low levels (split about half-and-half between medium and low).

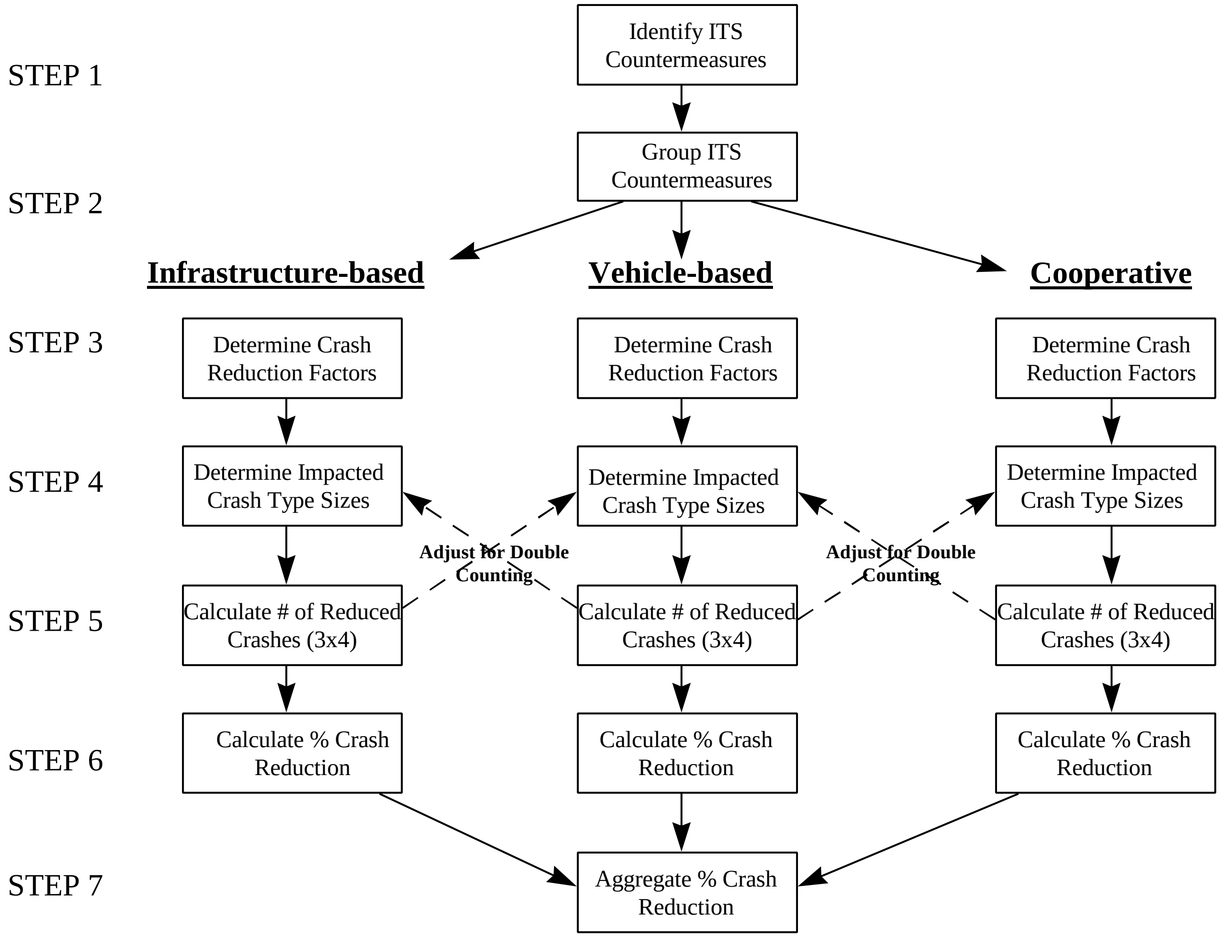
Table 3-1: Summary of ITS Countermeasures

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

Section 4: Methodology

This section introduces the methodology used to compute the national estimates for annual percentage reduction in both fatal and injury crashes as a result of 100% deployment of ITS technologies and services. These estimates were based on the theoretical and empirical data currently available in the literature. They were estimated by applying expected crash reduction rates for each ITS countermeasure (given in section 3) to specific crash problem sizes (given in section 2).   A model of the estimating process is given in figure 4-1. This process is explained in detail section 4.1. Section 4.2 provides a discussion of the assumptions made in this process.

Figure 4-1: Process for Estimating ITS Safety Benefits



4.1 Process for Estimating ITS Safety Benefits

The process in figure 4-1 can be applied for either fatal crashes or injury crashes. Step 1 of the process involves identifying all ITS countermeasures that have an impact on either fatal or injury crashes, depending on which crash severity is being measured. Once all of the countermeasures have been identified, they need to be grouped into one of the following three categories: infrastructure-based, vehicle-based or cooperative ITS (step 2). These groupings were discussed in section 3.

After step 2, the three groups of ITS countermeasures are analyzed separately. In this study, infrastructure-based countermeasures were analyzed first, then cooperative systems, and finally vehicle-based. Step 3 involves determining the crash reduction factors for each ITS countermeasure in the group. These crash reduction factors tell us what percentage of a specific crash type will be reduced by the given ITS countermeasure. Crash reduction factors were provided in section 3. In step 4, the size of the impacted crash type is determined for each countermeasure. This is done by querying the FARS and GES databases for specific crash types under certain conditions. The results of these queries were presented in section 2.

In step 5, we multiply the crash reduction factor determined in step 3 by the impacted crash size from step 4 for each countermeasure. This product represents the estimated number of reduced crashes for the given ITS countermeasure. Since there may be some interdependence between the three groups of countermeasures, an effort needs to be made to avoid double counting reduced crashes. There are two possible ways this issue could be treated.

The first method is to reduce the impacted crash sizes for vehicle-based systems by subtracting crashes that would already have been avoided by having infrastructure-based and cooperative countermeasures in place. For instance, we could reduce the crash type size for the rear-end CAS countermeasure by subtracting 24% of all rear-end crashes that occurred on urban freeways since ramp metering has the potential to reduce these crashes. The second way to treat double counting is by doing the reverse. In other words, reduce the impacted crash sizes for infrastructure-based and cooperative systems by subtracting crashes that would already have been avoided by vehicle-based countermeasures. The first of these methods will give more credit to infrastructure-based and cooperative countermeasures, whereas the second method gives more credit to vehicle-based countermeasures. For this study, the first method was primarily used out of convenience so the results may be slightly biased towards infrastructure and cooperative systems. There will also need to be some adjusting for double counting between infrastructure-based and cooperative ITS where the countermeasures impact the same type of traffic. In these cases, the infrastructure-based ITS were given more credit than the cooperative ITS. The reason for this was arbitrary. The issue of double counting will be explained in greater detail in sections 5 and 6.

In step 6 of the estimating process, we divide the number of reduced crashes calculated in step 5 by the total number of crashes occurring in a year to get the percent reduction in total crashes for each ITS countermeasure. Finally, in step 7 we aggregate the results of step 6 for both ITS groups to get an estimate for the total percent reduction in crashes resulting from 100% ITS implementation.

4.2 Assumptions

This subsection presents the major assumptions made in the process of estimating potential ITS safety benefits. The first group of assumptions deals with the baseline data and how it relates to future time frames and 100% deployment in this study. The next group of assumptions deals with how other factors may influence the ITS safety benefits estimate. Finally, an explanation of 100% deployment is given.

First of all, the baseline year for crash sizes is 1995, which provides a sound source of data and is representative of the potential crash sizes in the future. For simplicity, we are assuming a 0% ITS deployment in the base year. Secondly, no time frame is established for 100% deployment of safety-enhancing ITS countermeasures. Finally, the crash reduction percentages are presented as annualized savings in a future time period in which 100 deployment has occurred.

As for non-ITS factors influencing our estimate, no assumption is made on the future growth or decline in the safety problem due to other (non- ITS) factors. For example, an increase in non-ITS safety measures such as cracking down on drunk driving could affect our crash type sizes and thus, our overall estimate. We are also assuming that the distribution of crashes by type and road function will remain the same over the time period under study.

Finally, the term 100% ITS deployment can be thought of in two ways, depending on the market area (or category). First, with regard to vehicle-based systems, it simply means that 100% of the vehicles are equipped with each in-vehicle countermeasure. In other words, the entire vehicle fleet is equipped with CAS, mayday systems, navigation systems, etc. Second, with regard to infrastructure-based systems, it means that all of the infrastructure-based countermeasures are implemented wherever there is a safety problem that needs to be addressed. For instance, this does not necessarily mean that ramp meters will be implemented on every ramp on every urban freeway. It simply means that ramp meters will be implemented to the extent that they fully address the applicable safety problem, which does not imply complete coverage of the entire system. The meaning of 100% deployment for cooperative systems must be viewed as a combination of the two explanations given above.

Section 5: Fatal Crash Reduction

The purpose of this section is to compute a national estimate for the annual percentage reduction in fatal crashes as a result of 100% ITS implementation. This estimate is based on the theoretical and empirical data currently available in the literature. To estimate benefits, we apply expected crash reduction rates for each ITS countermeasure (given in section 3) to specific crash problem sizes (given in section 2) using the methodology discussed in section 4.

The rest of this section is organized as follows. The impacts of infrastructure-based, vehicle-based and cooperative ITS on fatal crashes are discussed in sections 5.1, 5.2, and 5.3 respectively. Section 5.4 provides an aggregated estimate for the combined impact of all ITS countermeasures on fatal crashes.

5.1 Infrastructure-based ITS

The safety impacts on fatal crashes for Infrastructure-based ITS are discussed below. As mentioned in section 3, infrastructure-based ITS applications include: freeway management systems, incident detection systems, video enforcement systems, traffic signal control systems, advanced warning systems, railroad crossing enforcement systems, and road weather information systems.

5.1.1 Freeway Management Systems

Freeway management, which includes ramp metering, is one area of ITS that has shown benefits already. In section 3, we established that ramp metering has a crash reduction factor of at least 24%. From table 2-1, we know that 3,566 fatal crashes occurred on urban freeways in 1995. Thus, when we multiply a 24 percent crash reduction factor by 3,566 we estimate that 853 fatal crashes will be reduced with ramp metering.

5.1.2 Incident Detection Systems

Incident detection systems are another area of Metropolitan ITS that may effect safety. In section 3, we showed that by providing motorists with advanced warning of incidents ahead and allowing incident management crews to respond to incidents quicker, this countermeasure could reduce fatal crashes by 18% on urban freeways. From table 2-1, we know that there were 3,566 fatal crashes on urban freeways in 1995. An 18% reduction in this number equals a reduction of 642 fatal crashes.

5.1.3 Video Enforcement Systems

Video enforcement of speeding and red light jumping is a promising technology for reducing crashes in urban areas. In section 3 we established an argument for video enforcement potentially resulting in a 20 percent reduction in fatal accidents on urban arterials. From table 2-1, we know that 8,170 fatal crashes occurred on urban arterials.

Therefore, we estimate that 20% or 1,634 of these crashes will be reduced with video enforcement.

5.1.4 Traffic Signal Control Systems

Adaptive traffic signal control has shown the potential to reduce crashes at intersections by as much as 18%. However, the only study that quantifies the crash reduction factor for traffic signal control is the FAST-TRAC study and as mentioned in section 3, this study also included non-ITS improvements which bias the results. Therefore, until another study comes out that quantifies the safety benefits of adaptive traffic signal control, this countermeasure will not be considered in the calculation of a national estimate for ITS safety benefits.

5.1.5 Advanced Warning Systems

Advanced on-road motorist information systems that warn commercial vehicles and other heavy trucks of potentially dangerous highway situations have shown potential for reducing truck crashes on highways. However, as mentioned earlier, the studies involving these systems are still ongoing, therefore these countermeasures will not be considered in the calculation of a national estimate for ITS safety benefits.

5.1.6 Railroad Crossing Enforcement Systems

Another infrastructure-based ITS countermeasure is railroad crossing enforcement systems. From section 3, we know that the crash reduction factor for this countermeasure is 78%. From table 2-5, we know that there were 390 fatal crashes at highway-rail grade crossings in 1995. Therefore, with grade crossing enforcement systems fully implemented we can expect 304 fewer fatal crashes per year.

5.1.7 Road Weather Information Systems

Weather-monitoring systems linked to variable message signs or in-vehicle devices improve safety by warning drivers of changes in road conditions or by implementing speed control. In section 3, a crash reduction factor of 40% was assigned for all crashes occurring on rural roads during inclement conditions. Inclement conditions refer to snowy or icy conditions on the roadway. From table 2-6, we know that 987 fatal accidents occurred when road conditions were reported as either snowy or icy. Therefore, using a 40% reduction factor, we can estimate a reduction in 395 fatal crashes per year.

From section 3, weather-monitoring systems equipped with visibility sensors have a crash reduction factor of 85% on days with poor visibility. From section 2, we know that 391 fatal crashes occurred in 1995 during foggy conditions. Therefore, we can estimate a reduction in 332 fatal crashes per year.

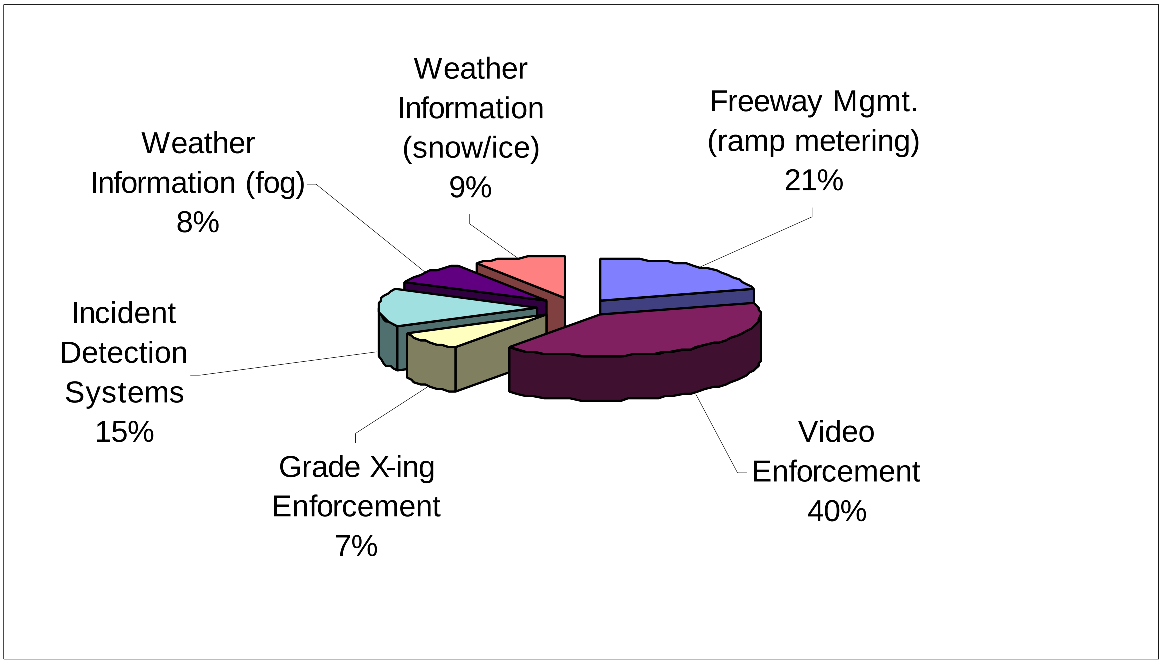
5.1.8 Combined Impact of Infrastructure-based ITS

A summary of the impacts of infrastructure-based ITS systems on fatal crash reduction is shown in table 5-1. From the table, we see that 4,163 fatal crashes can be reduced by infrastructure systems per year. This represents an 11.2% reduction in the total number of fatal crashes. We assume that safety contributions from each infrastructure-based ITS technology are independent, hence double counting between the infrastructure countermeasures was not addressed. The major contributor to this potential 11.2% reduction is video enforcement. This is graphically depicted in figure 5-1.

Table 5-1: Fatal Crash Reduction Estimates for Infrastructure-based ITS

ITS Technology	Impacted Crash Type	Adjusted Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
Ramp Metering	Urban Freeways	3,566	24%	856	2.3%
Video Enforcement	Urban Arterials	8,170	20%	1,634	4.4%
Grade X-ing Enforcement	Railroad Crossings	390	78%	304	0.8%
Incident detection	Urban Freeways	3,010	18%	642	1.7%
Weather Monitoring (snow/ice)	Rural, weather related	987	40%	395	1.1%
Weather Monitoring (fog)	Rural, fog related	391	85%	332	0.9%
Total				**4,163**	**11.2%**

Figure 5-1: Contribution to Fatal Crash Reduction by Infrastructure Countermeasure



5.2 Cooperative Systems

The three types of cooperative systems that have shown the potential to improve traffic safety are in-vehicle navigation systems, rural mayday systems and adaptive speed control. Their impacts on fatal crashes are discussed below.

5.2.1 In-vehicle Navigation

In section 3 we noted that there is an overall reduction in crash risk of up to 1 percent for motorists using navigation devices. The relevant crash population includes all crashes on urban arterials. From table 2-1, there were 8,170 fatal crashes on urban arterials in 1995. Of the 8,170 fatal crashes, we already established in section 5.1 that 1,634 of them will have already been reduced by video enforcement. Therefore, in order to avoid double counting, we adjust our urban arterial crash type size to be 6,536 fatal crashes. With a 1 percent decline in these crashes, we estimate a reduction of 65 fatal crashes.

5.2.2 Emergency Mayday Systems

By reducing the response time of emergency vehicles, rural mayday systems can reduce the likelihood of a fatality occurring after a crash. In section 3, we established a crash reduction factor of 7% for all fatal crashes occurring on rural roads. From section 2, we know there were 21,203 fatal crashes on rural highways in 1995. Since rural mayday systems can only reduce the severity of a crash after it has occurred, we must determine how many rural fatal crashes will have already been reduced by other ITS countermeasures before calculating the impact of mayday devices. Of the 21,203 fatal crashes that occurred on rural roads, an estimated 727 of them will be reduced by RWIS and 2,395 will be reduced by in-vehicle countermeasures[1]. Therefore, in order to avoid double counting, we adjust the crash type size on rural roads to 18,081 fatal crashes. A 7% reduction in this number equals a reduction of 1,266 fatal crashes.

5.2.3 Intelligent Speed Control Systems

Intelligent speed control systems can smooth the flow of traffic on freeways and thus reduce the likelihood of accidents. From section 3 we determined that intelligent speed control has the potential to decrease fatal crashes on urban freeways by 20 percent. From section 2, we know that there were 3,566 fatal crashes on urban freeways in 1995. In section 5.1, we determined that ramp metering could reduce 846 fatal crashes and incident detection systems could reduce 642 fatal crashes. Thus, the target crash size for fatal crashes on urban freeways is adjusted to 1290. A 20% reduction in this total is 258.

5.2.4 Combined Impact of Cooperative Systems

A summary of the impacts of cooperative systems on fatal crash reduction is shown in table 5-2. From the table, we see that 1,585 fatal crashes can be reduced by cooperative systems per year. This represents a 4.3% reduction in the total number of fatal crashes. The major contributor to this potential 4.3% reduction is rural mayday. This is graphically depicted in figure 5-2.

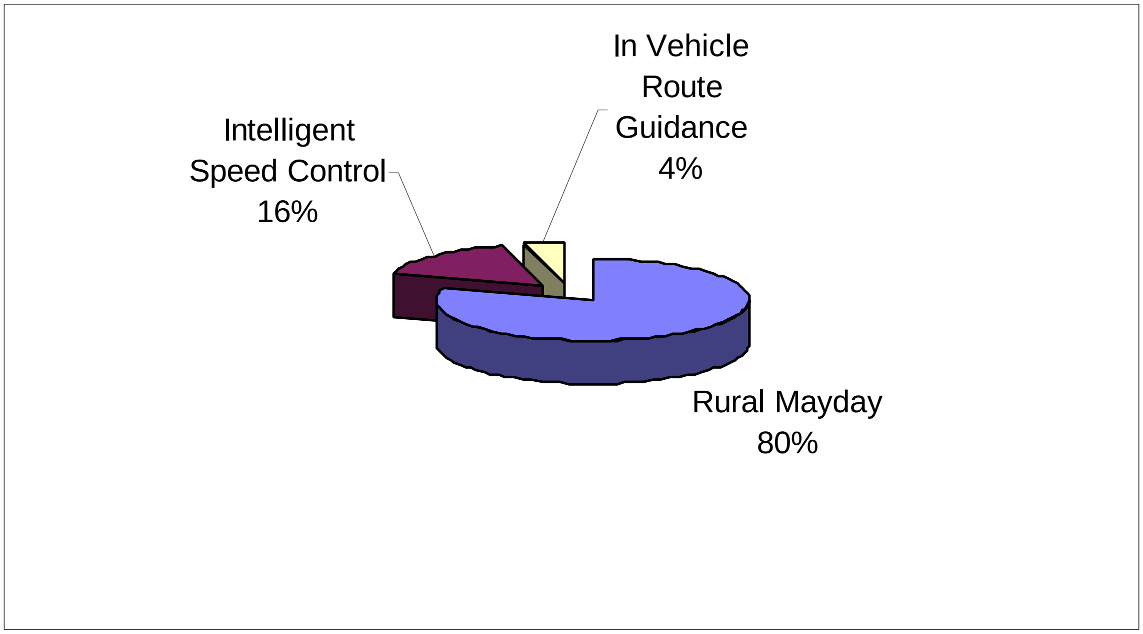
Table 5-2: Fatal Crash Reduction Estimates for Cooperative ITS

ITS Technology	Impacted Crash Type	Adjusted Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
In vehicle Navigation	Urban arterials	6,536	1%	65	0.2%
Rural Mayday	Rural roads	18,081	7%	1,266	3.4%
Intelligent Speed Control	Urban freeways	1,290	20%	258	0.7%
Total				**1,589**	**4.3%**

---

[1] From section 5.3, rear end CAS reduces 621 fatal crashes, lane change CAS reduces 75 fatal crashes and road departure CAS reduces 3,087 fatal crashes. Of these, using the rural/urban crash distributions from table 2-1, we estimate 310 rear end, 30 lane change and 2,055 road departure fatal crashes are reduced in rural areas for a total of 2,395.

Figure 5-2: Contribution to Fatal Crash Reduction by Cooperative ITS Countermeasure



5.3 Vehicle-based Systems

The three types of vehicle-based systems that have shown the potential to improve traffic safety are all crash avoidance systems: rear-end CAS, lane change/merge CAS, and road departure CAS. Their impacts on fatal crashes are discussed below.

5.3.1 Rear-end CAS

From section 3, about 48% of all rear-end collisions can be avoided using rear-end collision warning systems. In table 2-1 we noted that there were 1,665 fatal accidents involving rear-end collisions in 1995. Of these 1,665 fatal crashes, we estimate that ITS Infrastructure Systems and ITS cooperative systems have the potential to reduce 340 of them[2]. Therefore, in order to avoid double counting, we adjust the crash type size to 1,325 fatal rear-end crashes. A 48% reduction in this number equals a reduction of 636 fatal crashes.

5.3.2 Lane change/merge CAS

From section 3, lane change/merge crash avoidance systems can reduce lane change accidents by about 37%. From table 2-1, we know that there were 282 fatal crashes of the type sideswipe/same direction in 1995. As explained in section 2, this report uses sideswipe/same direction crashes to estimate the target crash size for lane change/merge CAS. Of the 282 fatal crashes, we estimate that infrastructure-based and cooperative ITS

---

[2] Using cross tabulations from section 2: Rear end crashes reduced by ITS infrastructure and ITS cooperative = [(.24+.18+.20)*382]+[(.20+.01)*363]+[(.78)*1]+[(.40)*27]+[(.85)*18] = 340

countermeasures will have already reduced 78 of them[3]. Therefore, in order to avoid double counting, we adjust our sideswipe/same direction crash type size to be 204 fatal crashes. Using the 37% reduction rate, we estimate a reduction of 75 fatal crashes.

5.3.3 Road Departure CAS

From section 3, road departure systems can result in a 24% decrease in single vehicle, run off the road type fatal crashes. From table 2-1, there were 14,445 of these type fatal crashes in 1995. Of the 14,445 fatal crashes, we estimate that infrastructure-based and cooperative ITS countermeasures will have already reduced 1,494 of them[4]. Therefore, in order to avoid double counting, we adjust our single vehicle, run off the road crash type size to be 12,951 fatal crashes. Using the 24% reduction rate, we estimate a reduction of 3,108 fatal crashes.

5.3.4 Combined Impact of Vehicle Systems

A summary of the impact of vehicle-based ITS on fatal crash reduction is shown in table 5-3. From the table, we see that 3,783 fatal accidents can be reduced by vehicle-based systems per year. This represents with a 10.2% reduction in the total number of fatal crashes. We assume that safety contributions from each vehicle-based technology are independent. We have also tried to ensure that we are not double counting accidents that would be reduced by infrastructure-based and cooperative ITS countermeasures. The majority of this 10.2% reduction is due to the roadway departure CAS as shown in figure 5-3. The reason for this is that roadway departure crashes have a high proportion of fatal crashes.

Table 5-3: Fatal Crash Reduction Estimates for Vehicle-Based ITS

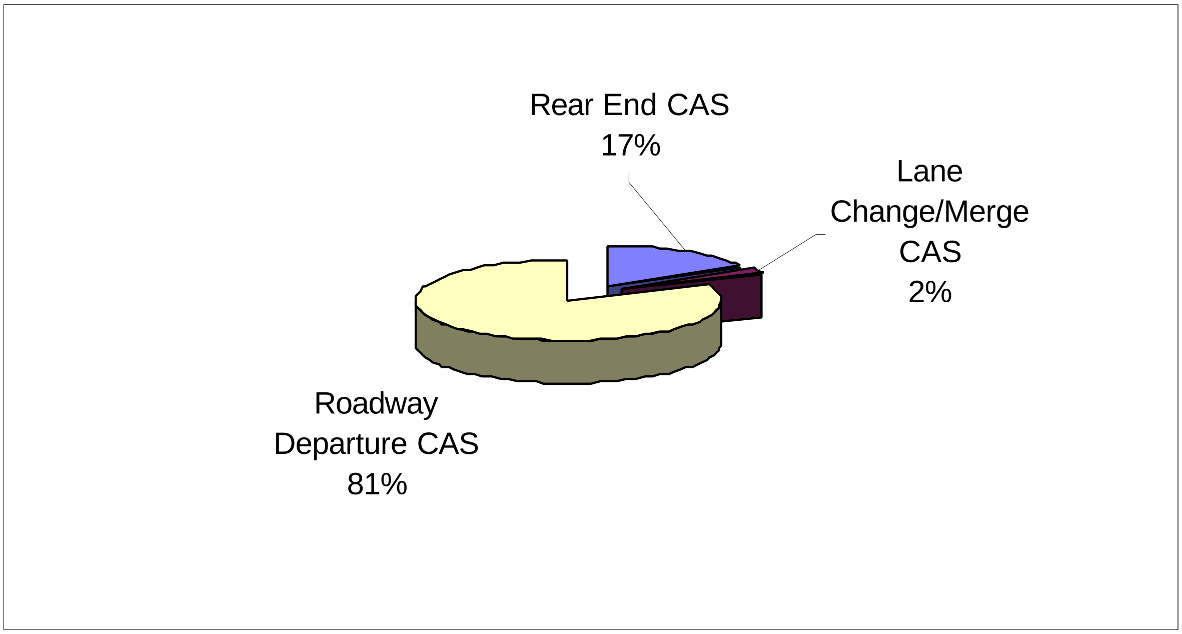
ITS Technology	Impacted Crash Type	Adjusted Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
Rear End CAS	Rear End	1,325	48%	636	1.7%
Lane Change/ Merge CAS	Side swipe, same direction	204	37%	75	0.2%
Roadway Departure CAS	Single Vehicle, off roadway	12,951	24%	3,108	8.4%
Total				**3,820**	**10.3%**

---

[3]. Using cross tabulations from section 2: lane change crashes reduced by ITS infrastructure and ITS cooperative = [(.24+.18+.20)*108]+[(.20+.01)*47]+[(.40)*1] = 78

[4] Using cross tabulations from section 2: road departure crashes reduced by ITS infrastructure and ITS cooperative = [(.24+.18+.20)*1386]+[(.20+.01)*1868]+[(.40)*327]+[(.85)*131] = 1494

Figure 5-3: Contribution to Fatal Crash Reduction by Vehicle Countermeasure



5.4 Total Fatal Crash Reduction

Since we have already eliminated double counting between crash reduction estimates for infrastructure-based, cooperative and vehicle-based systems, the crashes from table 5-1, table 5-2 and table 5-3 are additive. The reader is warned not to over-analyze the relative distribution of the crash reduction percentages since our double counting methodology biased the distribution in favor of the infrastructure-based and cooperative ITS countermeasures. For instance, if the double counting was treated in the reverse order with vehicle-based countermeasures given full credit, then vehicle-based countermeasures would have about a 2% higher total crash reduction while infrastructure and cooperative ITS would be a combined 2% lower.

Table 5-4 shows the total fatal crash reduction of 9,572 fatal crashes or 25.7% from implementing ITS with 100% market penetration. This result differs slightly from an earlier safety benefits study [17] because an improved methodology was used to estimate ITS safety benefits. Some of the improvements to this methodology include using more recent and refined crash size data, applying new and revised crash reduction factors, and introducing a treatment for double counting into the estimation process. The reader should recall that these estimates are based on the current state of knowledge and largely reflect medium to low levels of confidence in specific crash reduction factors.

Table 5-4: 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%**

Section 6: Injury Crash Reduction

The purpose of this section is to compute a national estimate for the annual percentage reduction in injury crashes as a result of 100% ITS deployment. This estimate is based on the theoretical and empirical data currently available in the literature. To estimate benefits, we apply expected crash reduction rates for each ITS countermeasure (given in section 3) to specific crash problem sizes (given in section 2) using the methodology discussed in section 4 and applied in section 5.

Many of the same crash reduction factors used in section 5 for fatal crashes are also used in this section for injury crashes. Therefore, in order to avoid redundancy, the discussion on how to calculate the safety benefits of each ITS countermeasure will be left out. Only the when there are major differences from section 5 will there be discussion. The summary tables showing the results of the calculations are still presented.

The rest of this section is organized as follows. The impacts of infrastructure-based ITS, vehicle-based ITS and cooperative ITS on injury crashes are discussed in sections 6.1, 6.2, and 6.3 respectively. Section 6.4 provides an aggregated estimate for the combined impact of all ITS countermeasures on injury crashes.

6.1 Infrastructure-based ITS

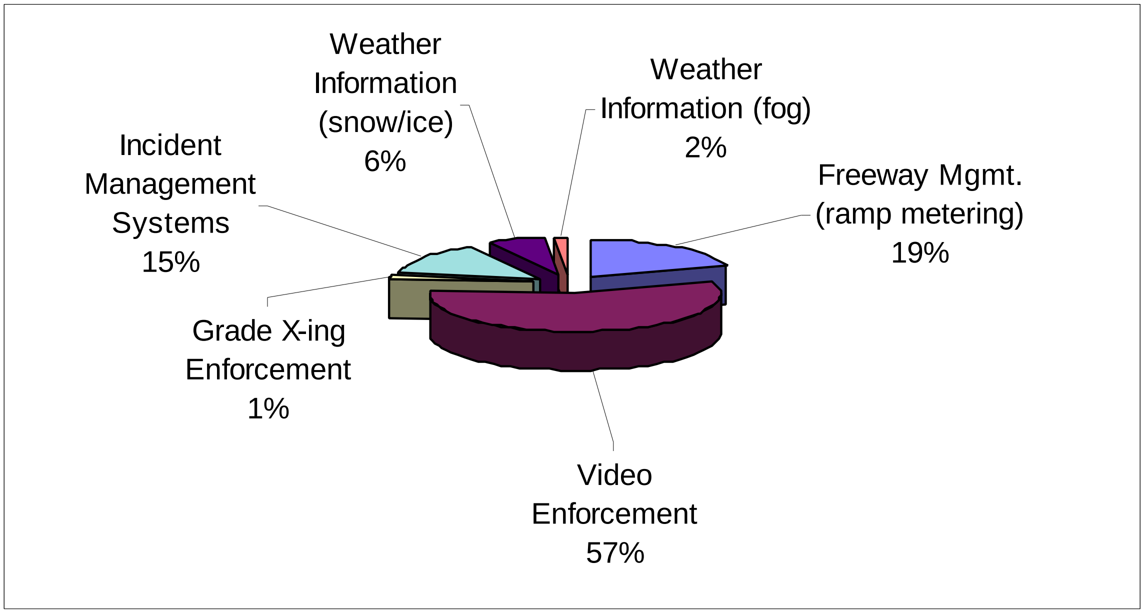
The calculation of the injury crash reduction from ramp metering, incident detection systems, video enforcement, railroad crossing enforcement and RWIS is similar to the calculation for fatal crash reduction in section 5. The same crash reduction factors are used with target crash sizes extracted from the GES database.

A summary of the injury crash reduction estimates for infrastructure-based systems are shown in Table 6-1. From the table, we see that 312,280 injury crashes can be reduced per year when ITS Infrastructure systems are implemented. This represents a 14.4% reduction in the total number of injury accidents. We assume that safety contributions from each ITS infrastructure countermeasure are independent. Figure 6-1 shows that over half of the injury crash reduction comes from video enforcement. One reason for this could be that a high number of injury accidents take place on urban arterials, which is the road type on which these two countermeasures are implemented.

Table 6-1: Injury Crash Reduction Estimates for Infrastructure-Based ITS

ITS Technology	Impacted Crash Type	Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
Ramp Metering	Urban Freeways	253,000	24%	60,720	2.8%
Video Enforcement	Urban Arterials	895,000	20%	179,000	8.3%
Grade X-ing Enforcement	Railroad Crossings	4,000	78%	3,120	0.1%
Incident Detection Systems	Urban freeways	253,000	18%	45,540	2.1%
Weather Monitoring (snow/ice)	Rural, weather related	47,000	40%	18,800	0.9%
Weather Monitoring (fog)	Rural, fog related	6,000	85%	5,100	0.2%
Total		**2,166,000**		**312,280**	**14.4%**

Figure 6-1: Contribution to Injury Crash Reduction by Infrastructure-based Countermeasure



6.2 Cooperative ITS

The calculation of the injury crash reduction from in-vehicle navigation systems and intelligent speed control is similar to the calculation for fatal crash reduction in section 5.

The same crash reduction factors are used with target crash size estimates extracted from the GES database. It should be noted that rural mayday systems do not contribute to injury crash reduction because they are only responsible for reducing emergency response times, not crash frequencies. Reducing emergency response times will reduce fatalities but not injury crashes, thus mayday systems are not included in the calculation of injury crash reduction. Also note that double counting was taken into account and the target crash sizes were reduced as discussed below.

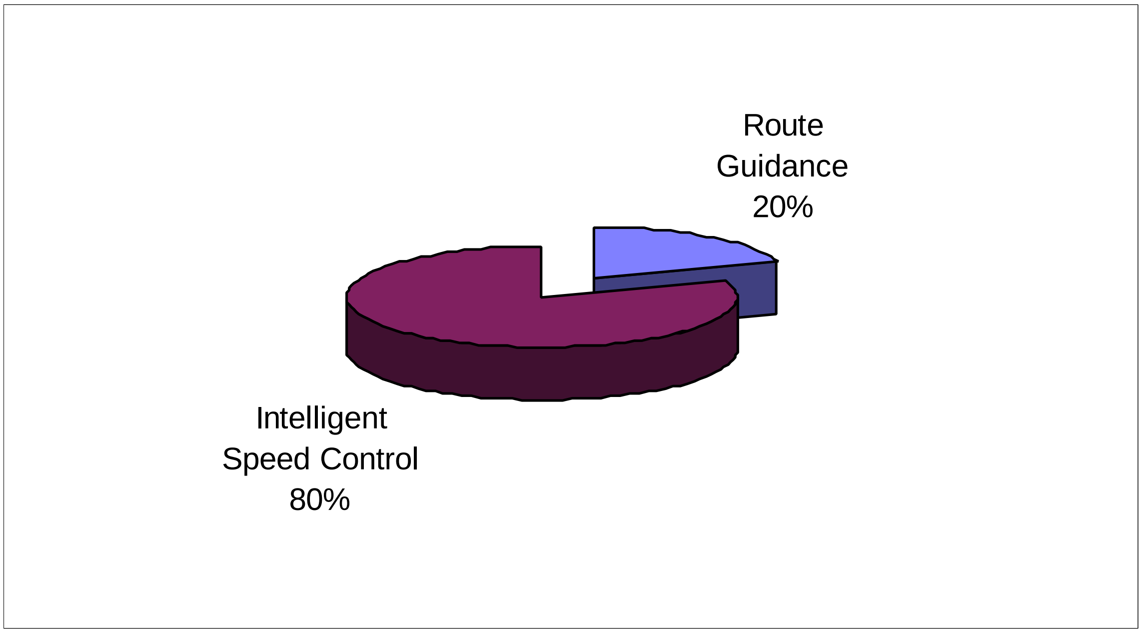
In section 2 we noted that there were approximately 253,000 injury crashes on urban freeways and 895,000 injury crashes on urban arterials in 1995. In section 6.1 we showed that ramp metering and incident detection systems could reduce injury crashes on urban freeways by 60,720 and 45,540 respectively. Also, in section 6.1 we showed that video enforcement could reduce injury crashes on urban arterials by 179,000. Thus, for cooperative systems, the target crash size for urban freeways is adjusted to 147,000 and the target crash size for urban arterials is adjusted to 716,000.

A summary of the injury crash reduction estimates for infrastructure-based systems are shown in Table 6-2. From the table, we see that 36,560 injury crashes can be reduced per year when cooperative ITS systems are implemented. This represents a 1.7% reduction in the total number of injury accidents. We assume that safety contributions from each ITS infrastructure countermeasure are independent. Figure 6-2 shows that almost most of the injury crash reduction comes from intelligent speed control.

Table 6-2: Injury Crash Reduction Estimates for Cooperative ITS

ITS Technology	Impacted Crash Type	Adjusted Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
In-Vehicle Navigation	Urban Arterials	716,000	1%	7,160	0.3%
Intelligent Speed Control	Urban Freeways	147,000	20%	29,400	1.4%
Total		**2,166,000**		**36,560**	**1.7%**

Figure 6-2: Contribution to Injury Crash Reduction by Cooperative Countermeasure



6.3 Vehicle-based ITS

The calculation of the injury crash reduction from all three types of crash avoidance systems is similar to the calculation for fatal crash reduction in section 5. The same crash reduction factors are used with target crash sizes extracted from the GES database. Also note that double counting was taken into account and the crash type sizes were reduced as discussed below.

In section 2 we noted that there were approximately 531,000 injury accidents involving rear-end collisions in 1995. Of these, we estimate that ITS Infrastructure and Cooperative Systems will have already reduced 119,000 crashes[5]. Therefore, in order to avoid double counting, the crash type size is adjusted to 412,000 rear-end injury crashes.

From section 2, we know that there were approximately 55,000 injury crashes of the type sideswipe/same direction in 1995. Since these types of crashes are indicative of lane change/merge crashes, we can use sideswipe/same direction type crashes to estimate injury crash reduction. Of the 55,000 injury crashes, we estimate that ITS Infrastructure and Cooperative Systems will have already reduced 14,000 of them[6]. Therefore, in order to avoid double counting, the sideswipe/same direction crash type size is adjusted to 41,000 injury crashes.

According to section 2, there were approximately 422,000 injury crashes of the type road departure in 1995. Of these, we estimate that ITS Infrastructure and Cooperative Systems

---

[5] Determined in a manner similar to that in section 5.3 using cross tabulations from the GES database.

[6] Determined in a manner similar to that in section 5.3 using cross tabulations from the GES database.

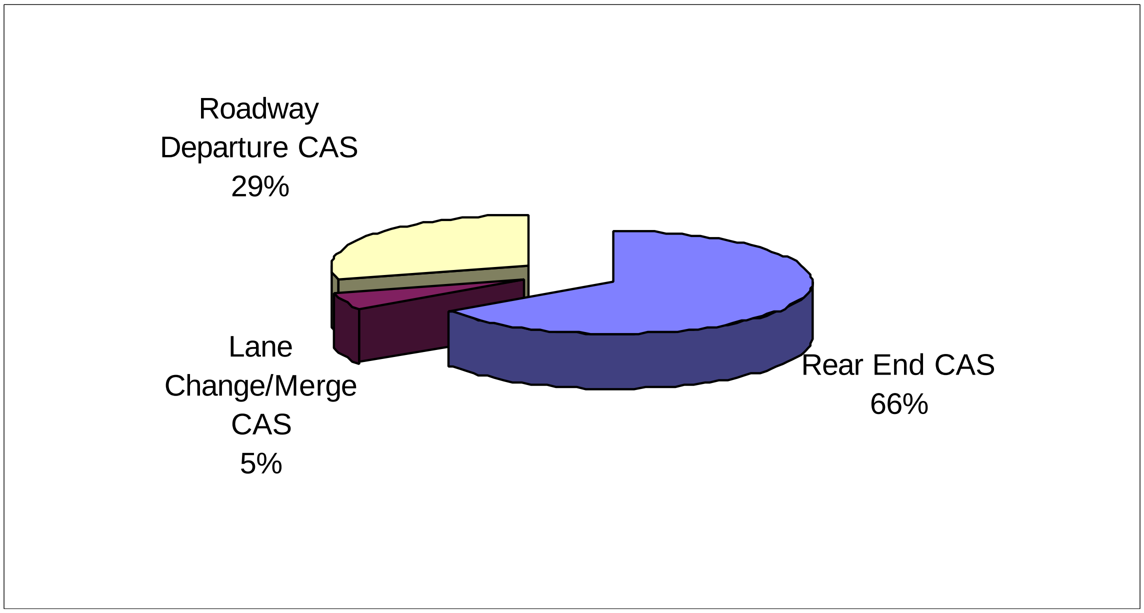
will have already reduced 60,000 of them[7]. Therefore, in order to avoid double counting, the single vehicle, run-off-the-road crash type size is adjusted to 362,000 injury crashes.

A summary of the injury crash reduction estimates for vehicle-based systems are shown in table 6-3. From the table, we see that 299,810 injury crashes can be reduced per year when ITS In-vehicle systems are implemented. This represents a 13.8% reduction in the total number of injury crashes. We assume that safety contributions from each ITS in-vehicle technology are independent. We have also tried to ensure that we are not double counting crashes that would be reduced by infrastructure-based and cooperative ITS countermeasures. Figure 6-3 shows that most of these injury crashes are reduced by the rear-end CAS. This is because 1) there are a large number of rear-end injury crashes to begin with and 2) the rear-end CAS is a very effective countermeasure, reducing nearly half of all rear-end crashes.

Table 6-3: Injury Crash Reduction Estimates for In-Vehicle Systems

ITS Area	ITS Technology	Impacted Crash Type	Adjusted Crash Type Size	Crash Reduction Factor	Crashes Avoided	Total Crash Reduction
Safety	Rear End CAS	Rear End	412,000	48%	197,760	9.1%
	Lane Change/ Merge CAS	Side swipe, same direction	41,000	37%	15,170	0.7%
	Roadway Departure CAS	Single Vehicle, off roadway	362,000	24%	86,880	4.0%
Total			**2,166,000**		**299,810**	**13.8%**

Figure 6-3: Contribution to Injury Crash Reduction by In-Vehicle Countermeasure



---

[7] Determined in a manner similar to that in section 5.3 using cross tabulations from the GES database.

6.4 Total Injury Crash Reduction

Since we have already eliminated double counting between crash reduction estimates for ITS infrastructure systems and those for in-vehicle systems, the crashes from tables 6-1, 6-2 and 6-3 are additive. The reader is warned not to over-analyze the relative distribution of the crash reduction percentages since our double counting methodology biased the distribution in favor of the infrastructure-based and cooperative ITS countermeasures. For instance, if the double counting was treated in the reverse order with vehicle-based countermeasures given full credit, then vehicle-based countermeasures would have about a 2% higher total crash reduction and infrastructure while cooperative ITS would be a combined 2% lower.

Table 6-4 shows the total injury crash reduction 648,650 crashes or 29.9% from implementing ITS with 100% market penetration. This result differs slightly from an earlier safety benefits study [19] because an improved methodology was used to estimate ITS safety benefits. Some of the improvements to this methodology include using more recent and refined crash size data, applying new and revised crash reduction factors, and introducing a treatment for double counting into the estimation process. The reader should recall that these estimates are based on the current state of knowledge and largely reflect medium to low levels of confidence in specific crash reduction factors.

Table 6-4: 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%**

Section 7: Conclusions and Recommendations

In this report, we estimated possible upper bounds for safety benefits associated with ITS implementation. It should be emphasized that these estimates are based on an assumption of 100 percent market penetration of the ITS technologies or user services. For many of these technologies, 100% deployment may never be achieved. Table 7-1 shows aggregate estimates of fatal and injury crash reduction due to ITS implementation. Note that crash reduction percentages are presented as annualized savings in a future time period in which 100% deployment has occurred. These savings are relative to the expected crash sizes for the no-ITS baseline. The reader should recall that these estimates are based on the current state of knowledge and largely reflect medium to low levels of confidence in specific crash reduction factors.

Table 7-1: Aggregate Estimates of ITS Safety Benefits

Goal Area	Percentage Decrease
Fatal Crash Reduction	26%
Injury Crash Reduction	30%

It is clear that more empirical evidence would be desirable to support these estimated benefits. Good baseline data exists for fatal and injury crashes in the form of the FARS and GES databases. However, many of the results regarding potential crash reductions resulting from ITS technologies are not empirically based. One reason for this is that many of the technologies, particularly vehicle-based technologies, have not yet been tested in the field. For example, the crash reduction rates from crash avoidance systems were determined using experimental data in conjunction with simple theoretical models rather than real world results [1]. Also, many of the empirical studies used to obtain crash reduction estimates were based on a simple before-and-after methodology, which is not always sophisticated enough to obtain an accurate sample of crash reduction factors. Therefore, it is recommended that more rigorous statistical studies be performed based on empirical evidence in order to provide better estimates of the potential safety benefits of ITS. Currently, these studies do not exist in the literature.

Another area of ITS safety benefits research that is missing is the impact of ITS on crash severity. Most of the before-and-after studies that were referenced in this report provide just one crash reduction factor for a given ITS countermeasure. In reality, each ITS countermeasure will have varying impacts on fatal, injury and property damage crashes. It is very important to obtain these different crash reduction factors if one is to calculate an accurate estimate of ITS safety benefits.

Also, there are a number of ITS countermeasures that either have no crash reduction factors associated with them or the crash reduction factor that was used has a low level of confidence (see table 3-1). The following ITS countermeasures are likely to have an impact on safety but were not considered in this report since a crash reduction factor could not be assigned to them:

- adaptive signal control,
- advanced warning systems (ramp rollover, downhill warning),
- night vision,
- driver monitoring, and
- ITS for CVO and transit.

ITS countermeasures that have crash reduction factors associated with them but require more research in order to obtain more confidence in these factors include:

- grade crossing enforcement,
- road weather information systems,
- in-vehicle navigation systems,
- mayday systems and
- intelligent speed control.

It is recommended that more evaluation research be performed in each of these areas in order to improve the overall level of confidence in the crash reduction factors and the safety benefits estimates. It is further recommended that the crash reduction estimates in this report be revised as more reliable and sophisticated studies on measured ITS benefits become available in the literature and new ITS countermeasures are introduced and tested.

Another recommendation is to improve the methodology for treating double counting between various ITS countermeasures. This will require acquiring more empirical data on the interaction between various ITS components. In order to obtain this data, it is necessary to have these countermeasures actually implemented together, which may not happen for some time.

Finally, although it was not the intent of this report, various market penetration values could be incorporated into this methodology in order to obtain crash reduction estimates over a defined time period. For instance, if one wanted to know how much ITS could potentially reduce fatal and injury crashes by the year 2005, they could introduce the expected market penetrations of ITS for that year and adjust the estimates accordingly. This process has already been carried out on a limited scale to obtain benefit estimates for the year 2005 for a number of ITS goal measures [20]. Further work in this area is recommended.

References

1. National Highway Traffic Safety Administration (1996), *Preliminary Assessment of Crash Avoidance Systems Benefits*, monograph, U.S. Department of Transportation, Washington, D.C.

2. National Highway Traffic Safety Administration (1995), *Traffic Safety Facts 1995*, U.S. Department of Transportation, Washington, D.C.

3. Federal Highway Administration (1995), *Highway Statistics 199*5, U.S. Department of Transportation, Washington D.C.

4. Office of Motor Carriers, FHWA (1997). *Large Truck Crash Profile: The 1996 National Picture*, Washinton D.C.

5. Tarko, Andrzej and Eranky, Shyam (1998). *Methodological Considerations in the Development and Use of Crash Reduction Factors*, Transportation Research Board Proceedings, Washington D.C.

6. Piotrowicz, G. and Robinson, J. (1995), *Ramp Metering Status in North America, June 1995*, U.S. Department of Transportation, Washington, D.C.

7. Summersgill, I., et. al. (1998)*, Benefits of the Automatic Incident Detection System on the M1*, United Kingdom Highways Agency, Transport Research Laboratory (to be published later this year).

8. Harris J. and Sands M. (1995), Life Saving Speed Camera Technology, *Traffic Technology International*, Spring 1995.

9. U.S. DOT (1996), *FHWA Scanning Tour of Speed Management and Enforcement Technology*, Washington D.C., February 1996.

10. Harbord, B. (1997), Success Over Stop-Start, *Traffic Technology International*, Oct/Nov 1997.

11. Rathbone, D. (1997), Cameras Reduce Red Light Running Violations by 20-30%, U*rban Transportation Monitor,* Vol. 11, No. 10, May 23, 1997.

12. Barbaresso, J. (1994), *Preliminary Findings and Lessons Learned from the FAST-TRAC IVHS Program*, Road Commission for Oakland County, Beverly Hills, Michigan.

13. Taylor, B. and Bergan, A. (1997), Words of Warning, *ITS: Intelligent Transport Systems*, Issue Number 10, May/June 1997.

14. Rathbone, D. (1995), Photo Enforcement Proves Very Effective, *Urban Transportation Monitor*, Vol. 9, No. 5, March 17, 1995.

15. European Commission DG VII/ DG XII (1996), *Progress in Telematics Applications for Road Transport in Europe*, RTT-HLG, November 1996.

16. Inman, V., et. al. (1996), *TravTek Global Evaluation and Executive Summary*, Federal Highway Administration, March 1996.

17. Evanco, W. (1996), *Reducing Accident Fatalities with Rural Mayday Systems*, Working Note WN96W0000048, Mitretek Systems, Washington, D.C.

18. Jesty, P. (1998), Easier Driving on Safer Roads, *Traffic technology International*, June/July 1998.

19. Shank, D. (1997), *Safety Benefits from ITS Services*, monograph, Mitretek Systems, Washington D.C.

20. Mitretek Systems (1998*), Working Paper: Estimating Target Values for ITS Goal Measures*, Washington D.C., October 1998.

σ **Mitretek Product**