Transit Safety Retrofit Package (TRP): Leveraging DSRC for Transit Safety – Fielding Results and Lessons Learned

US Department of Transportation
Intelligent Transportation Systems Joint Program Office
Federal Highway Administration
Federal Transit Administration
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November 2014

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A team led by Battelle, on behalf of the United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office, Federal Highway Administration, and Federal Transit Administration, deployed five collision avoidance applications on University of Michigan transit buses, including two new applications—one for pedestrian crosswalks and one for vehicles turning in front of transit buses at bus stops—identified as high-priority concerns by transit agencies. This system, called the Transit Safety Retrofit Package (TRP), was part of the USDOT’s Safety Pilot Model Deployment—a large-scale field demonstration of the potential benefits of 5.9GHz Dedicated Short-Range Communications (DSRC) wireless technology that is supporting related decisions by the National Highway Traffic Safety Administration. This article provides a summary of results, “fresh from the field”, pertaining to the transit safety applications, as well as the underlying project, system, and technologies.

The specific objectives of the TRP project were to design and develop safety applications for transit buses that can communicate using Vehicle-to-Vehicle (V2V) as well as Vehicle-to-Infrastructure (V2I) Connected Vehicle technologies for enhanced transit bus and pedestrian safety. It was of interest to determine if DSRC technologies could be combined with on-board safety applications to provide bus drivers real-time alerting of potential and imminent crashes.

To achieve the objectives of the study, the TRP project included developing, testing, installing, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleets, including installation of


TRP System Illustration
three Basic Safety Applications – Forward Collision Warning (FCW), Emergency Electronic Brake Lights (EEBL), and Curve Speed Warning (CSW), and development of two new transit safety applications – Pedestrian in Signalized Crosswalk Warning (PCW) and Vehicle Turning Right in Front of Bus Warning (VTRW). Data were collected from the equipped buses and provided to Volpe, The National Transportation Systems Center for independent evaluation. The following is a description of the five safety applications included in the TRP:

- **FCW**: This V2V application warns a bus driver when there is a risk of a rear-end collision with an equipped vehicle in the same lane in front of the bus. FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.
- **EEBL**: This V2V application warns a bus driver when there is a hard-braking event ahead of the bus from an equipped vehicle in the lane ahead of the bus or in an adjacent lane. The vehicle initiating the hard-braking may be several vehicles in front of the bus. EEBL is particularly useful when the bus driver’s line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog, heavy rain).
- **CSW**: This V2I application warns bus drivers when they are approaching or entering a curve at too high of a speed to negotiate it safely. CSW relies on roadside equipment and therefore is only available at designated locations.
- **PCW**: This V2I application warns a bus driver if pedestrians are in the intended path of the bus when making a right or left turn. This application incorporates two methods of detecting pedestrians—activation of the crosswalk button by a pedestrian and a microwave motion sensor that detects the presence of pedestrians in the crosswalk. The application provides two levels of alerts to the driver—an informational/cautionary indicator if the crosswalk button is activated and an imminent warning if a pedestrian is actually detected in the crosswalk.
- **VTRW**: This V2V application warns a bus driver of the presence of vehicles attempting to go around the bus to make a right turn as the bus departs from a bus stop. The application includes two levels of alerts to the driver—an informational/cautionary indicator if an equipped vehicle has moved from behind to beside the bus and an imminent warning if the equipped vehicle shows intent to turn in front of the bus.

**TRP System**

The TRP system leveraged components and approaches already used and proven on many other Safety Pilot Model Deployment vehicles. The TRP included the following system elements and functionality:

- **Transit Vehicle On-Board Equipment (OBE)** – The DENSO miniWSU Wireless Safety Unit (WSU) included a DSRC radio that received and transmitted Basic Safety Messages (BSMs) via 5.9 GHz DSRC. The miniWSU interoperated with other Model Deployment vehicles and Roadside Equipment (RSE) according to Institute of Electrical and Electronics Engineers (IEEE) 802.11p and 1609.2 standards and the SAE International J2735 message standard. A Samsung Galaxy Tablet computer provided the Driver-Vehicle Interface (DVI) and additional processing. The miniWSU interfaced with the DVI and vehicle Controller-Area Network (CAN) bus.
- **Safety Applications** – Battelle developed the two new transit-specific safety applications – PCW and VTRW – hosted on the Tablet computer. Three basic safety applications – FCW, EEBL, and CSW – common with other Model Deployment vehicles were
preloaded on the miniWSU. This article focuses on the newly-developed transit-specific applications.

- Crosswalk Motion Sensors – The MS SEDCO SmartWalk XP was used to detect pedestrians in intersection crosswalks in support of the PCW safety application. These units were mounted to existing poles at a recommended height of 10–12 feet, and employed microprocessor-analyzed Doppler microwave detection technology.

- Data Acquisition System (DAS) – The University of Michigan Transportation Research Institute (UMTRI) DAS was used to record data for the purpose of TRP evaluation, including data from the vehicle CAN bus, four video cameras, a range/position sensor, and the basic safety applications.

Transit-Specific Safety Applications

Pedestrian in Signalized Crosswalk Warning (PCW)

The PCW application was deployed at the intersection of Fuller Road and Medical Center Drive, in Ann Arbor, MI, next to the University Medical Center.

This intersection was chosen because it was an RSE / SPAT-enabled signalized intersection on a well-used bus route with significant pedestrian traffic.

Source: Battelle, Google Inc.

PCW Model Deployment Location
The PCW application improved safety of pedestrians by alerting the transit bus driver of a pedestrian in the crosswalk, through which the bus was expected to turn.

The PCW application was automatically "on" when the transit bus was "within range" of the intersection and in a turn lane as determined by Global Positioning System (GPS) position. When a pedestrian pressed the crosswalk call button for the crosswalk the bus was expected to traverse, a cautionary alert was issued to the transit bus driver. When a pedestrian entered the crosswalk, a warning was issued to the bus driver.

Pedestrian presence in the crosswalk was determined by the crosswalk motion sensors. Both the call button status and pedestrian presence in the crosswalk status were packaged in the Signal Phase and Timing (SPaT) message that was broadcast by the roadside DSRC radio and received/processed by the transit vehicle on-board equipment.

PCW alerts issued to the bus driver were displayed on the Driver-Vehicle Interface (Tablet computer), and accompanied by computer-generated verbal messages specific to the alert type.
Vehicle Turning Right in Front of Bus Warning (VTRW)

The VTRW application was deployed at 17 bus stop locations on the University of Michigan Commuter North and Commuter South routes.

These routes were chosen as best suiting the purpose of this application — detecting other vehicles traveling in the same lane as the bus, then forced to change lanes in order to pass the bus when it is stopped at a bus stop. The risks of this situation are compounded when the bus stop sits just prior to another roadway crossing or drive entrance commonly located in urban locations (i.e., near-side bus stops).

The VTRW application improved safety for both the passengers of the transit bus as well as third-party vehicle occupants by alerting the transit bus driver of a vehicle passing and navigating through the blind zone and ultimately turning into the transit vehicle’s direction of travel.

The VTRW application was automatically “on” when the transit bus stopped at an enabled bus stop and the driver showed an “intent to proceed” as determined by the bus being in a forward gear without the brakes applied. When a Model Deployment-equipped vehicle pulled out from the blind spot behind the bus, a cautionary alert was issued to the transit bus driver. When the same vehicle then proceeded to start to turn right in front of the bus, a warning was issued to the transit bus driver.

The remote vehicle’s path relative to the transit bus was determined based on the BSMs transmitted by the remote vehicle over DSRC radio at 10Hz and received by the transit bus’s DSRC radio. The position information included with the BSM was then compared to the bus’s own position to determine
relative path.

VTRW alerts issued to the bus driver were displayed on the Driver-Vehicle Interface (Tablet computer), and accompanied by computer-generated verbal messages specific to the alert type.

![VTRW Driver Alert Displays (Left: Caution; Right: Warning)](source)

**Summary of Results**

The TRP system was originally deployed onto the three University of Michigan transit vehicles with a full complement of TRP hardware and software on February 1, 2013. The system was used typically 12 hours per day for an eight-month deployment period.

Battelle collected and analyzed data from the deployment, developed limited system refinements based on initial lessons learned, and redeployed the refined system for four weeks during February and March 2014. Data from the redeployment was also collected and analyzed.

The USDOT Volpe Center will provide results including the safety impact of each of the TRP safety applications, as well as an assessment of driver acceptance and overall system performance. Information from the independent evaluation should be available in early 2015.

Battelle’s analysis, summarized here, focuses largely on transit application performance – PCW and VTRW accuracy and DVI efficiency.

For the original deployment, many PCW events were collected at the target intersection. For the redeployment, proportionately fewer events were

![Pedestrian Events February through September 2013](source)

![Pedestrian Events February and March 2014](source)
Vehicle turning right events occurred significantly less frequently than other event types because it took a combination of a TRP-equipped bus to be stopped in a VTRW-designed bus stop while another Model Deployment DSRC-equipped vehicle (i.e., using V2V communications) approached from behind and moved to pass the bus.

For the original deployment, several vehicle turning right events were captured. For the redeployment, proportionately fewer events were captured due to the much shorter data collection period.

Battelle analyzed the PCW and VTRW event data as compared to “ground truth” (objective data recorded by the DAS), to assess the performance of the applications and determine lessons learned.

DAS Video showing Valid PCW Warning (bus turning with pedestrian in crosswalk)
The analysis essentially compared the TRP Tablet-recorded event data to the “ground truth” as recorded by the Data Acquisition System (DAS).

The limited refinements for the redeployment targeted primarily the PCW application, and included adjustments to the crosswalk detectors intended to decrease false alerts for detection of vehicles in the crosswalk. Adjustments were also made to the lane tracking algorithm intended to decrease false alerts for buses traveling straight through the intersection instead of turning through the subject crosswalk. These revisions had the intended impact of reducing false alerts, though the rate remained high due to limitations of the underlying technologies.

The VTRW application was revised to include transmission gear position as an additional criteria for determining the bus driver’s “intent to proceed” to decrease nuisance alerts when there was no real collision threat. There were also minor adjustments to the Driver Vehicle Interface, including longer alert display times and verbal alerts instead of beeps.

Battelle’s major conclusions and lessons learned from this project are as follows:

- The TRP on-bus software was effective at providing alerts to transit drivers.
- The transit drivers expressed acceptance of the TRP concept.
- There was a high rate of false alerts for the PCW application due primarily to a combination of GPS limitations and pedestrian detector limitations.
- There was a high rate of false alerts for the VTRW application due to GPS limitations.
- Wide Area Augmentation (WAAS)-enabled GPS accuracy is insufficient for the PCW and VTRW applications. Typical lane width is 3.35 meters, thus accuracy within 1.675 meters is required, which cannot reliably be achieved with WAAS-enabled GPS. A more precise technology, such as Differential GPS, should be employed on future systems to achieve expected performance levels.
- The Doppler microwave-based crosswalk detectors are insufficient for the PCW application. A more discerning technology, such as high-speed imaging, should be employed on future systems to achieve expected performance levels.
- DSRC radio technology performed well – there were no TRP problems traced to DSRC radio communications.
- The short-term system refinements yielded expected performance improvements.

Additional information may be obtained from the Transit Safety Retrofit Package Development Final Report, FHWA-JPO-14-142, available from the National Transportation Library in Fall 2014.
Next Steps

Results from the independent evaluation, in addition to the general conclusions identified above, will assist the USDOT in determining specific areas of future research for improving the transit safety applications. In addition, the USDOT plans to pursue the development and testing of additional prototype Connected Vehicle transit safety applications, such as Intersection Movement Assist, Left Turn Assist, Transit Bus Stop Pedestrian Safety, and Blind Spot Warning / Lane Change Warning.

Selection of these applications is based on an analysis of collision data from the National Transit Database (NTD), prioritized by crash frequency and cost. The priority crash types include bus collisions at intersections, collisions at bus stops, including collisions with pedestrians, and side collisions with other moving vehicles. The NTD collision analysis report, FHWA-JPO-13-116, may be obtained from the National Transportation Library at http://ntl.bts.gov/lib/38000/38000/38051/fhwa-jpo-13-116.pdf.