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16. Abstract

The purpose of this study was to identify, through a literature review, the potential safety benefits of implementing various ITS technologies through Virginia's Smart Travel Program. This study was requested by the ITS Section of the Virginia Department of Transportation to document what is believed to be an underestimated benefit of ITS: safety.

Several Advanced Traffic Management Systems technologies improve safety, primarily through reducing congestion. In general, this reduces crash risk, particularly for multivehicle crashes. Advanced Traveler Information Systems (ATIS) provide information to the public by such means as the broadcast media, cable television, highway advisory radio, and the Internet. Although no studies document an impact, a simulation study showed that such a system has the potential to reduce crash risk.

Commercial Vehicle Operations (CVO) applications have the potential to reduce the risk of fatalities and serious injuries. CVO are generally geared to improving the efficiency of safety inspections and reducing inconvenience to motor carriers that are not in violation. Because of greater efficiency, more hazardous vehicles and drivers can be removed from service.

Much of the work on Advanced Vehicle Control and Safety Systems is in the developmental stages. Although vehicle-based warning systems would provide the driver with some warning once the vehicle enters a hazardous situation, road-based or integrated systems have the potential to warn the driver before entering the danger zone.

Advanced Public Transportation Systems and Advanced Rural Transportation Systems could have a positive impact on safety through the deployment of Mayday systems and alarms and other security warning devices that notify authorities in the event of an incident.

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FINAL REPORT

EXPECTED SAFETY BENEFITS OF IMPLEMENTING INTELLIGENT TRANSPORTATION SYSTEMS IN VIRGINIA: A SYNTHESIS OF THE LITERATURE

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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EXECUTIVE SUMMARY

Introduction

The purpose of this study was to identify through a literature review the potential safety benefits of implementing various ITS technologies through Virginia's Smart Travel Program. This study was requested by the ITS Section of the Virginia Department of Transportation to document what is believed to be an underestimated benefit of ITS: safety.

Results

Advanced Traffic Management Systems (ATMS)

ATMS gather data through such means as loop detectors and video surveillance to determine traffic flow and congestion and to detect incidents. Several ATMS technologies have been shown to improve safety.

ATMS reduces congestion. In general, this reduces crash risk, particularly for multivehicle crashes. Further, the risk of secondary crashes is reduced, as crash risk increases as much as 600% once a crash occurs on a congested facility.

Freeway management systems reduce crashes. In San Antonio, crashes during the peak hours were reduced by 35% and in Minneapolis by 27%.

Traffic signal management systems reduce stops at traffic lights. A traffic signal management system in Los Angeles, in which signal timing on the network was centrally coordinated, resulted in a 40% reduction in stops at traffic lights. Such a reduction in traffic stops would be expected to reduce the number of rear-end crashes.

Ramp metering, which regulates the flow of traffic onto a facility, is particularly effective in reducing crashes. In Seattle, crashes were reduced by 62% during peak hours after ramp meters were installed, and in Oregon, crashes were reduced by 43% after a similar system was installed. In Denver, rear-end and sideswipe crashes decreased 50% after a ramp metering system was installed.

Radar-activated speed warnings can reduce speeds. The strategic placement of radar-activated truck speed warnings at curves that present a truck rollover risk resulted in a substantial reduction in truck speeds in Colorado and on the Capital Beltway around Washington, D.C. Although 10 rollover crashes occurred on the beltway ramps on which the warning devices were installed in the 5 years prior to installation, none occurred in the subsequent 3 years.

Automated enforcement can reduce crashes. In London, the use of photo radar reduced crashes 20% to 80% at various locations and reduced speed 10%. Using automated cameras to enforce red-light violations reduced violations 30% in San Francisco; 23% in Howard County, Maryland; and 20% in New York City. The use of automated cameras at rail-grade crossings in Los Angeles reduced violations 92%. Reductions in violations would be expected to reduce crashes as well.

Radar-activated variable message signs have the potential to improve safety in work zones. A study in Virginia showed that the use of radar-activated variable message signs to alert speeding drivers to slow down was effective in reducing the number of vehicles that speed through work zones. Such reductions in speeding vehicles would be expected to improve work zone safety.

Advanced Traveler Information Systems (ATIS)

The impact of ATIS on safety is difficult to measure. ATIS provide information to the public by such means as the broadcast media, cable television, highway advisory radio, and the Internet. No studies document an impact on safety. However, an experimental in-vehicle navigation system, TravTek, was tested in Orlando. A simulation study showed that such a system has the potential to reduce crash risk by 4% and reduce crash risk to diverted vehicles by 10%, with no adverse impact on the highway network as a whole.

Commercial Vehicle Operations (CVO)

CVO applications have the potential to reduce the risk of fatalities and serious injuries on the highway. CVO are generally geared to improving the efficiency of safety inspections and reducing inconvenience to motor carriers that are not in violation. In Oregon and the Midwest, screening drivers and vehicles and increasing the efficiency of inspections resulted in an increase in the number of inspections and the number of drivers and vehicles in violation that are removed from service. Because of the difference in mass between passenger vehicles and large trucks, collisions between these vehicles tend to be severe.

Advanced Vehicle Control and Safety Systems (AVCSS)

Much of the work on AVCSS is in the developmental stage. AVCSS include advanced collision avoidance systems and automated highway systems such as headway, lane, and speed detection and warning systems that help keep the driver on the roadway and avoid crashes with other vehicles. Although vehicle-based warning systems warn drivers once their vehicle enters a danger zone, road-based or integrated systems have the potential to warn drivers before they enter the danger zone.

Examples of successful implementation of collision warning devices are tests by Greyhound and Transport Besner Trucking Company. With Greyhound, crashes were reduced 40% when vehicles were equipped with the warning device, and with Transport Besner, crashes were reduced 33%. Advanced warning flashers at high-speed intersections have also proven effective, resulting in a 35% reduction in crashes at intersections with an approach speed of 80 km/h or greater.

Advanced Public Transportation Systems (APTS)
and Advanced Rural Transportation Systems (ARTS)

These systems could have a positive impact on safety through the deployment of Mayday systems and alarms and other security warning devices that notify authorities in case of an incident. Although many APTS incidents are likely to be crime related, such devices can cut incident notification time, thereby reducing total response time by about 40%. A German study estimated that such a reduction in response time would result in a 12% increase in a vehicle occupant's chances for survival in a rural crash.

FINAL REPORT

EXPECTED SAFETY BENEFITS OF IMPLEMENTING INTELLIGENT TRANSPORTATION SYSTEMS IN VIRGINIA: A SYNTHESIS OF THE LITERATURE

Jack D. Jernigan
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"Safety is one of the most underestimated benefits of intelligent transportation systems."

J. R. Robinson
Virginia Department of Transportation

INTRODUCTION

The U.S. Congress established the nation's intelligent transportation systems (ITS) program with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. ITS uses computer and telecommunications technologies "to enhance the safety and efficiency of surface transportation" (General Accounting Office, 1997: 1). These systems can be grouped into the following areas:

- *Advanced Traffic Management Systems (ATMS)* collect and analyze traffic data. These data are gathered through such means as loop detectors and video surveillance to determine traffic flow and congestion and to detect incidents.

- *Advanced Traveler Information Systems (ATIS)* disseminate information to the public. Means of dissemination include the broadcast media, cable television, highway advisory radio, and the Internet.

- *Commercial Vehicle Operations (CVO)* target motor carrier safety and productivity. This includes technological advances that improve safety inspections and reduce paperwork and inconveniences to motor carriers that are not in violation.

- *Advanced Vehicle Control and Safety Systems (AVCSS)* include Advanced Collision Avoidance Systems (ACAS) and Automated Highway Systems (AHS). ACAS concentrate on crash avoidance, and AHS focus on the long-term objective of providing for "hands-off" driving.

- *Advanced Public Transportation Systems (APTS)* include fixed-route and demand-responsive public transportation. This area includes public information and public transportation management (e.g., intermodal scheduling).

- *Advanced Rural Transportation Systems (ARTS)* include adaptations and applications of ITS for a rural environment (Federal Highway Administration, 1996).

Some of these systems, such as AHS, have not yet been implemented, but certain technological applications are being deployed today and others can be deployed in the short run. Traffic signals can be coordinated so that the highway network can achieve optimal performance given the level of demand. Travelers can be advised of potential delays and be given information on alternate routes. Incidents can be detected as they happen, thereby improving response time and decreasing the time an incident affects the highway system.

The GAO (1997) noted significant obstacles to the widespread deployment of ITS. One was the lack of cost-benefit data concerning ITS. Perhaps one of the underestimated benefits of ITS is improved transportation safety. Reducing traffic congestion and providing advanced warnings to motorists have the potential to reduce crashes and the resulting injuries and fatalities. Detecting traffic crashes and other incidents as they happen can reduce secondary crashes and the time it takes to transport an injured person to a medical facility, thereby having the potential to reduce injuries and save lives.

PROBLEM STATEMENT

Although a number of ITS technologies have been implemented or are planned for implementation in Virginia, the expected safety benefit of those technologies has not been determined.

PURPOSE AND SCOPE

The purpose of this study was to conduct a literature review to identify the potential safety benefits of implementing various ITS technologies through Virginia's Smart Travel Program. This study was requested by the ITS Section of the Virginia Department of Transportation to document what is believed to be an underestimated benefit of ITS: safety. The study did not provide a benefit/cost analysis but was limited to investigating the state of knowledge regarding the potential transportation safety benefits of ITS.

METHODS

A review of the literature on the expected and documented safety benefits of ITS technologies was conducted.

POTENTIAL SAFETY BENEFITS OF ITS TECHNOLOGIES

Advanced Traffic Management Systems

Congestion Reduction

Crash risk typically increases as traffic volumes increase (Chang. 1982). In congested conditions, crashes are more likely to involve multiple vehicles rather than single vehicles (Ceder, 1982). Thus, as congestion decreases, crashes, particularly multivehicle crashes, can be expected to decrease.

User services such as ramp metering, incident management systems, and coordinated traffic signal systems can improve traffic flow and reduce congestion (Tedesco, Alexiadis, Loudon, Margiotta, & Skinner. 1993). This, combined with reducing speed variance and the number of stops, may reduce crashes and enhance safety. Further, safety may be enhanced by diverting vehicles from a congested facility to a less congested one.

The most frequent causes of traffic congestion are incidents such as crashes, vehicle breakdowns, and other unpredictable events (Meyer, 1989). Reducing the number of incidents should reduce congestion. Reduced congestion, in turn, should further reduce the number of crashes. Thus, the use of ITS technologies, such as video surveillance, sensors, and variable message signs, can reduce congestion and reduce travel time by 10% to 45% during peak periods.

Tedesco, Alexiadis, Loudon, Margiotta, and Skinner (1993) noted that reducing congestion can lead to a reduction in secondary crashes. In the event of a crash, the risk of a secondary crash is increased by more than 600%. Sullivan and Hsu (1988) estimated the increase at 300%. Both estimates are large because once a crash occurs, congestion, speed variance, and traffic stops increase, thereby increasing crash risk. Thus, ITS systems that reduce crash risks will likely greatly reduce the risk of secondary crashes.

Henk (1996) reported on the evaluation of the TransGuide system in San Antonio, Texas, which uses variable message signs, video cameras, and loop detectors to aid in the detection of incidents. After the implementation of the system, incident response time improved by about 20%, crashes decreased by 35%, and secondary crashes decreased by 30%.

The General Accounting Office (1994) indicated that properly designed traffic control signal systems can reduce congestion and crashes along a corridor or highway network. The City of Los Angeles Department of Transportation (1994) reported on the effectiveness of a traffic signal management system that adjusts for traffic conditions. Stops at traffic lights have decreased by more than 40%. Such a reduction would be expected to reduce the number of rear-end crashes as moving traffic approaches the stopped or slowing queue.

The Minnesota Department of Transportation (1989) reported that a freeway management system has provided considerable safety benefits. In the Minneapolis/St. Paul area, the system includes metered ramps, highway advisory radio, closed circuit television cameras, variable message signs, and a central traffic management center. In the 10 years after implementation, the average peak speed increased from 55 to 74 km/h. Traffic crashes during the peak period decreased by 27%, and the crash rate decreased by 38%, which reflected a 32% increase in traffic.

Ramp Metering

Henry and Meyhan (1989) conducted a 6-year evaluation of the Seattle, Washington, ramp metering and freeway management system. Overall, highway capacity during the peak period increased by 10% to 100% and travel speeds increased. Crash rates were reduced by 62%.

The Oregon Department of Transportation (1982) also found that ramp metering provided substantial safety benefits. In slightly more than 1 year after ramp meters were installed, the average travel speed in the afternoon peak hours increased from 26 to 66 km/h and in the morning peak hours from 64 to 69 km/h. In the afternoon peak hours, crashes declined by more than 43%.

Piotrowicz and Robinson (1995) reported on a pilot ramp-metering project in Denver, Colorado, in 1981. An 18-month evaluation revealed that the peak driving speed increased 57% and rear-end and sideswipe crashes decreased 5% because stop-and-go conditions were eliminated. After this evaluation, the use of ramp meters was expanded. The overall frequency of crashes did not increase between the first evaluation and 1989, but traffic volumes did increase, producing an overall decrease in the peak crash rate. Rear-end and sideswipe crashes decreased by 50%, however, when the ramp meters were in operation.

Piotrowicz and Robinson (1995) reported that, in all, the benefits of ramp metering include crash rate reductions of 24% to 50%, increased throughput of 17% to 25%, and an increased mainline speed of 16% to 62%. These improvements reduce congestion and decrease travel times during peak periods.

Automated Enforcement

Harris and Sands (1995) reported that automated speed enforcement, which uses cameras to detect speeding vehicles, has positive safety benefits. In London, installation of such cameras was followed by a 10% reduction in speed and an estimated 20% to 80% reduction in crashes. Serious injuries and fatalities were reduced by about 50%.

Automated enforcement is also being applied to intersections to detect drivers who run red lights and violate rail-crossing warnings. Proper and Cheslow (1997) reported that using cameras to detect red-light violations resulted in a reduction in violations of 30% in San Francisco; 23% in Howard County, Maryland; and 20% in New York City. In Los Angeles, photo enforcement at rail crossings resulted in a 92% reduction in violations at one location and a 78% reduction at another. Fort Mead, Florida, reported a 50% reduction in violations, and Jackson, Mississippi, reported a 60% reduction (Proper & Cheslow, 1997).

Work Zones

Radar can be combined with variable message signs to create a dynamic system to reduce vehicle speeds through work zones (Garber & Patel, 1994). The researchers tested four messages displayed to drivers who were exceeding the speed limit in work zones. All of the messages were effective in significantly reducing the speed of vehicles traveling 95 km/h or faster in a 89-km/h work zone. The reductions in speed were significantly greater than when only signing as specified in the *Manual of Uniform Traffic Control Devices* was used.

In a follow-up study, Garber and Srinivasan (1998) found that the effectiveness of the combined use of radar and variable message signs does not diminish in long work zones. However, drivers tend to speed up through the work zone. The researchers suggested that in long work zones, the use of a second dynamic system might aid in maintaining reductions in speed.

Warning Systems

Among the potential crash reduction technologies reported by Mitretek Systems (1996) was the Dynamic Truck Speed Warning System for Long Downgrades, which was installed in the Denver area in 1995. Although the evaluation of the system was not complete, anecdotal evidence suggests that truck drivers who receive a warning to slow frequently apply their brakes immediately.

Deeter and Bland (1997) reported that a truck speed warning system installed on a curve with a design speed of 72 km/h on I-70 in Glenwood Canyon, Colorado, reduced the average truck speed from 106 to 77 km/h.

Taylor and Bergan (1997) reported that ITS can be used effectively to prevent truck rollovers. In 1993, three exit ramps on the Capital Beltway in Washington, D.C., had systems installed to warn truck drivers to slow down when they exceed the safe speed for those ramps. Between 1985 and 1990, 10 rollover truck crashes occurred at these ramps, but in the 3 years following the installation of the warning system, none occurred. Further, the average truck speed decreased by 10 km/h.

Advanced Traveler Information Systems

Saxton (1996) concluded that ITS has the potential to improve transportation safety. He noted that some enhancements may be indirect by reducing driver stress and indecision and providing for smoother vehicle flow. ITS can also provide advisory information based on real-time roadway, traffic, and environmental conditions.

Inman, Sanchez, Bernstein, and Porter (1996) evaluated an in-vehicle navigation system known as TravTek that used an in-vehicle visual display of a map and voice directions. No statistically significant reductions in crashes or near crashes occurred. However, using simulation techniques to estimate the potential safety impact of the system, the researchers estimated a potential reduction in crash risk to be as much as 4%. In simulations in which drivers were given real-time information to divert onto a lower-class roadway to avoid potential problems on the mainline, diverted drivers had as much as a 10% reduction in crash risk. The network as a whole showed either no increase in crash risk to a slight decrease in crash risk from the diversion, which lessened the congestion on the mainline.

Commercial Vehicle Operations

Because the mass of large trucks is so great in relation to passenger vehicles, the risk of fatality is great when these vehicles collide. Mitretek Systems (1996) reported a potential reduction of 14% to 32% in fatal crashes involving commercial vehicles based on hypothetical usage of CVO services and the implementation of changes in inspection practices.

Garber and Black (1995) noted the potential for ITS to improve the safe operation of large trucks on rural secondary roads. In particular, sideswipe, angle, and rear-end crashes accounted for more than 75% of large truck crashes on secondary roads in Virginia. Driver-related failure accounted for more than 70%. The study recommended that vehicle on-board radar (VORAD) vehicle detection and driver alert system could be deployed to reduce these types of crashes.

Krukar and Evert (1990) reported that an early information network in Oregon allowed an increase of 90% in truck weighings and a 428% increase in the number of safety inspections, even though there was only a 23% increase in staff. Mitretek Systems (1996) noted that although such an increase in inspections is not a direct indicator of crash reductions, it should provide for enhanced traffic safety.

Moses and Savage (1993) estimated that motor carrier safety programs such as the Motor Carrier Safety Assistance Program and federal safety audits result in a decrease of 2,500 to 3,000 crashes per year. Mitretek Systems (1996) noted that such estimated safety benefits are predictors that ITS enhancements to inspections and electronic screening should produce further reductions in crashes.

The Upper Great Plains Transportation Institute (1996) found that safety inspections could be enhanced through the use of ITS. The study was conducted in 10 states in the Midwest using a system that allowed inspectors to screen drivers and vehicles to determine which were at high risk for violation. Drivers and vehicles that had previously been placed out of service for safety violations were screened. Safety inspectors were able to remove 50% more drivers and vehicles from service than they had using conventional methods.

Desmond (1995) reported on two projects that use automatic vehicle identification (AVI) and an automatic vehicle classification (AVC) system combined with the use of weigh in motion (WIM) to allow certain commercial vehicles to bypass weigh operations. Because fewer trucks will have to decelerate and accelerate around weigh stations, such systems should reduce the number of crashes involving trucks. However, no data were presented to document whether such reductions occurred on the facilities in these projects.

Advanced Vehicle Control and Safety Systems

Farber, Freedman, and Tijerina (1995) provided a breakdown of the eight crash types that account for approximately 68% of all crashes nationally. They based their figures on research conducted by the Battelle Memorial Institute. The authors noted that rear-end crashes account for 23%, single-vehicle run-off-road crashes for 20%, backing for 1%, lane change for 4%, signalized intersection straight crossing path for 3%, unsignalized intersection straight crossing path for 6%, intersection left turn across path for 7%, and opposite direction for 3%.

The authors also noted the breakdown of key causal factors in these crashes and the collision avoidance systems concepts that can help reduce these types of crashes. Although most collision avoidance systems are in the developmental stages, the Intelligent Vehicle Initiative sponsored by the federal government may speed the development and deployment of these systems.

Farber, Freedman, and Tijerina (1995) noted that in rear-end crashes, the key causal factor in 93% was following too closely and/or driver inattention. These types of crashes might be reduced by the use of forward obstacle and headway detection systems.

In single-vehicle run-off-road crashes, the key causal factors were driver incapacitation, such as driving under the influence (DUI) or fatigue, in 23% of crashes; slippery roads in 20%; excessive speed in 14%; and driver inattention and/or evasive maneuver in 15%. These types of crashes might be reduced by the use of driver impairment detection systems, pavement monitoring and speed warning systems, curve detection and speed warning systems, and lane detection and warning systems.

In 61% of backing crashes, the driver did not see what his or her vehicle hit. Rear-zone monitoring systems might reduce these types of crashes. In 27% of backing crashes, the crash was attributed to improper backing, which the authors speculate might include the driver's failure to look while backing. In these cases, cross traffic gap monitoring and warning systems might reduce crashes. Similarly, in lane-change crashes, the driver was most likely to be unaware of the other vehicle. In these cases, side-zone detection systems might reduce crashes.

In signalized intersection straight crossing path crashes, the driver deliberately ran or tried to beat the red light in 39% of crashes. These crashes were attributed to driver inattention in 36% of crashes, DUI in 13%, and obstructed vision in 4%. These crashes might be reduced by the use of signal-cued warning and control systems and driver impairment detection systems.

In 49% of unsignalized intersection straight crossing path crashes, the crash was attributable to misperceiving the other vehicle. In 23%, driver inattention was the key causal factor. Obstructed vision or impairment was the key causal factor in 18% of crashes, and deliberate sign violation was the key factor in 3%. These crashes might be reduced by the use of sign-cued warning and control systems, cross traffic gap monitoring and warning systems, and driver impairment detection.

In intersection left turn across path crashes, the key causal factor in 28% was misperceiving the other vehicle. The driver looked but did not see the other vehicle in 24% of crashes, had obstructed vision in 24%, and deliberately violated the traffic control device in 16%. These crashes might be reduced by opposite traffic gap monitoring and warning systems.

In opposite direction crashes, DUI was a key causal factor in 37%, an evasive maneuver in 18%, slippery roads in 15%, and driver inattention in 7%. These crashes might be reduced by the use of driver impairment detection systems, forward obstacle and headway detection systems, lane detection and warning systems, and pavement monitoring and speed warning systems.

Fancher et al. (1994) also estimated the potential of crash avoidance technologies to enhance safety. They noted that the systems with the greatest potential to reduce crashes are headway control systems for rear-end crashes, lane-edge detection systems for run-off-road crashes, longitudinal control systems for non-vehicles in the roadway, lane-keeping systems, night vision enhancements, and impaired driver detection and warning systems for a variety of crashes.

In particular, the researchers estimated that night vision enhancements would reduce all crashes by 3.6% and overall crash costs by 7.3%. They also suggested that substantial benefits occur with driver impairment detection and warning systems. Although such systems would not serve to prevent a substantial number of crashes, crashes involving impaired drivers are substantially more severe than the typical crash. Thus, any prevention of crashes would provide disproportional safety benefits. The researchers estimated that such systems would reduce overall crash costs by 9.9%.

Vehicle-based friction and ice detection warning systems are estimated to have the potential to reduce all crashes by 4% and crash costs by 3.3%. However, because the driver may already be going too fast for conditions, the effectiveness of the system is estimated to be no more than 33%. On the other hand, roadside friction and ice detection and warning systems are predicted to reduce crashes and crash costs by the same magnitude. Yet the system is likely to be more effective than the vehicle-based system because it would provide for advanced warning of hazardous conditions. Thus, crashes could be reduced by as much as 8% and crash costs as much as 6.6%.

Lateral lane-edge detection and warning system are predicted to reduce all crash costs by 10.6%. Such a warning system, even if the driver was unable to avoid the crash, would likely result in the driver braking to slow the vehicle, thereby reducing the severity of the crash.

Dynamic horizontal curve speed advisory systems warn drivers of excessive travel speeds where design limitations or crash problems exist. The researchers estimated that such a system can be very effective for spot improvements.

Longitudinal control systems for non-vehicles are predicted to reduce crash costs by 3.4%. Much of this benefit would be reducing the severity of pedestrian crashes. Headway control systems are predicted to reduce crashes by 13.5% and crash costs by 7.2%. This is because of the relatively high incidence of rear-end crashes.

Cooperative and road-based warning systems that warn of oncoming vehicles are predicted to have the potential to reduce crash costs by 1.2%. These systems are predicted to be less than 50% effective because of the uncertainties of what evasive action to take. However, these systems may provide for effective spot improvements.

Lane keeping systems have the potential to prevent run-off-road and head-on crashes. Such systems are estimated to have the potential to reduce crash costs by 7.3%, which is a low estimate given that it was based on an estimate of 25% effectiveness. Warning systems for the presence of vehicles on major and minor intersecting roads are predicted to reduce crash costs by 2.8%. These systems would reduce crashes in crossing path crashes but have an estimated effectiveness of 50% because drivers would still be responsible for responding to the warning.

Warning systems for left turns are estimated to have the potential to reduce crash costs by 1%. Effectiveness is estimated to be less than 50% because of the reliance on drivers to respond to the warning.

Mitretek Systems (1996) reported that an advanced collision-warning device has provided evidence of enhanced safety for both a trucking company and a bus company. When such a device was installed in the entire fleet for Transport Besner Trucking Company and combined with a safety-training program, crashes were reduced by 33%. An earlier version of such a device that was installed in half of the Greyhound Bus fleet was associated with a 20% reduction in crashes. Mitretek Systems extrapolates that equipping the entire fleet might have been associated with a 40% decrease in crashes.

The *Urban Transportation Monitor* (1998) noted that the selective use of Active Advanced Warning Flashers at signalized intersections can reduce crashes. Typically, these devices are deployed where the approach is on a steep downgrade, where the intersection may not be clearly visible to approaching vehicles, where placement of a signal may be unexpected or no signal is installed for a considerable distance, or where the design speed is 70 km/h or greater. Use of advance warning flashers is associated with significant reductions in crash rates. At intersections with long distance detectors and approach speeds of at least 80 km/h, crashes decreased by 35%.

Advanced Public Transportation Systems

Alarms and other early warning devices used in public transit can increase safety for passengers by providing for faster emergency response in the event of crashes or crime. Jones (1995) reported that a silent alarm system on buses in Denver, Colorado, reduced police response to crimes on buses from a mean of 10 minutes to a mean of 2 minutes.

Goeddel (1996) noted the reported benefits of APTS transit management systems. Among the benefits most often cited by transit agencies using APTS are increased safety and security for transit users and drivers. Although many of the benefits cited involve security, monitoring systems and silent alarms have the benefit of alerting authorities in the event of crime or incidents. Goeddel noted that transit officials have estimated a 40% decrease in response times to such incidents (ITS America, 1995).

Advanced Rural Transportation Systems

Mayday devices, which would alert authorities of a crash and its location in rural areas, are noted as having the potential to reduce fatalities. Evanco (1996) estimated that if incident notification times were reduced in rural areas from the current average of 9.6 minutes to 4.4 minutes, many lives could be saved. If a Mayday system were implemented to provide early identification of 60% of rural crashes, fatalities could be reduced by 7%. If such early identification could be provided for all rural crashes, fatalities could be reduced by 12%.

Apogee/Hagler Bailly (1997) noted that ITS can improve transportation safety in rural areas. The use of Mayday systems can cut notification and response time to traffic crashes. Such systems are of particular use in rural areas where emergency response units may not be able to locate a vehicle easily. In these cases, vehicles equipped with a device that will pinpoint the vehicle's exact location can further reduce response times.

Deeter, Lacey, and Smith (1996) reported on a Mayday project in central Colorado. The Colorado State Patrol noted the potential of such a system to improve response times to incidents. This system is also expected to aid in the location of vehicles by providing their exact location, which is often difficult for motorists to determine and relay accurately to dispatchers.

Mitretek Systems (1996) noted that simulated emergency calls from vehicles using an on-board crash notification system in Germany decreased response time by 43% (Intelligent Transport Systems, 1995). Such a decrease is estimated to correspond with a 12% increase in an occupant's chance for survival. A similar reduction in response time might be expected in the United States, which has average response times similar to those noted in the study.

CONCLUSIONS

Advanced Traffic Management Systems

- *Measures that reduce congestion can be expected to reduce crashes.* Measures that reduce congestion, whether through diverting traffic onto other facilities or by enhancing the ability of vehicles to move freely, have demonstrated their ability to reduce crashes. Particularly noteworthy is the reduction in secondary crashes.

- *Ramp metering reduces congestion and crashes.* Reductions in crash rates have ranged from 5% to 62% on the affected roadways during times of meter operation.

- *For spot improvements, automated enforcement reduces the number of violations and decreases the number of crashes.*

- *The combined use of radar and variable message signs in work zones can improve compliance with speed limits in work zones.*

- *Providing a specific warning for a particular section of roadway, such as grade and curve warnings, leads to safer driving behavior and/or fewer crashes.*

Advanced Traveler Information Systems

- *Although general advisory information is expected to provide safety benefits, no studies document the impact of ATIS on safety.*

Commercial Vehicle Operations

- *Using CVO produces more efficient enforcement of weight limits and safe operation of heavy trucks.*

- *Using AVI, AVC, and WIM allow specified commercial vehicles to bypass weigh stations, which lessens the number of trucks that must decelerate and accelerate on a highway.* Although no studies document crash reductions, these systems are expected to reduce crashes involving commercial vehicles.

Advanced Vehicle Control and Safety Systems

- *Much of the work on collision avoidance systems is still in the developmental stages.* Although vehicle-based systems would provide some warning for drivers, roadway-based or integrated systems would be potentially more effective because they have the ability to warn drivers before they enter the danger zone.

Advanced Public Transportation Systems

- *Using alarms and other security warning devices on public transit provides for the security of passengers and for the rapid deployment of emergency response in the event of an incident.*

Advanced Rural Transportation Systems

- *Using Mayday systems have much potential to reduce response time to crashes in rural areas.* Estimates are that Mayday systems could cut response times from an average of almost over 9 minutes to less than 5 minutes.

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