Introduction

This factsheet is based on past evaluation data contained in the ITS Knowledge Resources database at: www.itskrs.its.dot.gov. The database is maintained by the U.S. DOT’s ITS JPO Evaluation Program to support informed decision making regarding ITS investments by tracking the effectiveness of deployed ITS. The factsheet presents benefits, costs and lessons learned from past evaluations of ITS projects.

The U.S. Department of Transportation’s (USDOT) Connected Vehicle program is working with state and local transportation agencies, vehicle and device makers, and the public to test and evaluate technology that will enable cars, buses, trucks, trains, roads and other infrastructure, and our smartphones and other devices to “talk” to one another. Cars on the highway, for example, would use short-range radio signals to communicate with each other so every vehicle on the road would be aware of where other nearby vehicles are. Drivers would receive notifications and alerts of dangerous situations, such as someone about to run a red light as they are nearing an intersection or an oncoming car, out of sight beyond a curve, swerving into their lane to avoid an object on the road.

Connected Vehicle (CV) safety applications will enable drivers to have 360-degree awareness of hazards and situations they cannot even see. Through in-car warnings, drivers will be alerted to imminent crash situations, such as merging trucks, cars in the driver’s blind side, or when a vehicle ahead brakes suddenly. By communicating with roadside infrastructure, drivers will be alerted when they are entering a school zone, if workers are on the roadside, and if an upcoming traffic light is about to change.

CV deployment sites predominantly feature safety applications as the driving force. CV safety applications include Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), and Vehicle-to-Pedestrian (V2P) applications.
A description of the V2I safety applications follows:

- **Red Light Violation Warning (RLVW)** – An application that broadcasts signal phase and timing (SPaT) and other data to the in-vehicle device, allowing the vehicle to compute warnings for impending red light violations.

- **Stop Sign Violation Warning (SSVW)** – An application that broadcasts the presence and position of a stop sign to the in-vehicle device, allowing the vehicle to determine, and provide alerts and warnings, if the driver is at risk of violating the stop sign.

- **Stop Sign Gap Assist (SSGA)** – An application that utilizes traffic information broadcasting from roadside equipment to warn drivers of potential collisions at two-way stop controlled intersections.

- **Pedestrian in Signalized Crosswalk Warning** – An application that warns drivers when pedestrians, within the crosswalk of a signalized intersection, are in the intended path of the vehicle.

- **Curve Speed Warning (CSW)** – An application that broadcasts precise geometric information and road surface friction to the in-vehicle device, allowing the vehicle to provide alerts and warnings to the driver who is approaching the curve at an unsafe speed.

- **Spot Weather Impact Warning (SWIW)** – An application that warns drivers of local hazardous weather conditions by relaying weather data to roadside equipment, which then rebroadcasts to nearby vehicles.

- **Reduced Speed/Work Zone Warning (RSZW)** – An application that utilizes roadside equipment to broadcast alerts to drivers warning them to reduce speed, change lanes, or watch for stopped traffic ahead within work zones.

Other V2I safety applications include Oversize Vehicle Warning (OVW) and Railroad Crossing Violation Warning (RCVW). These applications have developed concepts of operations and system requirements, but have not yet been prototyped and tested in an operational environment.

V2V devices would use the dedicated short range communications (DSRC) to transmit data, such as location, direction and speed, to nearby vehicles. That data would be updated and broadcast up to 10 times per second to nearby vehicles, and using that information, V2V-equipped vehicles can identify risks and provide warnings to drivers to avoid imminent crashes. Vehicles that contain automated driving functions—such as automatic emergency braking and adaptive cruise control—could also benefit from the use of V2V data to better avoid or reduce the consequences of crashes.

V2V communications can provide the vehicle and driver with enhanced abilities to address additional crash situations, including those, for example, in which a driver needs to decide if it is safe to pass on a two-lane road (potential head-on collision), make a left turn across the path of oncoming traffic, or determine if a vehicle approaching an intersection appears to be on a collision course. In those situations, V2V communications can detect developing threat situations hundreds of yards away, and often in situations in which the driver and on-board sensors alone cannot detect the threat.

A description of the V2V safety applications follows:

- **Forward Collision Warning (FCW)** – warns drivers of stopped, slowing, or slower vehicles ahead. FCW addresses rear-end crashes that are separated into three key scenarios based on the movement of lead vehicles: lead-vehicle stopped (LVS), lead-vehicle moving at slower constant speed (LVM), and lead-vehicle decelerating (LVD).

- **Emergency Electronic Brake Light (EEBL)** – warns drivers of heavy braking ahead in the traffic queue. EEBL would enable vehicles to broadcast its emergency brake and allow the surrounding vehicles’ applications to determine the relevance of the emergency brake event and alert the drivers. EEBL is expected to be particularly useful when the driver’s visibility is limited or obstructed.

- **Intersection Movement Assist (IMA)** – warns drivers of vehicles approaching from a lateral direction at an intersection. IMA is designed to avoid intersection crossing crashes, the most severe crashes based on the fatality counts. Intersection crashes include intersection, intersection-related, driveway/alley, and driveway access related crashes. IMA crashes are categorized into two major scenarios: turn-into path into same direction or opposite direction and straight crossing paths.

NHTSA estimates that safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of non-impaired crashes, including crashes at intersections or while changing lanes.
- Left Turn Assist (LTA) – warns drivers to the presence of oncoming, opposite-direction traffic when attempting a left turn. LTA addresses crashes where one involved vehicle was making a left turn at the intersection and the other vehicle was traveling straight from the opposite direction.

- Do Not Pass Warning (DNPW) – warns a driver of an oncoming, opposite-direction vehicle when attempting to pass a slower vehicle on an undivided two-lane roadway. DNPW would assist drivers to avoid opposite-direction crashes that result from passing maneuvers. These crashes include head-on, forward impact, and angle sideswipe crashes.

- Blind Spot/Lane Change Warning (BS/LCW) – alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane. BS/LCW addresses crashes where a vehicle made a lane changing/merging maneuver prior to the crashes.

V2P detection systems can be implemented in vehicles, infrastructure, or with pedestrians themselves to provide warnings to drivers, pedestrians, or both through in-vehicle systems and handheld devices.

A description of V2P safety applications follows:

- Mobile Accessible Pedestrian Signal System (PED-SIG): allows for an automated call from the smartphone from a visually impaired pedestrian to the traffic signal. The application provides audio cues to the pedestrian to safely navigate the crosswalk and alerts drivers attempting to make a turn to the presence of a visually impaired pedestrian.

- Pedestrian and Signalized Crosswalk (PED-X): warns drivers when pedestrians are within the crosswalk of a signalized intersection, or are in the intended path of the vehicle.

- Intelligent Pedestrian Traffic Signal (IPTS): utilizes VRU2I (vulnerable road user-to-infrastructure) communications where pedestrians may activate green light demand for crossing an intersection via their smart phone. While pedestrians are crossing, the IPTS may detect pedestrians to determine if the pedestrian phase should be extended to ensure safe crossing.

- Intelligent Pedestrian Detectors (IPD): automatically detects pedestrians and places requests for pedestrian signals on their behalf, generally shortening the amount of time pedestrians must wait before they can cross.

See the ITS website (www.its.dot.gov) for the most up-to-date information about CV safety applications.

**Benefits**

NHTSA estimates that safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of non-impaired crashes, including crashes at intersections or while changing lanes.

**V2I Safety Applications.** Research on V2I safety applications has revealed the potential population of crashes that can potentially be addressed by various applications. If one assumes full market penetration and 100% effectiveness of the application, those would be crashes they can be avoided. Although we know this is not the case, it provides an upper bound on what could be achieved. **Figure 1** contains a summary of this information. Intersection-focused safety applications may potentially address up to 575,000 crashes per year. Curve Speed Warning safety applications may potentially address up to 169,000 crashes per year.¹
Figure 1: Estimated Range of Benefits for V2I Safety Applications (Targeted Annual Crashes in U.S.).

V2V Safety Applications. NHTSA has released a notice of proposed rulemaking that would require auto manufacturers to install V2V communications in their new vehicles, over a short implementation schedule, capable of producing the basic safety message (BSM) and communicating that message with other vehicles. The maximum annual benefits represent the crashes, fatalities, injuries, and property damage only vehicles (PDOVs) that can be reduced annually after the full adoption of DSRC and safety related applications. Once fully deployed, DOT estimates the proposed rule would:

- Prevent 439,000 to 615,000 crashes annually (equivalent to 13 to 18 percent of multiple light-vehicle crashes)
- Save 987 to 1,366 lives
- Reduce 305,000 to 418,000 MAIS 1-5 injuries, and
- Eliminate 537,000 to 746,000 property damage only vehicles (PDOVs)

(MAIS: Maximum Abbreviated Injury Scale)

The costs and benefits of the proposed rule were estimated by considering a scenario where manufacturers would, in addition to the DSRC technology, voluntarily install two safety apps that currently are deemed to be enabled only by V2V. These two safety apps are Intersection Movement Assist (IMA) and Left Turn Assist (LTA). This scenario is reasonable because the incremental cost of IMA and LTA is less than one percent of the DSRC costs and the industry has indicated that these two apps are already in their research and deployment plan. Moreover, it is believed that this scenario is likely to understate benefits because manufacturers may choose to offer other safety apps that use V2V technology beyond these two, as well as various other technologies that use DSRC, such as vehicle-to-infrastructure (V2I) or vehicle-to-pedestrian (V2P) technologies. Note that the range of benefits is due to the use of range of effectiveness rates and the two benefit estimating approaches. The two benefit approaches deployed a different treatment on the distribution of benefits from crashes involving different model year vehicles.

Other illustrative CV safety benefits are highlighted in the table below:
Table 1: CV Safety benefits

<table>
<thead>
<tr>
<th>Application</th>
<th>Location Deployed or Tested</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian warning system (V2P)</td>
<td>Portland, OR</td>
<td>• 23% of pedestrians reported that a crosswalk transit vehicle turn warning system help them avoid a collision with a bus. (2015-01001)</td>
</tr>
<tr>
<td>Forward collision warning systems (V2V)</td>
<td>France, Germany, Sweden, Italy</td>
<td>• 70% of drivers in a large-scale field operational test (euroFOT) felt that forward collision warning systems increased safety. (2014-00950)</td>
</tr>
<tr>
<td>Curve speed warning systems (V2I)</td>
<td>France, Germany, Sweden, Italy</td>
<td>• 75% of drivers in a large-scale field operational test felt that curve speed warning systems increased safety. (2014-00953)</td>
</tr>
<tr>
<td>Connected Vehicle Warning Systems with Autonomous Emergency Braking</td>
<td>Australia (simulation study)</td>
<td>• Connected vehicle warning systems and autonomous emergency braking can reduce fatalities by 57 percent (simulation study) (2014-00965)</td>
</tr>
</tbody>
</table>

**Costs**

For V2V safety equipment with IMA and LTA applications, the proposed rule’s vehicle technology cost was initially estimated to range from $249 to $351 per affected vehicle including the component costs for DSRC radios, DSRC antenna, GPS, hardware security module, two apps, and malfunction indicators as well as the installation labor costs. The vehicle component unit costs were based on the supplier’s confidential response to the agency’s request for cost information. These costs come down to less than $200 per vehicle by 2025 (for one radio).²

**Case Study / Lessons Learned – Safety Pilot Model Deployment (Ann Arbor)/USDOT**

The Connected Vehicle Safety Pilot was a research program that demonstrated the readiness of DSRC-based connected vehicle safety applications for nationwide deployment. The vision of the Connected Vehicle Safety Pilot Program was to test connected vehicle safety applications, based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications systems using dedicated short-range communications (DSRC) technology, in real-world driving scenarios in order to determine their effectiveness at reducing crashes and to ensure that the devices were safe and did not unnecessarily distract motorists or cause unintended consequences.³

Research from the National Highway Traffic Safety Administration (NHTSA) showed that connected vehicle technology has the potential to address a very significant number of light vehicle crashes and heavy truck crashes by unimpaired drivers. Since safety is the USDOT’s top priority, the potential safety benefits of this technology could not be ignored. At the time, more research was necessary to determine the actual effectiveness of the applications and to understand the best ways to communicate safety messages to motorists without causing unnecessary distraction.

The Connected Vehicle Safety Pilot was part of a major scientific research program run jointly by the U.S. Department of Transportation (USDOT) and its research and development partners in private industry. This research initiative was a multi-modal effort led by the Intelligent Transportation Systems Joint Program Office (ITS JPO) and the National Highway Traffic Safety Administration (NHTSA), with research support from several agencies, including Federal Highway Administration (FHWA), Federal Motor Carrier Safety Administration (FMCSA), and Federal Transit Administration (FTA).

This one-year, real-world deployment was launched in August 2012 in Ann Arbor, Michigan. The deployment utilized connected vehicle technology in over 2,800 vehicles and at 29 infrastructure sites at a total cost of over $50 million dollars.
in order to test the effectiveness of the connected vehicle technology. Key lessons from the Safety Pilot Model Deployment include:

- When deploying complex ITS projects such as those with Connected Vehicle technologies, use a modular project structure and focus on high priority objectives and project components.
- When embarking on a connected vehicle project, develop a focused outreach plan that identifies all stakeholders, the message appropriate for each stakeholder and the method in which you will reach the stakeholders.
- Perform a thorough and thoughtful analysis when scoping, sizing, and identifying the geographic location of connected vehicle projects, and ensure that the strategies used to recruit test subjects or drivers are consistent with these assumptions and those of the experimental plan.
- Clearly communicate requirements and testing procedures to connected vehicle device developers, and allow for industry input and iteration for less mature devices.
- Specify interoperability testing requirements and steps as part of the connected vehicle device requirements prior to starting multiple rounds of testing, feedback, reset, and retesting.
- Conduct a data collection pilot test to validate end-to-end data acquisition, transfer, processing, and quality assessment processes.

More details regarding these lessons can be found online at Safety Pilot Model Deployment: Lessons Learned.

References


All other data referenced is available through the ITS Knowledge Resources Database, which can be found at http://www.itsknowledgeresources.its.dot.gov/.