ITS DEPLOYMENT EVALUATION

*Executive Briefing*

### Highlights

- Intersections are markedly dangerous for roadway users, especially vulnerable road users such as pedestrians and cyclists.
- ITS applications can help improve safety at intersections by reducing crash risk, improving driver responsiveness and pedestrian confidence, and enhancing data collection to support safety analyses.
- Investing in foundational technologies, such as fiber optics, sensors, and roadside units, can support a variety of ITS applications at intersections to improve safety.

*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.*

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# ITS for Safe Intersections

## Introduction

Each year, roughly one-quarter of traffic fatalities and about one-half of all traffic injuries in the United States are attributed to intersections [1]. According to the latest data from the National Highway Traffic Safety Administration (NHTSA) [2,3], an estimated 42,939 people died in motor vehicle traffic crashes in 2021, a 10.1% increase compared to 39,007 fatalities reported in 2020. From 2020 to 2021, pedestrian and pedalcyclist fatalities and injuries increased at an alarming rate. For example, pedestrian fatalities increased 13% and pedestrian injuries increased 11% from 2020 to 2021.

In response to growing concerns regarding the safety of vulnerable road users at intersections and as part of the recent National Roadway Safety Strategy (NRSS) Call to Action [4], the United States Department of Transportation (U.S. DOT) aims to improve intersection safety via a comprehensive suite of intersection safety considerations, including but not limited to roadway geometry, policy, and technology-based approaches. Intelligent Transportation Systems (ITS) technologies offer the potential to improve intersection safety for vulnerable road users and vehicles at intersections. Figure 1 shows some of the ways in which ITS can support intersection safety.


**Figure 1:** Connectivity technologies that allow vehicles to communicate with each other, other road users, and the intersection infrastructure can support intersection safety (Source: iStock, edited by U.S. DOT) [5].

Specifically, ITS technologies can detect various road users, warn about unsafe conditions, and even react to (e.g., automatic emergency braking) or control different situations (e.g., signal changes). For example, U.S. DOT's Intersection Safety Challenge is seeking to transform intersection safety through innovative applications of emerging ITS, including machine vision, sensor fusion, and real-time decision-making, to identify and mitigate unsafe conditions involving vehicles and vulnerable road users [6], including those with and without connectivity.

## Benefits

There are a wide variety of ITS applications that can support safer intersections. Many of these ITS technologies have been field tested and/or deployed at intersections, with evaluation benefits available. Some of these safety benefits and other secondary benefits are summarized below:

- **Minimized crash frequency, severity, and risk:** ITS has the potential to reduce the frequency of crashes as well as crash severity at intersections. For example, a field study in Salt Lake City, Utah demonstrated how signal preemption could benefit snowplow operations during the 2019-2020 winter season by leveraging vehicle-to-everything (V2X) technology. Evaluation of the field study showed a larger reduction in roadway crash rates (up to 3.87) and crash severity on roads equipped with V2X technology compared to roads without it (2023-B01752). Additionally, ITS has the potential to reduce crash risk at intersections, especially for rear-end and right-angle crashes, by reducing the number of vehicles caught in dilemma zones [7]. Dilemma zones are situations where at the onset of the yellow light, some drivers may decide to proceed while others may decide to stop, which often leads to hard braking and/or red-light violations. An Integrated Intelligent Intersection Control System (III-CS) field tested in Maryland reduced the number of vehicles per hour in a dilemma zone by 18 percent (2022-B01657).
- **Improved driver responsiveness:** The American Association of State Highway Transportation Officials (AASHTO) Green Book recommends a perception-reaction time (PRT) of 2.5 seconds for motorists [8]. ITS can reduce PRT by warning drivers of unsafe situations, giving them sufficient time to respond to potential collisions. For example, a camera-based pedestrian detection and alert system tested at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia provided emergency alerts to drivers traveling at 10-20 miles per hour, allowing them sufficient time to brake and avoid colliding with a crossing pedestrian (2021-B01611). As part of the safety impact assessment of Connected Vehicle Pilot safety applications in New York City, Intersection Movement Assist (IMA), a vehicle-to-vehicle (V2V) application, demonstrated a reduction in brake reaction time by 1.3 seconds (2022-B01691). Additionally, a pedestrian crossing warning system in Cleveland, Ohio that included 24 equipped

> Intersection Conflict Warning Systems (ICWS) installed at 93 unsignalized rural intersections in Minnesota, Missouri, and North Carolina had estimated **benefit-to-cost ratios ranging from 16 to 39,** with safety benefits estimated by reductions in crash frequency (2021-B01606).

buses and 3 instrumented intersections reduced bus driver reaction time to pedestrian conflicts by 19 percent (2022-B01675).

- **Greater pedestrian confidence:** Safer intersections bring additional benefits as well, such as increased pedestrian confidence while crossing due to enhanced safety. For example, 83 percent of pedestrians with vision disabilities who participated in a field test indicated in a survey that they felt safer crossing signalized intersections with New York City's Mobile Accessible Pedestrian Signal System (PED-SIG) application (2022-B01695).
- **Improved safety analyses:** ITS can support better, more detailed data collection that can, in turn, allow for new or enhanced safety analyses. For example, a case study from Bellevue, Washington explains how video-based advanced analytics can provide highly detailed data on road user types and speeds, detect speeding infractions and lane violations, and identify near-crashes at intersections (2022-B01617).

## Costs

The costs associated with supporting safe intersections through ITS applications vary significantly due to their broad range of uses. Additionally, costs depend on the maturity, complexity, and scale of the ITS implementation. Often, ITS applications at intersections rely on one or more sensors (e.g., CCTV, radar, LiDAR, thermal, infrared). Based on over 20 years of collected cost data [9], the capital cost per CCTV video camera (adjusted to 2020 dollars) has ranged from under $2,000 to $20,000 per camera. If existing sensors can be leveraged for new ITS applications, this could save some on deployment costs. Agencies have used their existing sensors and/or added new sensors to support intersection safety for pedestrians.


**Figure 2:** Example bus driver display of pedestrian warning alert as part of the Enhanced Pedestrian Crossing Warning (E-PCW) application in Cleveland, Ohio (Source: FTA).

As part of their Enhanced Pedestrian Crossing Warning (E-PCW) system, the greater Cleveland, Ohio metropolitan area added Forward Looking Infrared (FLIR) cameras to improve pedestrian detection. The total system cost of their enhanced pedestrian crossing warning system, including the new sensors, high-precision Global Navigation Satellite System (GNSS) for vehicle tracking, and various V2V and vehicle-to-infrastructure (V2I) components outfitting 24 buses and instrumenting 3 intersections was estimated at $359,441 (2022-SC00516). Figure 2 shows an example of a warning being displayed on an onboard monitor within one of the equipped buses as a pedestrian crosses an intersection. The average unit cost of the intersection infrastructure was $69,078, with the signalized intersection costing $82,768, the non-signalized intersection costing $71,772, and the mid-block pedestrian crossing costing $52,696.

In another example, the Maryland Department of Transportation (MDOT) State Highway Administration (SHA) summarized investment costs to support a Mobile Accessible Pedestrian Signal System (PED-SIG) [10]. PED-

SIG enables visually impaired pedestrians to use traffic signals more safely and effectively. The system allows their smartphone to make an automated request to the traffic signal for priority and provides audio cues for them to safely navigate the crosswalk. According to the MDOT SHA summary, as of summer 2020, the following investment costs applied to PED-SIG (2023-SC00543):

- **V2X roadside unit (RSU) cost per intersection (on signalized corridors):** $26,000
- **V2X signal controller cost per intersection (on signalized corridors):** $10,000
- **Fiber optics cost per mile:** $158,000

Investment in supporting infrastructure, such as V2X components and fiber optic cable as just mentioned, can be leveraged not only for PED-SIG but other ITS applications to support intersection safety.

In another example, the MDOT SHA piloted a pedestrian collision warning system at one intersection in Prince George's County in 2020-21 [11]. A summary of the rounded project cost breakdown is shown in Table 1 (2023-SC00542). While some of the costs were higher than anticipated (e.g., RSU vendor costs, costs associated with staff installation time), MDOT SHA was able to save on some equipment costs, since the intersection signal infrastructure was fairly new and well prepared for the pedestrian collision warning system. Additionally, given that this was a first-time deployment that required staff to upskill, they expect future costs to be lower.

**Table 1:** Sample Pedestrian Collision Warning System Pilot Project Costs at One Intersection in Maryland (2020-21) [11]

| Project Item | Cost |
|---|---|
| Vendor (including RSU, sensors, system, and maintenance for 12 months, and install staff time) | $50,000 |
| MDOT SHA project management and installation staff time | $20,000 |
| MDOT SHA Engineering Design | $7,500 |
| Maryland SHA Offices review, approval, and install (mixed staff and consultant support) | $6,500 |

## Best Practices

While ITS applications to support safe intersections are wide ranging, there are some best practices that apply to most situations. A few recent lessons learned are summarized below with respect to ITS installation and testing, performance, security, and user experience.

### ITS Installation and Testing

- Utilize partnerships with private auto shops to perform sensor installations. For example, Smart Columbus Program participants noted that they had a favorable opinion of Smart Columbus working with small-business auto shops to perform installations (2022-L01145).
- Run an integrated, multi-channel outreach campaign to recruit private drivers. A well-defined and robust private driver recruitment program, including an email campaign, word-of-mouth tactics, and paid radio advertisements, may be needed to achieve a sufficient number of private drivers for a study. Most private drivers that engaged with the Smart Columbus Program, for example, identified with messaging that targeted them as "early adopters" (2022-L01145).
- Perform regression testing of the full system any time that any component is changed (2022-L01145).
- Lastly, understand the time requirements for integration testing of a full set of CV applications (2022-L01145).

### ITS Performance

- Improve the validity of V2V alerts with better accounting of relative elevation and heading between the host vehicle and remote vehicle for IMA and forward collision warning (FCW) applications, as found by the Tampa Hillsborough Expressway Authority (THEA) Connected Vehicle Pilot (2022-L01154).
- When confronted with a large volume of data, it is recommended to bin the data before processing to reduce analysis run-time (2022-L01145).
- Calculate key performance measures such as the mean and maximum deceleration rates, driver stopping status, and maximum brake time (2022-L01119).

> A driver simulator study on a smartphone-based pedestrian-to-vehicle warning technology demonstrated that providing additional distance-to-pedestrian information leads to improved safety and driving performance (2022-L01119).

### Security

- Utilize secure data storage platforms when analyzing data that may contain personally identifiable information (PII) (2022-L01154).
- Also, utilize a secure Internet Protocol version 6 (IPv6) connection to allow on-board unit vendors to connect to their respective remote services for firmware updates (2022-L01145).

### User Experience

- Enable real-time monitoring and notifications for mobile pedestrian application data stream connections to improve user experience in case of data transmission failures (2022-L01162).
- Continuously engage with stakeholders and maintain positive impressions to help circumvent any disruptions to schedules and plans (2022-L01145).
- Laboratory-based tests suggest that the use of external human-machine interfaces can improve pedestrian comprehension of automated vehicle's (AV) status and intentions. As pedestrians and cyclists currently rely more on driver-related cues over vehicle-signaling systems, it is important for

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AVs to assist them in identifying intent without verbal communication or hand signals, since future AVs will not have a driver to provide such cues (2022-L01089).

## Success Story

Researchers from the University of Maryland developed and tested an Integrated Intelligent Intersection Control System (III-CS) for the MDOT SHA to address safety and efficiency issues [12, 13, 2022-B01657]. The III-CS focuses on advancing the existing practice of actuated signal control with safety-oriented dynamic algorithms that can minimize the risk of incurring rear-end collisions. Specifically, it executes the optimal green termination algorithm under the actuated control function to concurrently minimize the likelihood of rear-end collisions and total traffic delay, and dynamically extend the all-red extension to prevent angled crashes. Figure 3 illustrates the dynamic all-red extension (DARE) function.

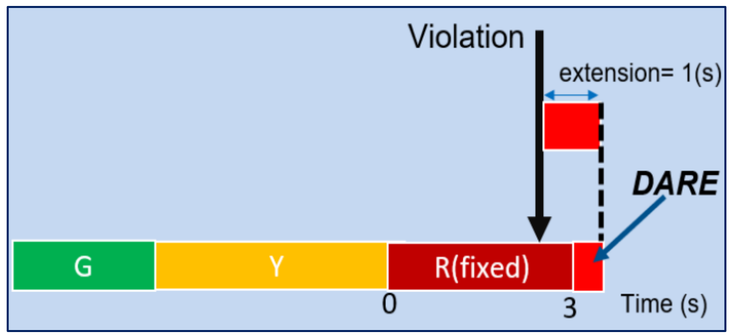


**Figure 3:** Graphical illustration of the dynamic all-red extension (DARE) function as part of III-CS (Source: MDOT).

The team conducted extensive before and after field studies to understand the benefits of the deployed III-CS. Using field data to calibrate key parameters, the researchers used simulation to evaluate pre-deployment characteristics and estimate the risk of rear-end and angle crashes at three high-risk intersections. After assessing characteristics of the three candidate intersections, III-CS was deployed at one intersection on Maryland State Route 4 in Prince George's County. Field data were collected on two days in January and March 2021, approximately one and three months after full deployment, and compared with pre-deployment data from a day in April 2019.

The deployed III-CS has proved its effectiveness in preventing angled crashes by detecting all red-light-running violations. The system correctly activated the DARE in time for all ten of the observed red-light-running violations that took place 2 seconds after the onset of the red phase (with three observed on January 28, 2021, and seven observed on March 22, 2021), thereby achieving a detection rate of 100 percent. However, over the entire observation period, the system activated 32 unjustified DARE extensions (with nine on January 28, 2021, and 23 on March 22, 2021), resulting in a false alarm rate of 7.3 percent per cycle for the first after-

**Figure 4**: Screenshot of video footage identifying red-light runners (Source: MDOT).

period and 11.7 percent for the second. The average number of red-light running vehicles per cycle was reduced from the before-period of 0.119 to 0.063 and 0.116, respectively, in the two after-periods, although the authors point to a need for more extensive field tests. Additionally, III-CS optimally activated or terminated the green extension and significantly reduced the number of vehicles trapped in the dilemma zone, which is the main contributing factor to rear-end collisions.

Figure 4 shows a screenshot of sample video footage of III-CS correctly identifying a red-light violation and executing DARE at the intersection. III-CS is designed with the notion of minimizing any additional hardware and computation so that the entire system can be deployed at existing actuated-control intersections with minimal additional costs.

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