ITS DEPLOYMENT EVALUATION

Executive Briefing

Vision Zero and ITS

Highlights

- The USDOT's National Roadway Safety Strategy outlines the Safe System Approach with the purpose of reaching the goal of zero roadway fatalities.
- ITS technologies have the capabilities to address the objectives and purpose of the Safe System Approach.
- Federal Transit Administration (FTA) developed an enhanced version of the Transit Safety Retrofit Package (TRP) system.

This brief is based on past evaluation data contained in the ITS Databases at: www.itskrs.its.dot.gov. The databases are maintained by the U.S. DOT's ITS JPO Evaluation Program to support informed decision making regarding ITS investments. The brief presents benefits, costs and best practices from past evaluations of ITS projects.

Introduction

In the United States, more than 370,000 people lost their lives in transportation incidents from 2011-2020, including more than 350,000 on U.S. roads [1]. Safety is among the top priorities of the U.S. Department of Transportation (USDOT) and reducing these numbers is of critical importance.

The 2022 USDOT's National Roadway Safety Strategy (NRSS) outlines the Safe System Approach as the guiding paradigm to reduce serious injuries and deaths on our Nation's highways, roads, and streets. The Safe System Approach works by building and reinforcing multiple layers of protection to prevent crashes from happening and mitigate the harm caused to those involved when crashes do occur. Those layers of protection include [2]:

- **Safer People** – Motivating all drivers and road users to practice safe and responsible behavior on our roads.
- **Safer Vehicles** – Deploying accessible vehicle safety technologies to help minimize crashes and their potential harm.
- **Safer Speeds** – Encouraging all roadway users to drive at safe speeds through education, enforcement, and roadway design.
- **Safer Roads –** Implementing safer roadway environments to assist in the safety of drivers and road users on our highways, roads, and streets.
- **Post-Crash Care** – Providing quicker access to medical care and safer environments for first responders in order to increase the survivability of crashes and reduce secondary crash vulnerability.

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The USDOT's goal is to set the standard for zero roadway fatalities [2]. This idea of zero roadway fatalities was adopted from *Vision Zero*, an original initiative developed in Sweden in 1997 [3]. Vision Zero is a paradigm that acknowledges that all traffic deaths are preventable, and instead of trying to perfect human behavior, focus should instead shift to integrating human failings into the solutions approach [3]. With this integrated understanding, the USDOT's NRSS formed the basis of the Safe System Approach on the following principles: (1) death and serious injury is unacceptable, (2) humans make mistakes, (3) humans are vulnerable, (4) responsibility is shared, (5) safety is proactive, and (6) redundancy is crucial [4].

Figure 1: Objectives of the Safe Systems Approach (Source: USDOT)

Intelligent Transportation Systems (ITS) solutions have the capability to address these objectives and support the purpose of the Safe System Approach by providing technologies that help reach the goal of zero roadway fatalities. Some of those technologies include Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS) in vehicles, increased connectivity between road users, vehicles and the roadway infrastructure, and enhanced detection and enforcement.

Benefits

Examples of safety benefits resulting from the application of ITS solutions using the USDOT Safe System Approach are described below.

Safer People

Using ITS technologies, road users have been encouraged to practice safe and responsible behavior on roads and alert them of potential hazards to reduce the frequency and severity of crashes. Distracted driving is a major contributing factor to crashes which result in fatalities, and injuries. According to the National Highway Traffic Safety Administration (NHTSA), distracted driving claimed 3,142 lives in 2020. This represents 8.1 percent of all fatalities in 2020 [5]. Incentive-based smartphone applications that feature a reward system in which young drivers earn points for miles driven without any phone interaction could reduce the percentage of distracted trips by up to 41 percent, as demonstrated in College Station, Texas (2022-B01661). The number of pedestrians' and bicyclists' lives lost as results of traffic crashes has increased significantly over the last decade. As of 2020, a total of 7,454 pedestrians and pedalcyclists lost their lives in traffic crashes, representing about 17 percent of all fatalities reported for the same year [6]. Pedestrian safety technologies that detect both pedestrians and bicyclists, can deploy a cautionary visual alert to drivers to help them avoid conflicts with pedestrians. Researchers at the FHWA Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia conducted field tests on a vehicle-based camera and radar based pedestrian detection system which issued in-vehicle alerts to drivers to increase the time the driver could react to avoid a crash. The test results showed that the pedestrian detection system was successful at detecting 97 and 63 percent of pedestrians and bicycles, respectively (2021-B01611). The system's ability to detect and warn drivers of at-risk pedestrians could potentially prevent crashes in several cases including where pedestrians act unexpectedly or are difficult to see, when the driver is distracted from the roadway, and in crowded urban settings.

Safer Vehicles

Vehicles can be equipped with ITS, including ADAS and ADS, to increase situational awareness and reduce the likelihood of a crash thus reducing injuries and fatalities. For example, Drowsy Driver Warning Systems installed in vehicles, monitor drivers for signs of fatigue or inattentiveness while driving. Lane Departure Warning Systems use cameras to detect lane markings and alert the driver when the vehicle begins to drift from its lane without use of the turn signal. Automatic Emergency Braking Systems apply the vehicle's brakes automatically to avoid or mitigate an impending forward crash with another vehicle. In the U.S., over 90 percent of new vehicles are equipped with at least one ADAS feature [7]. Studies have shown that vehicles equipped with ADAS have the potential to reduce crash rates by 47 percent (2017-B01216). Further, NHTSA research shows that connected vehicle (CV) technology could potentially address approximately 80 percent of the crash scenarios involving non-impaired drivers [8]. This research shows that CV technology could help prevent the majority of crashes that typically occur at intersections or while changing lanes. Additionally, evaluation results from a CV pilot deployment in New York City indicated a reduction of conflict risk between host and remote vehicles after being given a warning from an Intersection Movement Assist (IMA) V2V application (2022-B01650).

Figure 2: Lane Departure Warning Scenario (Source: FHWA)

Safer Speeds

Speeding is a major contributing factor in traffic crashes that result in fatalities. Data provided by NHTSA shows that 11,258 (representing 29% of all of fatalities) lives were lost in speed related traffic crashes in 2020 [6]. Using ITS technologies, posted speed limits can be dynamically adjusted, advising, or enforcing drivers to change vehicular speeds, reducing risk of crashes and fatalities. Variable Speed Limits (VSL) are ITS technologies that vary speed limits on critical sections of highways based on the prevailing conditions on the roadway. They are deployed to help with safety during adverse weather conditions or in advance of slowdowns and potential lane closures, which could reduce the probability for secondary crashes. There are two types of VSL deployments – advisory and regulatory. VSL deployments in Georgia (on I-285) and Wyoming (on I-80) have yielded significant reductions in crashes with crash modification factors ranging from 0.35 to 0.73 depending on the crash type and severity. On average, crash reductions of about 29 percent and 34 percent were associated with VSL installations in Georgia and Wyoming, respectively. Additionally, estimated benefit to cost ratios of about 40:1 and 9:1 were reported for Georgia and Wyoming, respectively (2022-

Figure 3: Variable Speed Limits (Source: WSDOT)

B01653). Smartphone-based applications such as the Intelligent School Zone Beacons (ISZB) are ITS technologies that alert drivers when they exceed a given speed threshold in an active school zone. The intelligent beacons broadcast the status of the school zone (active or not) connect to a smartphone-based app installed on drivers' smartphones. If a driver's vehicle speed exceeds the internal threshold set in the app while within the school zone "geo fence", an alert is triggered on the app to warn the driver. ISZBs have been shown to reduce speeding probability up to 35 percent based on a study in Gainesville, Florida (2021-B01598). Based on this study, future opportunities exist for in-vehicle CV-based school zone speed warning applications.

Safer Roads

Intersection Conflict Warning Systems (ICWS) are ITS technologies that have been used to improve safety at stop-controlled intersections by reducing the frequency and severity of crashes. The system operates by alerting drivers on intersecting streets of approaching conflicting vehicles using a combination of static road signs and flashing lights. ICWS are currently installed in selected locations in several states. A Pooled Funded Study in multiple states including Minnesota, Missouri, and North Carolina reported statistically significant reduction in crashes with crash modification factors ranging from 0.43 to 0.85. The study also estimated benefit to cost ratios of 27:1 for all two-lane at two-lane roadway intersections and 10:1 for four-lane at two-lane roadway intersections (2021-B01606). According to the Federal Highway Administration (FHWA), over 25 percent of fatal crashes are associated with a horizontal curve, and the vast majority of these crashes are roadway departures. The average crash rate for horizontal curves is about three times that of other types of highway segments [9]. The Minnesota Department of Transportation tested a Dynamic Curve-Speed Warning System which consists of a device located in the vehicle capable of providing a visual and auditory warning to the driver when approaching a potentially hazardous curve at an unsafe speed. Results of the study showed that drivers approached horizontal curves at 8 to 10 percent slower speeds than when not using the system (2021-B01604). Reduced speeds at curves could translate into fewer crashes since a large percentage of roadway departure crashes are speed related.

Post-Crash Care

Providing effective post-crash care and response is critical in reducing fatalities on our roads. Emergency Vehicle Preemption (EVP) systems interrupt normal traffic signal timing to provide a green light to approaching emergency vehicles so they can maneuver through intersections to get to emergencies safely and quickly. Harris County, Texas, deployed an emergency medical service priority signal system at 50 intersections on Louetta Road. Emergency services personnel expressed positive impact of the system to their response to incidents and the agency has found no detrimental effects to normal intersection operations (2016-B01103). Traffic Signal Preemption for emergency vehicles is a connected vehicle (CV) application enabling the rapid movement of emergency vehicles on arterials. The strategy was tested in a microscopic traffic simulation using the City of Toronto network

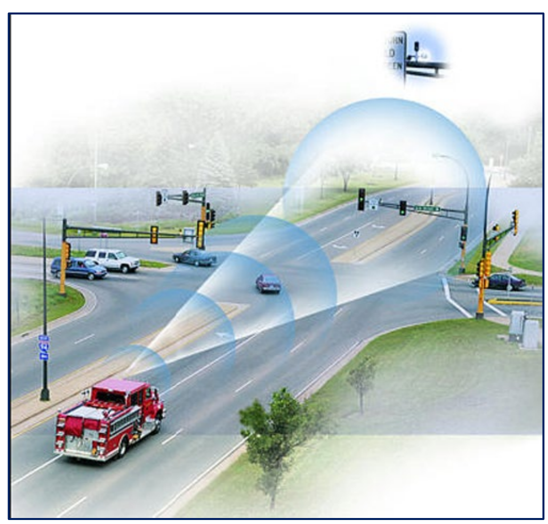

Figure 4: Concept of Emergency Vehicle Preemption (Source: FHWA)

and 150,000 vehicles. Results from the simulation showed significant reduction of up to 50.94 percent in emergency vehicle response time (2018-B01259). Additionally, Emergency Vehicle Alert systems equip vehicles with the ability to broadcast real-time incident information to a mapping provider that can push notifications to subscribers within the vicinity of an incident. The Pennsylvania Turnpike Commission equipped 158 maintenance and service patrol vehicles with the ability to broadcast emergency alerts. The number of crashes involving freeway maintenance vehicles responding to incidents decreased from 30 to 0 between Years 2018 to 2020 (2022-B01684).

Costs

Table 1 summarizes examples of ITS solutions to improve safety and their associated cost.

Table 1: ITS Solutions and Associated Cost

Safe System Approach	ITS Solution	Description	Cost
Safer People	Camera-Based Vision System	Vision-based ADAS use cameras strategically placed around the perimeter of a vehicle to improve blind-spot detection on both cars and trucks. The technology is often installed in cities where large vehicle collisions with pedestrians and bicyclists are a major problem.	The cost of the technology can range from $5,000 to $6,000 per vehicle to install (including all equipment and cabling) (2020-SC00469).
Safer Vehicles	Advanced Driver Assistance Systems (ADAS)	ADAS are vehicle-based safety technologies that work by alerting or assisting drivers to prevent or mitigate crashes.	The Florida DOT sponsored a study which evaluated the safety implications an ADAS system installed on 10 Regional Transit System buses. The installation costs for each ADAS system included a one-time cost of $8,900 and an additional yearly cost of $240 (2023-SC00524).
Safer Speeds	Dynamic Curve Speed Warning Application (DCSWA)	DCSWA is a smartphone-based driver-interface that utilizes a common map application interface to access curve information using cellular communications, and visually displays the advisory speed. It further assesses the GPS speed and direction to issue an alert if the vehicle is found to be exceeding the curve advisory speed.	Minnesota DOT sponsored a research project to develop a prototype DCSWA using cloud-based V2I communications with a project cost of $80,000 (2020-SC00474).

Safe System Approach	ITS Solution	Description	Cost
Safer Roads	Intersection Collision Warning Systems (ICWS)	ICWS operates by alerting drivers on intersecting streets of approaching conflicting vehicles using a combination of static road signs and flashing lights.	Minnesota DOT evaluated ICWS installed on two-lane at two-lane intersections and for four-lane at two-lane intersections. The system cost ranged from $9,000 to $142,500 (2018-SC00392).
Post-Crash Care	Emergency Signal Preemption Systems (ESPS)	ESPS are designed to disrupt the regular timing of traffic signals and grant a green light to emergency vehicles approaching intersections. This enables emergency vehicles to navigate through intersections quickly and safely to reach their destinations without delay.	Texas DOT evaluated multiple projects in Texas using Transportation Systems Management and Operations (TSMO) strategies. An ESPS cost approximately $4,000 per intersection with recurring operations and maintenance cost estimated to be $250 Annually (2022-SC00523).

Best Practices

Safer People

Cellular smartphones hold great potential for rapid deployment of connected pedestrian safety applications due to their increasing availability and continuous technological improvements. A variety of smartphone-based applications have been developed to enhance pedestrian safety at intersection and midblock crossings. As part of a CV Pilot Deployment, the Tampa Hillsborough Expressway Authority (THEA) aimed to test a connected urban environment and measure the effect and impact of CVs in a busy downtown area with high pedestrian densities. THEA deployed Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) CV solutions within the environment with the goals of enhancing pedestrian safety, reducing conflicts between street cars, pedestrians, and passenger cars at locations with high volumes of mixed traffic, among others. The CV Pilot uncovered technical deployment issues related to smartphone-based pedestrian safety applications. The following lessons learned are obtained from the CV Pilot study (2021-L01027).

- As of 2020, Global Positioning System (GPS) technology on current smartphones are unable to sufficiently determine a pedestrian's location and speed, making the application too inaccurate to safely utilize.
- Assess the various hardware features offered under different phone models, as some models do not include key features (e.g., heading).
- There may are challenges related to Wi-Fi connectivity. Smartphones may not be able to connect to public Wi-Fi access spots. Furthermore, if a smartphone has previously connected to a particular public Wi-Fi network, it may try to automatically connect to it again, which could prevent the device from connecting to the Wi-Fi network that communicates with the roadside unit.

Safer Vehicles

With growing concerns that partial automation and ADAS equipped vehicles may give drivers a false sense of security and lead to distracted and/or dangerous driving behavior, researchers at the Virginia Tech Transportation Institute, in collaboration with the American Automobile Association (AAA) conducted a study of driver's behavior in partially automated and ADAS equipped vehicles. Researchers recruited participants who regularly drove ADAS equipped vehicles at least 60 miles per weekday within the Washington DC Metro Area and equipped participant's vehicles with various sensors and cameras to collect driving behavior data. The study found that using ADAS resulted in increased occurrence of distracted driving behaviors (2019-L00925). It was recommended that more research is needed regarding driver understanding and use of systems over time and in the evaluation of what types of information, consumer education or training promote the safest interactions with ADAS at all points in their lifecycle. Similarly, researchers at the Insurance Institute for Highway Safety (IIHS) and Massachusetts Institute of Technology (MIT) investigated the possible extent of driver disengagement when using partially automated vehicles. The study found that the most common disengagement behaviors include cell phone usage, taking hands off the wheel, and fiddling with in-vehicle electronics. The longer drivers used partial automation, the more likely they were to become disengaged from the task of driving. The research team advised that manufacturers consider implementing more robust driver engagement and monitoring systems (2020-L00993).

Figure 5: ADAS equipped vehicle (Source: iStock)

Safer Speeds

Under a variable speed limit (VSL) pilot program, the Texas DOT and the Texas A&M Transportation Institute (TTI) studied the effectiveness of temporarily lowering speed limits to address inclement weather, congestion, road construction, and other factors that can affect the safe and orderly movement of freeway traffic. VSL systems were implemented along sections of freeways in three cities (San Antonio, Temple, and Ranger) under varying site conditions including urban congestion, construction work zone and weather-related sites (2017-L00780). The lessons learned from the pilot test include the following:

- It is preferable to use permanent equipment that is mounted over the travel lanes, as temporary equipment is not suited for long-term operations.
- Fully understand existing speed profiles and ingress/egress characteristics on the corridor. Ensure appropriate spacing for VSL systems and modifications to sensor inputs.
- Prepare for a high incidence of equipment and communication failures by enhancing algorithms to address these challenges. Also, boost public confidence in the displayed messages by ensuring they are accurate and consistent. Furthermore, evaluate algorithms effectiveness through shadow mode testing.
- Take into account the need of sharing real-time information with other organizations, such as the Department of Public Safety.

- Carry out extensive and continuous public outreach efforts to help drivers comprehend and adhere to the variable speed limits.

Safer Roads

As researchers and practitioners continue to find and implement innovative ITS solutions to make our roads safer, the lessoned learned in previous projects encourage improvements in best practices for future projects. The following best practices are obtained from the installation of Intersection Conflict Warning Systems (ICWS) in Minnesota, Missouri, and North Carolina (2021-L01066):

- Technical issues and maintenance problems may arise in the absence of adequate resources to monitor the system 24/7. Also, an ICWS should be installed only where it is warranted to save time, money, and efforts.
- If a continued trend in certain types of collisions (such as angle collisions) is observed after installation of ICWS, it is recommended to revisit the design of the intersection and implement a different design to improve safety.

Figure 6: ICWS (Source: MnDOT)

- Follow the guidelines in the Manual on Uniform Traffic Control Devices (MUTCD) when placing the appropriate warning signs to improve driver perception and response time.
- In selecting the appropriate warning signs to display, practitioners are advised to avoid using "Traffic Approaching When Flashing" signs due to the possibility of the sign not flashing in certain cases and may lead to litigation in the event of a collision.

Post-Crash Care

The USDOT ITS Joint Program Office (JPO) and the FHWA Office of Operations commissioned a series of six case studies to explore how catastrophic events impact management and operations of the surface transportation system, and how the surface transportation is utilized in such emergency situations (2010-L00511). Although the events analyzed in the case studies do not cover crash incidents specifically, several valuable lessons learned and recommendations from the studies are relevant in providing effective and efficient post-crash care. These include:

- Agencies must collaborate to make advanced preparations and develop response plans to manage emergency events. The response plans should provide predetermined roles, clear and understandable chains of command, early detection, and correction of deficiencies in emergency response, and accessibility and preparedness of suitable resources. Further, emergency response plans should be updated continually and rehearsed.
- Agencies are advised to take experiences from previous catastrophes and incorporate into designs, operations, and management.
- Employ advanced technologies to disseminate real-time information and ensure system redundancy.

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Success Story

The Federal Transit Administration (FTA) developed an enhanced version of the Transit Safety Retrofit Package (TRP) system that was originally part of the USDOT Safety Pilot Model Development, a large-scale Connected Vehicle (CV) deployment. The Transit Safety Retrofit Package (TRP) was a collection of applications that would allow vehicles to communicate using Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technologies with the goal of reducing vehicle and road user conflict with transit buses.

The Enhanced TRP (E-TRP) was deployed with the same goal in mind. The E-TRP system has upgraded versions of the Pedestrian in Crossing Warning (PCW) and Vehicle Turning Right in Front of Bus Warning (VTRW) CV applications. Key technologies within these applications included Dedicated Short-Range Communications (DSRC) for vehicle-to-vehicle and vehicle-to-infrastructure communication, high-precision Global Navigation Satellite System (GNSS) for vehicle tracking, and Forward Looking Infrared (FLIR) cameras for enhanced pedestrian detection.

Figure 7: The E-PCW application displaying an Inform alert for a pedestrian at the curb and a Warning alert for a pedestrian in the crosswalk (Source: FTA)

The E-TRP system was deployed, tested, and evaluated in 24 transit buses and at three field testing locations in the Greater Cleveland, Ohio area. The deployment included two subsystems: (i) In-Vehicle Subsystem (IVS), a transit vehicle-based subsystem, and (ii) a Roadside Subsystem (RS) at each of the selected street intersections. The three intersections included: one signalized intersection, one non-signalized intersection, and one mid-block crossing.

Both upgraded versions of the CV applications in the E-TRP-equipped transit buses generated “Inform” alerts and “Warning” alerts to the bus drivers. The Enhanced Pedestrian in Crossing Warning (E-PCW) application displayed “Inform” alerts when a pedestrian was on the curb and “Warning” alerts when a pedestrian was in the crosswalk. The Enhanced Vehicle Turning Right in Front of Bus Warning (E-VTRW) application displayed “Inform” alerts when another CV-equipped vehicle was moving from behind the bus to beside the bus, and “Warning” alerts when the other vehicle was turning right in front of the bus illegally.

To test the IVS of the two CV applications, the transit buses operated in revenue service for six months in 2018. For the first month, the IVS displayed no alerts and only recorded the bus driver’s reaction time to hitting their brakes. For next five months, the bus driver was receiving “Inform” and “Warning” alerts at the selected street intersections for both pedestrians and vehicles.

The objective of deploying these CV applications was to further analyze potential benefits of how CV technology can improve safety. **Table 2** summarizes the key findings from the E-TRP evaluation analysis areas and the performance measures used in each analysis area (2022-B01675).

Table 2: E-TRP Evaluation Summary [9]

Evaluation Criteria	Performance Measures	Key Findings
System Performance	• False Alarm Rate	• 81% correct alerts • 10% incorrect alerts • 9% false alarms (mostly caused by lighting and environmental conditions)
Safety Impact	• Collision Reduction	• 17% increase in bus driver response (braking) time from seeing E-PWC warning alerts
Return on Investment	• Benefit Cost Ratio	• Showed an estimated average annual system benefit of $106,452 with the estimated deployment cost being $2,163,180. • The cost of the E-TRP system could be recuperated in a little more than 20 years because of risk reduction
Driver Acceptance	• Usability • Perceived Safety Benefits • Unintended Consequences • Desirability	• Only 13 out of 751 E-TRP drivers participated in the survey, therefore driver acceptance results were not statistically significant and may not be representative of the system

Overall, the evaluation of the deployed E-PCW application exhibited reliable system performance, a positive safety impact, a reasonable return on investment, and generally positive driver acceptance. As part of USDOT's broader ITS and Connected Vehicle research program, the E-TRP system deployment illustrates significant safety benefits of advanced safety applications.

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