Center for Advanced Multimodal Mobility Solutions and Education

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THE USE OF CONNECTED VEHICLE TECHNOLOGY TO FACILITATE MULTIMODAL WINTER TRAVEL (PHASE I)

Final Report

by
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DISCLAIMER

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EXCUTIVE SUMMARY

Winter weather impacts the safety, mobility and economic productivity of surface transportation systems. Snow and ice on roads reduces friction and visibility, leading to accidents, injuries and death. Nationally, snowy, slushy or icy pavement conditions are present in about 27 percent of weather-related crashes, or over 300,000 crashes annually. Inclement weather conditions also impact public transport passenger behavior and public transport service performance, and multimodal commuters including pedestrians and cyclists are particularly susceptible in winter weather events. Connected Vehicle (CV) technology is well-suited to address multiple safety and mobility impacts of winter weather. Accurate and real time traffic information, route operation information and road weather information are essential for commuters to take a high level-of-service trip.

A nationwide survey of transit operation managers or supervisors was conducted to assess priorities for transit applications of CV technologies to improve safety and mobility during winter. A summary of findings from the survey are as follows: 1) the biggest influence of winter storms on transit operations are snow build-up at stops, route delays, and route changes/cancellations; 2) notifications to passengers or users is primarily done via local news stations and large notices on transit authority websites, 3) most transit agencies use road weather information and forecasts to improve transit operations, 4) the transit CV applications thought to have the most potential for improving winter transit travel are pedestrian warning and left turn assistance warning, 5) the greatest concerns for CV technology are increased driver distraction, safety consequences of equipment failure, and system performance in poor weather.

Two applications of CV technology for improved multimodal winter travel are presented in the Concept of Operations chapter: 1) *CV applications in winter transit operations*--- mobile road weather-related data and traffic flow data will be collected from CV technology enabled city fleet vehicles, transit vehicles and private vehicles through CAN-Bus, automatic vehicle location (AVL), and sensors mounted on the vehicles. These route-specific data will be combined with point data from road weather information system (RWIS), traffic loop data, and traffic cameras. After data processing and analysis, road segment weather and traffic information will be analyzed by transit operators to provide real-time and forecast route information. 2) *CV applications in multimodal commuter winter travel advisories and warnings*---the road segment weather information and transit route information will be shared to multimodal commuters through a Smartphone App to allow commuters to select proper trip behavior (trip time, trip modes, trip routes, etc.).

This project has laid the foundation to address the innovative use of CV technology for improving multimodal winter travel. Future phases of this project are suggested to include pilot transit and bicycle/pedestrian CV technology applications to compare transit operations efficiency and the costs and benefits of the CV solution.

Chapter 1. Introduction

1.1 Problem Statement

The Federal Highway Administration (FHWA) has estimated that "over 70 percent of the nation's roads are located in snowy regions…and nearly 70 percent of the U.S. population lives in these regions" (Fig. 1). As such, it is desirable to use the best technologies to enhance the transportation system user experience during the winter season. Smart snowplows have been increasingly used as mobile data collection platform for enhanced winter operations, featuring automatic vehicle location (AVL) and other sensors. For winter travel, there are also existing technologies such as road weather information systems (RWIS), dynamic message signs (DMS), and traveler information systems. Connected vehicle (CV) data could be utilized to enhance these strategies by supplementing or complimenting current roadway sensing components to improve the effectiveness of the system operations to react to changing road weather conditions. The 360° awareness by snowplow operators and increased system reliability are envisioned to reduce the risk of vehicle crashes and enhance the efficiency of system operations. Road weather data collection will be improved by utilizing weather sensors in CVs and by transferring collected data through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, which has been demonstrated in the European WiSafeCar project (Sukuvaara and Nurmi, 2012). Connected Vehicle Reference Implementation Architecture (CVRIA) developed by FHWA (Sill, 2017) has defined how CVs will contribute to the road weather management data collection and information dissemination. The enhanced road weather condition information can be communicated to the general public so that they can slow down, choose a different route, or stay home in light of inclement weather.

In this context, there is an urgent need to identify and demonstrate the operational scenarios in which CV technology can be employed to improve winter road surface condition monitoring and traveler information, with a focus on multimodal travel.

1.2 Objectives

This project aims to investigate how CV data could be utilized to improve decision-making for roadway operations subject to inclement winter weather events (e.g., snowstorm, icy roads) and enhance situation awareness of drivers, thus improving the multimodal traveler experience. The focus will be placed on the intersection of public transit routes, bicycle lanes, and multimodal commuters. In order to identify specific CV applications for multimodal winter travel the following tasks were undertaken: 1) review and synthesize relevant literature, 2) distribute and analyze a nationwide survey of transit agencies, and 3) develop the Concept of Operations (ConOps) for the use of CV technology to facilitate multimodal winter travel.

1.3 Report Overview

The remainder of this report is organized as follows: Chapter 2 presents a comprehensive review of the state-of-the-art and state-of-the-practice literature. Chapter 3 provides a detailed analysis of the results of the survey of transit agencies. Chapter 4 describes the Concept of Operations. Finally, Chapter 9 concludes this report with a summary and a discussion of the directions for future research.

Chapter 2. Literature Review

2.1 Introduction

This chapter provides a review and synthesis of the state-of-the-art and state-of-the-practice literature on the use of CV technology for winter road weather applications and CV applications in transit, bicycle and pedestrian travel modes.

2.2 CV Technology Applications for Winter Travel

Road Weather Information System (RWIS) stations at fixed locations and manual patrolling are widely adopted by Departments of Transportation for understanding current weather conditions, and using this information (as well as weather forecasts) for determining winter road maintenance activities (plowing, deicing, anti-icing, etc.). However, it must be noted that the pointwise RWIS data are inadequate when it comes to predicting the surface conditions along roads (Drobot et al.; 2010; Shi et al., 2007). Thus there is an interest in "filling in the gaps" between RWIS stations by using mobile sensors mounted to patrol vehicles and plows (Drobot et al. 2010; Nordin et al., 2013). The broad availability of road weather data from an immense fleet of mobile sources will vastly improve the ability to detect and forecast road weather and pavement conditions (Hill, 2013). Connected vehicle technologies can provide data connectivity and communication between data from mobile sensors such as vehicle probe and data from fixed RWIS stations (Dey et al., 2015). The combination of vehicle probe data and RWIS data may have the potential to provide the meteorological and transportation agencies with a high temporal and spatial data set of road and atmospheric conditions (Drobot et al., 2010).

Based on existing research, CV technology can be applied in several areas to benefit winter travel (Figure 1). CV data collected from mobile vehicles (snowplows), roadside RWIS stations and other sources (such as cameras) will be processed and analyzed in transportation management centers (servers) and then useful road weather information will be disseminated to different user groups, such as winter maintenance personnel, traffic management centers, transit authorities, and travelers. This is done through in-vehicle display, 511 system, mobile apps, social media, websites, radio etc. CV data will provide real-time, location specific road weather data that can be used for optimal winter road maintenance actions and scheduling of labor, materials and equipment (Pisano, 2017; Chapman & Drobot, 2012), transit route optimization, and traveler expectations and trip planning.

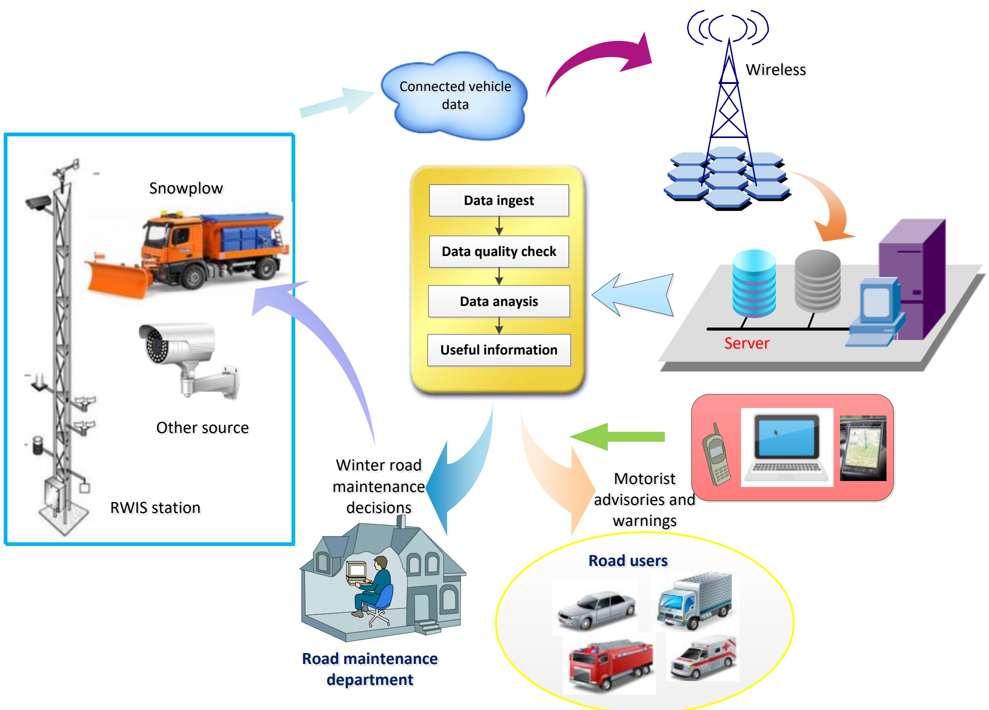

Figure 1: CV technology applications for winter travel.

A summary of existing research of CV technology applications for winter travel is shown in Table 1. Many researchers and transportation communities have worked to explore how to capitalize on CV technologies to enhance safety and mobility, but few are specifically geared towards improved winter travel. Two topic areas worth noting are winter road maintenance and road weather advisories/warnings for travelers.

Table 1: Summary of Relevant CV Technology for Winter Travel

CV Data	CV Application	Ref
Winter Road Condition Assessment and Maintenance		
Road condition assessment	Proposes data from weather stations and friction data from fleets of connected cars can be used to predict the slippery road conditions.	Panahandeh et al., 2017
Road condition assessment	Proposed using crowdsourcing with numerous probe vehicles and sensors installed on vehicles and smartphones for collecting pavement condition information.	Dennis et al., 2014
Road condition assessment	Proposed Droid smartphone app (DataProbe) to collect data to estimate slippery road condition.	Robinson, 2012
Road condition assessment	Demonstrated a smart phone based system was capable of providing reliable results in comparison with the current method of patrol reporting for route-level monitoring of winter road conditions.	Linton & Fu, 2015
Road condition assessment	Demonstrated vehicle-based image data combined with RWIS data and machine-learning models to improve accuracy of smartphone-based road surface condition	Linton & Fu, 2016
Road condition imagery	Iowa DOT uses plow dashboard-mounted mobile phones and an app to take images of road surface and provides images to maintenance managers and the general public on a web service (Track a Plow).	Hirt B, 2017

Road weather and condition	The FHWA Every Day Counts program Integrating Mobile Observations (IMO) is working with 23 state DOTs. IMO involves collecting weather and road condition data from government fleet vehicles, such as snowplows. The focus is on supplemental data from ancillary sensors installed on the vehicles, such as pavement temperature sensors, and includes native vehicle data such as windshield wiper status and anti-lock brake or traction control system activation. The data provides maintenance managers with an extremely detailed view of the weather and road conditions along the road network.	Pisano, 2017
Road Weather Advisories and Warnings for Motorists		
Snowplow Camera Images; Traveler Information System	MnDOT installed network video dash cameras and ceiling-mounted cameras on 226 snowplows. The cameras were integrated with the onboard MDC/AVL equipment and automatically captured snapshots of road conditions during plowing.(Hirt, 2017). Images were sent to MnDOT's server and then imported in near-real-time to the MnDOT travel information website and MnDOT 511 mobile app for up-to-the-minute use by the traveling public.	Hirt, 2017
Using Clarus Data for Disseminating Winter Road Weather Advisories and Other Weather-Related Alerts	▪The New York State 511 system combines the road weather information from Clarus and other weather data sources to generate various weather alerts pertaining to snow, ice, winds, and other severe weather conditions, and posts these alerts on the 511NY website. ▪Western States One-Stop Shop project creates a user-friendly website that integrates and displays weather and road condition information for a four-state region from Clarus, CCTV, NWS and other data.	Alfelor et al., 2012
Other Winter Travel Application		
The Road Weather Management Program	IntelliDrive's Dynamic Mobility Applications capitalize on vehicle-infrastructure connectivity by using data from vehicle probes and other real-time data sources, and enable TMCs to manage mobility between and across modes more effectively while providing information to travelers to support dynamic decision making.	Alfelor & Yang, 2011
Rural Variable Speed Limit Corridors	In the project, a research vehicle was equipped with connected vehicle technology and vehicle data were collected during storm events along a rural VSL corridor. Also tested NCAR's Pikalert system and suitability of CV data for VSL decision-making algorithms.	Hammit & Young, 2015
WYDOT CV Pilot Deployment Program	The Wyoming Department of Transportation's (WYDOT) Connected Vehicle (CV) Pilot Deployment Program is one of three USDOT CV Pilots. The Wyoming pilot will specifically use V2V and V2I technology to reduce the impact of adverse weather on truck travel in the I-80 corridor in Wyoming.	Gopalakrishna, 2015
Weather Responsive Traffic Management	FHWA, Michigan DOT, Minnesota DOT, and Nevada DOT joined to work under the IMO (integrated mobile observations) project and develop an architecture that provides efficient WRTM (Weather Responsive Traffic Management) strategies and advanced data collection and analysis.	Belzowski, 2016

2.3 CV Technology Applications for Multimodal Travel

Research on CV technology for multimodal travel (transit, bicycle and pedestrian modes) is more limited than the broader CV applications for fleet and private vehicles, and currently nonexistent for winter travel applications. This section provides a summary of the research identified for these alternative travel modes (transit, bicycle and pedestrian).

2.3.1 **Transit CV Technology**

The ITS Joint Program Office of the US Department of Transportation began looking at transit CV safety research areas by studying transit vehicle collision characteristics. The six application areas recommended for development, in order of priority, are:

1) "Transit-Vehicle/Pedestrian Warning Applications: These applications may consider vehicle-to-infrastructure (V2I) or vehicle-to-pedestrian (V2P) communications to provide warnings to transit vehicles of a pedestrian's presence in the roadway – either in a crosswalk or outside of the crosswalk.
2) Bus Stop Warning Applications: Using vehicle awareness messages, applications could be developed to alert nearby vehicles or pedestrians of the presence of a transit vehicle at or near a bus stop.
3) Left Turn Assist Warning Applications: These applications could provide information to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to inform them of hazards to completing a safe left turn. These applications may be supported using vehicle-to-vehicle (V2V) communications where vehicles share information about their location, speed, trajectories, and other vehicles at the intersection.
4) Forward Collision Warning Applications: These applications could alert and then warn drivers if they fail to brake when a vehicle in their path is stopped or traveling slower.
5) Blind Spot Warning/Lane Change Warning Applications: These applications could warn drivers when they try to change lanes if there is a car in the blind spot of an overtaking vehicle.
6) Angle Collisions at Intersections Warning Applications: These applications could provide warnings to drivers at signalized intersections, at intersections equipped with stop signs, highway rail intersections (HRI), or light rail intersections." (Schneeberger et al., 2013)

The top priority transit CV application (Transit Bus Stop Pedestrian Warning (TSPW) was subsequently funded for development of a Concept of Operations (Pierece & Zimmer, 2015) with detailed scenarios of transit bus and pedestrian positioning and the required anticipate hardware, software and equipment. The application is geared towards alerting pedestrians at bus stops of approaching and departing transit vehicles, as well as alerting transit vehicle and other connected vehicles of pedestrians potentially in harm's way.

2.3.2 **Bicycle and Pedestrian CV Technology**

There are only a few documents related to safety of bicyclists and pedestrians in a Connected and Autonomous Vehicle (CAV) environment despite the fact that 17 percent of all motor vehicle fatalities in 2013 involved these and other nonvehicle occupants (Dopart, 2015).

Notably the Pedestrian and Bicycle Information Center (Sandt & Owens, 2017) has listed ten key challenges that will need to be overcome:

1) The Detection Problem: it's currently easier for vehicle to detect, recognize and anticipate the movements of other vehicles than pedestrians and bicyclists
2) The V2X Problem: technology is not currently advanced enough and there are equity and privacy issues to overcome
3) The Communication Problem: pedestrians and drivers currently have an unofficial communication system involving facial expressions and gestures that may not be factored into a CAV environment
4) The Right-of-Way Problem: whether a pedestrian, cyclist, or vehicle has the right of way is dependent on local and state customs and laws
5) The Passing Problem: Again, there is no universal law or established research to indicate when and how a vehicle should pass bicyclists
6) The Speed Problem: posted speed limits are maximum legal speeds, but personal preference and environmental/roadway conditions (such as the presence of significant pedestrian or bicycle traffic) may cause some drivers to choose to drive slower
7) The Pickup/Dropoff Problem: mobility and visibility challenges of drivers while parking or backing up put pedestrians and cyclist at more risk
8) The Driver Handoff Problem: there will be several decades in which vehicles with varying levels of automation are on roads and research is needed to know when vehicles should execute maneuvers themselves or give control back to the driver
9) The Mode Shift Problem: will a CAV environment lead to more vehicle miles traveled and more lanes/parking requirements, or eliminate excess vehicles is still up in the air
10) The Data Problem: In the event of a crash, pre and post data could be helpful in analyzing single and multiple incidents, although currently access and sharing of data is limited because of the proprietary nature of much of the technology

A small business innovation research (SBIR) grant has led to the development and testing of hardware and software for a CV bicycle to communicate with infrastructure and vehicles and is currently undergoing pilot testing (Jenkins et al., 2017).

Chapter 3. National Survey of Large Transit Agencies

3.1 Introduction

A survey was designed to gather information from transit operation managers or supervisors on their relevant experience and insights. The objective of the survey was to assess priorities for transit applications of connected vehicle technologies to improve safety and mobility during winter. The survey questionnaire was distributed online to over 50 large transit agencies. In total, the research team collected 15 effective responses from city transit authorities in Washington State, Montana, Colorado, Michigan, Iindiana, Illinois, Pennsylvania, Virginia, Maine, New Hampshire, Massachusetts, and Connecticut (Figure 2).

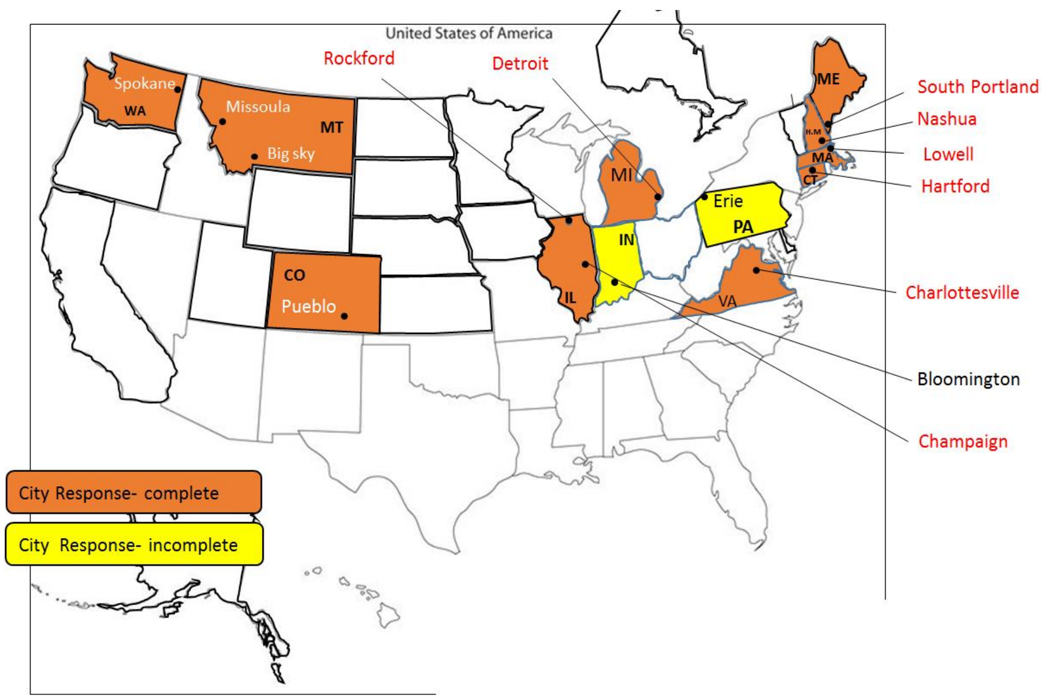

Figure 2: Distribution of survey respondents

3.2 Survey Response Analysis

The survey questions were designed to collect information about how winter storms affect transit operations and which CV technologies

3.1.1. **How do winter storms currently affect your operations? (check all that apply)**

Respondents were asked to select from several options and offer other impacts of winter storms to transit operations. The options provided were: route delays, changed or cancelled routes, snow build-up at stops, high labor needs for snow removal and salting, and icy tracks. Route delays and snow build-up at stops were the most often selected responses, followed closely by changed or cancelled routes and high labor needs for snow removal and salting (Figure 3). Not many selected icy tracks – as not all respondents have rail transit.

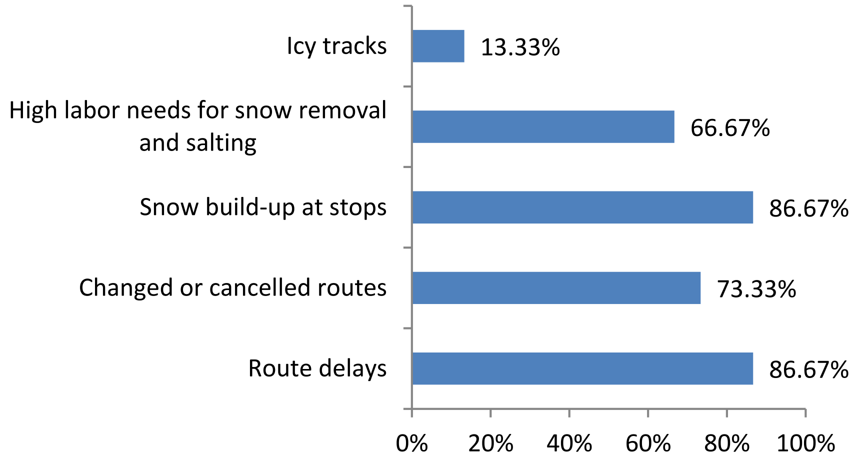

Figure 3: Influence of winter storms affect transit operations

3.1.2. How do you communicate to passengers/users when winter storms cause delays or cancellations? (check all that apply)

Figure 4 shows the level of use of different information display methods for transit agencies. The most used means are local news station and large notices on the main page of the agency's website (80%). The next is social media alerts (73%), and then smartphone APP and AVL/live map (47%). In addition, variable message signs at bus stop/transit hubs and direct text/e-mail updates for registered clients are also used by transit agencies when winter storms cause delays or cancellations.

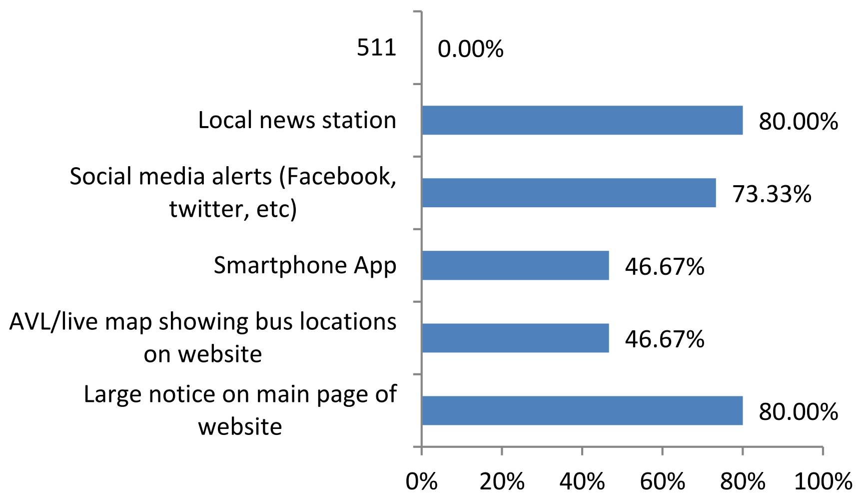

Figure 4: The use of communication methods by transit agencies during winter storms

3.1.3. Which of the following might be beneficial during winter storms to improve operations?

This question asked respondents what type of road weather data would be beneficial to know in order to improve operations during winter storms. The choices provided were: pavement condition, pavement and air temperature, precipitation type and amount, visibility, wind speed and direction, and road friction/grip. Pavement condition and precipitation type/amount were the most often-selected response (Figure 5), followed by temperature and visibility.

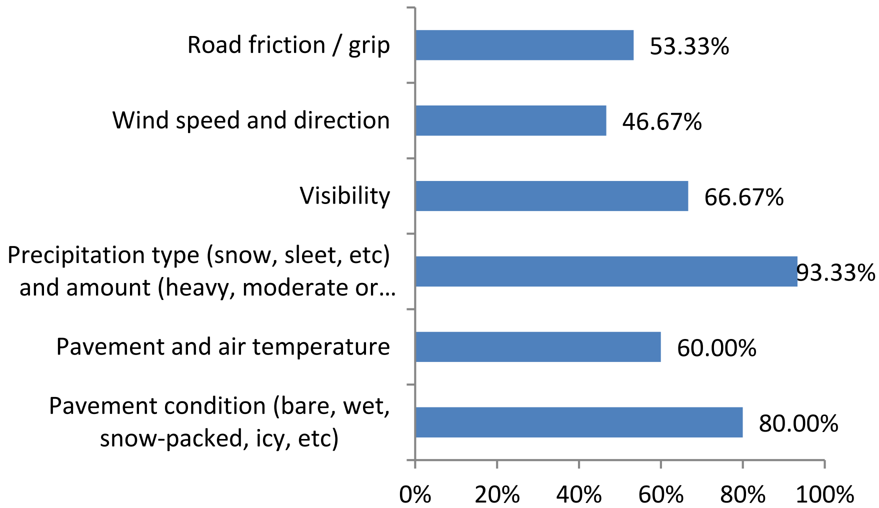

Figure 5: Relative importance of road weather information during winter storms

3.1.4. **Do you currently use any of the above [road weather data] during winter storms?**

Most transit agencies do use road weather information (93%). The one respondent that indicated they didn't chose the following three reasons for not using road weather data: don't have access to current data/information, wouldn't use the information to change operations, and never considered looking for this information.

3.1.5. **What are your current methods of obtaining the [road weather] information?**

Most transit agencies rely on weather forecast websites although some use RWIS or local weather stations in the city (Figure 6).

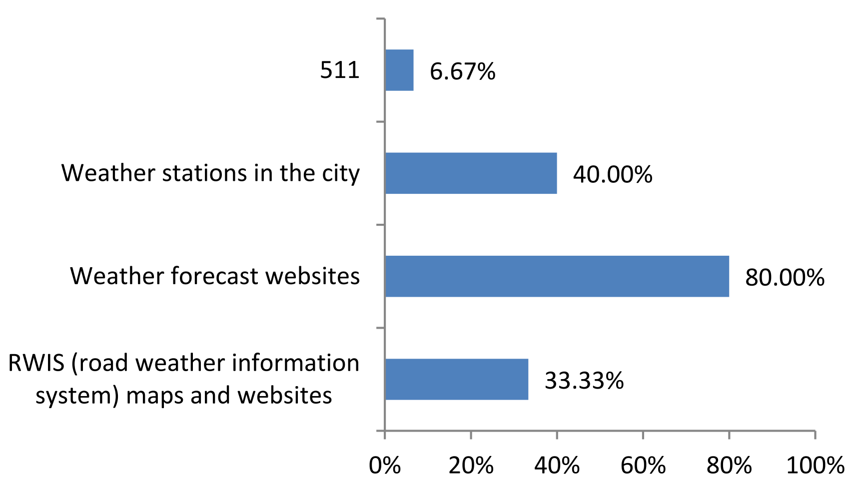

Figure 6: Methods of obtaining road weather information during winter storms

3.1.6. Connected vehicle (CV) technology can provide information about real-time, location-specific weather data (windshield wiper status indicates rain or snow, traction control system activation can indicate icy roads, cameras can show road condition, etc.). How useful do you think CV weather data will be to improve safety and mobility of winter transit operations?

All respondents had positive opinions of the potential of CV weather data to improve winter transit operations (Figure 7).

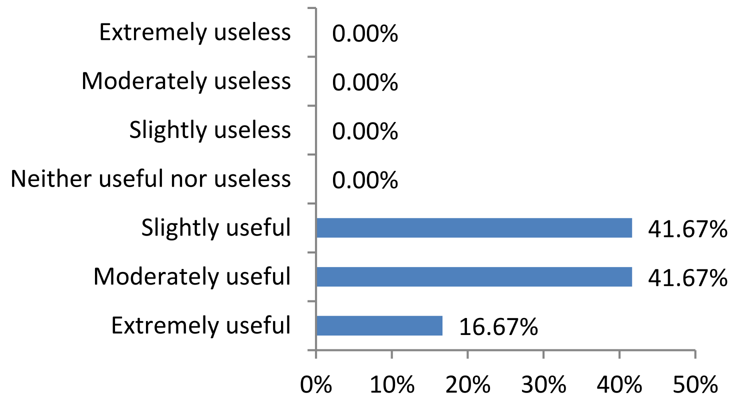

Figure 7: Potential usefulness of CV data for improving winter transit operations

3.1.7. How useful do you think each application will be for improving safety and mobility during winter?

The six transit CV technologies identified during the literature search were listed and respondents were asked about the potential usefulness of the each during the winter season. The six transit CV technologies are:

11) Pedestrian Warning Application for Transit Vehicles: communications to provide warnings to transit vehicles of a pedestrian's presence in the roadway – either in a crosswalk or outside of the crosswalk.
12) Bus Stop Warning Application to alert nearby vehicles and pedestrians: communications to alert nearby vehicles or pedestrians of the presence of a transit vehicle at or near a bus stop.
13) Left Turn Assistance Warning Application: communications to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to inform them of hazards to completing a safe left turn.
14) Forward Collision Warning Application: alert and then warn drivers if they fail to brake when a vehicle in their path is stopped or traveling slower.
15) Blind Spot Warning/Lane Change Warning Application: warn drivers when they try to change lanes if there is a car in the blind spot of an overtaking vehicle.
16) Angle Collisions at Intersections Warning Application: warnings to drivers at signalized intersections, at intersections equipped with stop signs, highway rail intersections (HRI), or light rail intersections.

The highest ranking CV application is the pedestrian warning application for transit vehicles, followed by left turn assistance and forward collision warning applications (Figure 8).

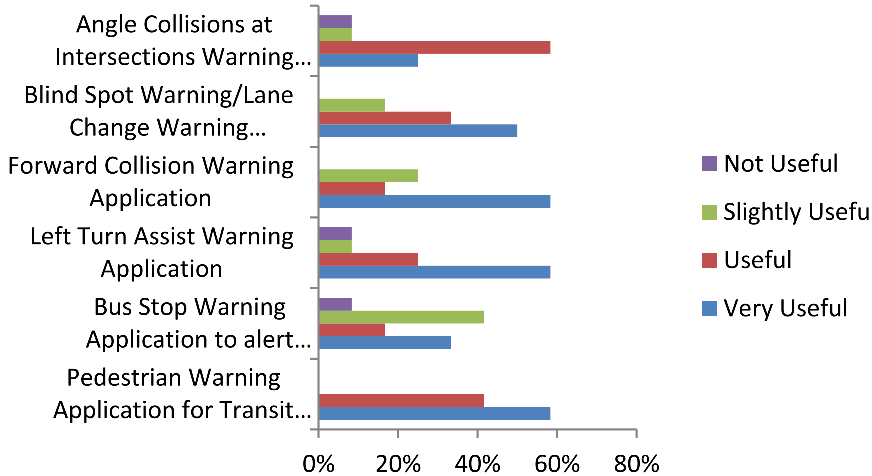

Figure 8: The potential usefulness of several transit CV technologies

3.1.8. How concerned are you about the following issues?

As a whole, increased distraction for drivers is the largest concern with 58% very concerned and 25% moderately concerned. Both the safety consequences of equipment failure or system failure and system performance in poor weather are also concerning to individuals with 42% very concerned and 33% moderately concerned. Other notable concerns are drivers' overreliance on the technology (33% very concerned and 50% moderately concerned) and legal liability for drivers/owners (58% very concerned and 8% moderately concerned). A total of 54.54% people expressed high level of concerns on interacting with non-connected vehicles. In addition, some respondents are also concerned about system security (25% very concerned and 8% moderately concerned). Only 18% and 17% respondents are very concerned about learning to use connected vehicles and data privacy, respectively.

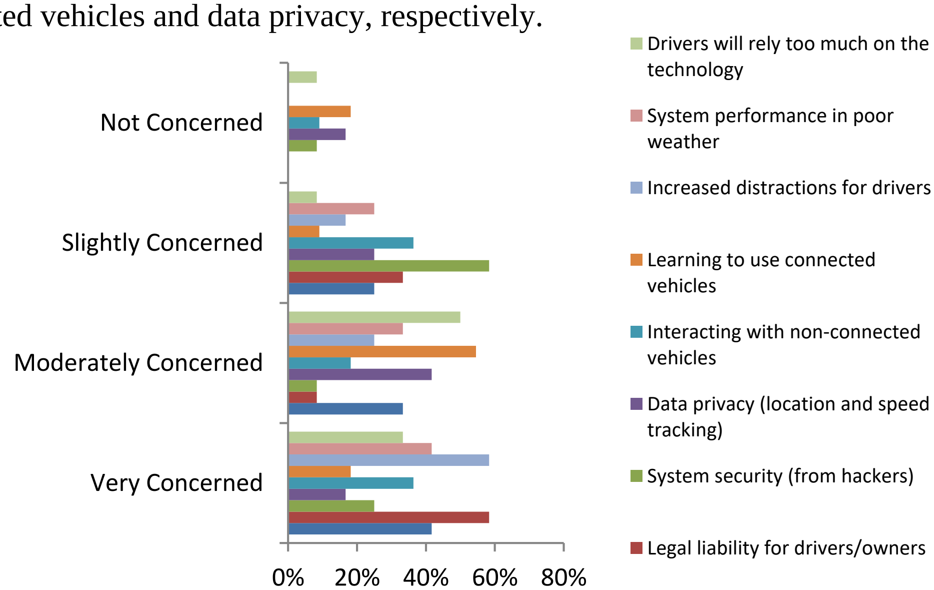

Figure 9: The degree of concern of different issues related to CV applications

3.1.9. **Please share any comments/thoughts regarding Connected Vehicle technologies for improving safety and mobility of transit during winter storms.**

This open-ended question was answered by seven respondents. Generally, they think the CV technology will be useful for improving transit operations, but they are concerned about the cost and effectiveness. The as-received responses are:

- Not sure technology is developed enough for routine transit operations.
- The concern is that drivers may come to rely too much on the technology, and not pay as much attention to their driving as they should.
- Driver interaction should be minimum
- We regularly deal with these conditions in the winter. Not entirely sure if this information would be that helpful, as conditions tend to be either ok, or generally bad everywhere in our service area.
- Would want to see a pilot program and review data before implementing changes. This is very expensive technology and we operate a very large fleet. There would need to be proven results before a capital investment of this size would "pencil out".
- I think it is normal for drivers, especially, to rely heavily on these technologies when they are available. This, in my experience, is detrimental to driver awareness. For the most part, when there are adverse or extreme weather conditions present, I would rather have my drivers relying on their own senses and judgement - not the technology.
- I think they are really useful but am concerned about the over reliance.

3.3 Summary

The respondents to the survey were mainly distributed in northwest and northeast areas. All the respondents thought winter storms would bring a series of negative impacts on transit operation. The biggest influences are snow build-up at stops and route delays (87% respectively). Routes changes or cancellations were also a noticeable influence of winter storm (73%). When winter storms cause route changes or cancellations, the transit agencies will adopt various methods to notify the passengers or users. Local news stations and large notices on their main website are the most used means. Other measures include smartphone app, social media station, VMS signs at bus stop and direct text or email for users.

During winter storms, some useful road weather information can be beneficial for improving transit operations. The most important information for improving winter transit operation is precipitation type (snow, sleet, etc.) and amount (heavy, moderate or light). Moreover, pavement condition and visibility are also very useful. Currently, majority of transit agencies use this information in transit operations. Generally, the transit agencies can collect this information by different methods including RWIS, weather forecast websites, weather stations, reports from drivers, human observations by field personnel, etc.

Compared with the current information collection methods, CV technology can provide accurate, real-time road weather data, and all the respondents thought it was useful to improve the transit operations in winter storms. In six potential CV transit applications, Pedestrian Warning Application for Transit Vehicles is thought the most beneficial for improving safety and mobility during winter with 58% very useful and 42% useful. Left turn assistance warning application is the next with 58% very useful and 25% useful. Other useful applications include Forward Collision Warning Application, Blind Spot Warning/Lane Change Warning Application, Angle Collisions at Intersections Warning Application, Bus Stop Warning Application to alert nearby vehicles and pedestrians.

Although they have positive attitudes to CV technology for winter transit operations, they are still concerned about this new technology. The largest concern is increased distractions for drivers. Both the safety consequences of equipment failure or system failure and system performance in poor weather are also notable. In addition, other aspects including drivers' overreliance on the technology, legal liability for drivers/owners, interacting with non-connected vehicles, as well as system security are among the concerns as well.

However, all the respondents are still eagerly looking forward to see the pilot program and expect the development prospect of CV transit application.

Chapter 4. Concept of Operations

4.1 Introduction

This document is a baseline Concept of Operations (ConOps), and its format generally follows the standard defined by the IEEE Guide for Information Technology Concept of Operations Document.

The objectives of ConOps are as follows:

- Document the existing system.
- Identify the high-level needs to be addressed.
- Provide a conceptual overview of the desired system.
- Define users and operational scenarios of the proposed system.
- Present operational impacts of the proposed system.
- Analyze advantages and limitations of the proposed system.

The ConOps will form the foundation for the application of a pilot system design and development of multimodal connected vehicle technology for transit and bicycle commuters in Spokane, WA. The purpose of this document is to capture user needs for winter travel and explore how CV technologies will fulfill these needs as well as describe the proposed system characteristics and applications from a user's viewpoint. The primary intended audience for this document is the end users including transit agencies, multimodal commuters (bike or walk in combination with transit), and motorists.

As stated above, the purpose of this project is to reduce traffic impact of adverse winter weather and improve winter travel through connected vehicle technology. There are two primary applications that are developed. They are as follows.

- CV applications in winter transit operations--- mobile road weather-related data and traffic flow data will be collected from CV technology enabled city fleet vehicles, transit vehicles and private vehicles through CAN-Bus, AVL, and sensors mounted on the vehicles. These route-specific data will be combined with point data from road weather information system (RWIS), traffic loop data, and traffic cameras. After data processing and analysis, road segment weather and traffic information will be analyzed by transit operators to provide real-time and forecast route information.
- CV applications in multimodal commuter winter travel advisories and warnings---the road segment weather information and transit route information will be shared to multimodal commuters through a Smartphone App to allow commuters to select proper trip behavior (trip time, trip modes, trip routes, etc.).

4.2 Current Situation

This section will describe the background, operational policies and constraints, current system, involved personnel (users), and support concept of the transit and multimodal commuter situation in Spokane, Washington.

4.2.1 **Background and objectives**

Winter weather impacts the safety, mobility and economic productivity of road transportation. Snow and ice on roads reduces friction and visibility, leading to accidents, injuries and death. Nationally, snowy, slushy or icy pavement conditions are present in about 27 percent of weather-related crashes, or over 300,000 crashes annually (FHWA 2017). Many studies have demonstrated increased accidents and fatalities during winter in general or icy/snowy conditions in particular, with some noting increased severity at the beginning of winter (Khattak & Knapp 2001 – Iowa; Maze & Hans, 2007 - Iowa; Boon & Cluett, 2002 – Washington; Goodwin, 2003 – national; Saha et al., 2016 – national; Dey et al., 2015 – Finland & UK; Andersson, 2010 – Sweden & UK). However, drivers actually tend to drive slower during winter weather, reducing crash severity, and become more competent during the winter season (Pisano et al, 2008). The consequence of slower, safer driving during winter weather is reduced mobility and economic impacts. The mobility impacts of winter weather on the road transportation system include decreased traffic speed, flow, volume and capacity and increased car-following distances, travel time, and start-up delays (Pisano et al., 2002; Hill, 2013; FHWA, 2017; Strong et al., 2010; Pisano, 2017). The economic impacts of winter weather range from indirect costs associated with traveler delays and environmental impacts of winter road maintenance, to the direct costs of plowing, material application and consequent corrosion impacts to infrastructure and vehicles.

Inclement weather conditions also impact public transport passenger behavior and public transport service performance that will influence the normal operations of transit. (Hofmann & O'Mahoney, 2005). Obviously, multimodal commuters including transit passengers, motorists, pedestrians and cyclists are susceptible in winter weather events. Accurate and real time traffic information, route operation information and road weather information are essential for commuters to take a high level of service trip.

4.2.2 **Operational Policies and Constraints**

Many transit agencies have documented policies and procedures that describe strategies for operating transit service under various adverse weather conditions. In many instances, the documented guide appears to be derived from personnel experience and informal rules of practice.

4.2.3 **Current System**

There is a great demand to have knowledge about road weather conditions in order to implement optimal transit operation and to initiate traveler advisories and warnings for road users. Roadside Weather Information Systems (RWIS) is the most used for transportation department and transit agencies to gather road weather data, including but not limited to pavement surface temperature, pavement status, wind speed, and precipitation amount (Chaney et al., 2016; Linton & Fu, 2016). While the basic sensing technologies in RWIS are not cheap, the current RWIS are mainly mounted along the roadway at fixed location. Hence, we can only collect detailed road weather information for these specific points along the roadway using RWIS, but information on conditions between these points cannot be obtained (Strong & Fay, 2007; Shi, 2007), which contributes to low spatial resolution (Linton & Fu, 2016).

In recent years, numerous vehicle-based technologies have been developed to achieve improvements in winter travel efficiency, mobility and safety (Ye et al., 2012). Among them, AVL has been widely adopted by large transit agencies by equipping transit vehicles and city fleet vehicles with AVL that can broadcast vehicles' real-time location.

Recent advances in ITS and RWIS have made non-invasive road weather sensors viable options to estimate friction coefficient. Non-invasive sensors use infrared spectroscopy principles to measure road surface conditions from above the roadway and estimate friction using algorithms based on the presence of snow, ice or water. Mobile friction measurements can be used to establish a decision support model which can warn drivers of potentially slippery conditions on pavement (Najafi et al., 2016).

Connected vehicles equipped with weather sensors could enhance mobile road weather data collection (Dey et al., 2015). Road weather data collection will be improved by utilizing weather sensors in CVs and by transferring collected data through V2V and V2I communication (Sukuvaara and Nurmi, 2012). Although mobile sensors are less widespread than fixed sensors, several state transportation agencies have deployed maintenance fleet vehicles equipped with mobile environmental sensors (Hill, 2013) The Iowa DOT has installed mobile phones on the dashboards of its snowplows and developed an app that prompts the phones to take a snapshot at predetermined intervals when the trucks are in motion (over 10 mph). These images were provided to the general public over the Internet. (Hirt, 2017). The Michigan DOT adopted a Droid smartphone to road condition estimation, which used a Bluetooth wireless link as the primary interface method between the smartphone device and an external sensor module and a CAN device (Robinson, 2012). The Minnesota DOT installed network video dash cameras and ceiling-mounted cameras on one-quarter of MnDOT's total snowplow fleet. The cameras were integrated with the onboard MDC/AVL equipment and automatically captured snapshots of road conditions during plowing. In addition to these efforts by state agencies, a Connected Vehicle Program that could be widely deployed on light and heavy vehicles has the potential to dramatically increase the number of mobile sensor systems across the United States (Hill, 2013). The Connected Vehicle Reference Implementation Architecture (CVRIA) developed by FHWA in the U.S. has defined how connected vehicles will contribute to the road weather management data collection and information dissemination (Sill, 2017). CV technologies will enable traffic managers to deliver road weather advisories and traffic information directly to the vehicle onboard unit as a visual display to drivers.

4.2.4 **Involved Personnel (Users)**

Use of road weather information in winter transit operation: Transit operators and supervisors obtain and make extensive use of road weather information. This information helps transit operators and supervisors make decisions for route operations, including decisions about rerouting, the schedule of route, route cancellation as well as inspection and maintenance of transit vehicles during winter storms. Transit route operation strategies will be transfered to bus drivers via in-vehicle display.

Use of road weather information by multimodal commuter: Traffic managers disseminate road weather information and transit route information to multimodal commuters to influence their travel decisions. Different types of road users have varying information needs. In the event of a road closure, recreational travelers may need alternate route information, while commuters familiar with their route may not. Transit passengers are interested in real time transit route information. Pedestrians and cyclists may also need information about weather and pavement condition. Overall, road weather and traffic information allows travelers to make decisions about travel mode, departure time, route selection, vehicle type and equipment, and driving behavior. Road weather information, traffic information and transit route information can be disseminated via roadway infrastructure, telephone systems, websites, and other broadcast media. Roadway systems that are typically controlled by traffic managers use HAR, dynamic message signs, and flashing beacons atop static signs to alert users to hazards. Interactive telephone systems and applications on smart phones allow users to access road weather and traffic information both pre-trip and en route.

4.3 Justification for and Nature of Changes

This section describes the justification for changes, description of needed changes, and priorities amongst the changes.

4.3.1 **Justification for Changes**

Accurate road and weather condition is essential to improve winter travel, particularly in information-based decision-making, such as winter transit operation and traveler advisories and alerts. Currently, road weather data collected from RWIS and fixed cameras are the main data sources for winter transit operation and traveler information system. However, RWIS and cameras can only provide the road weather data of fixed point along the road that means the relevant transportation agencies are not able to get route-specified road weather information that is very significant to analyze road and weather conditions. The spatial density of the deployment of these fixed detectors is a limiting factor that impacts the effectiveness of information-based strategies. In recent years, many local DOT and transit agencies also install AVL in their city fleet vehicles and transit vehicles and can acquire mobile data from these fleets, but it is only automatic vehicle location data used to reveal current vehicle locations. Although state and local DOT made a great of effort on enhancement of road weather data gathering, there are also gaps.

The availability of road weather data from a connected vehicle environment including both fixed and mobile data sources will change this situation and fill these gaps. Mobile data, from CAN-Bus of city fleet vehicles and transit vehicles as well as additional, specialized sensors mounted on these vehicles will dramatically expand the ability to monitor road weather and pavement conditions with high spatial resolution and temporal resolution. With the connected vehicle road weather data, traffic agencies and transit agencies can issue accurate and real time travel information to users and make optimal transit operation strategies.

4.3.2 **Description of Needed Changes**

Two CV applications are proposed: 1) CV application in winter transit operations, and 2) CV application in multimodal commuter advisories and warnings

By combining connected vehicle data with RWIS, transit agencies will have a better source to obtain road weather information and enhanced capability to respond to adverse winter weather conditions. This application will allow transit vehicles operators to interact with in-vehicle equipment to receive instructions on their actions during winter weather events. CV application in winter transit operation will assist transit operators and supervisors and transportation agency to make more efficient decisions. For transit agency, this application will enhance the efficiency of their winter transit operation. For transit operators, this application will support them to make more optimal treatments when responding to snow/ice weather condition.

The connected vehicle application in multimodal commuter advisories and warnings will push roadway link-specific information to users' in-vehicle devices or personal wireless devices. This application will allow multimodal commuters to access relevant travel warnings and advisories and transit route information through in- vehicle display, phone system, smartphone apps, radio broadcasts and traditional roadway infrastructure as well.

4.3.3 **Priorities among the Changes**

The most urgent change is to develop a number of connected vehicles that are able to participate in vehicle to vehicle and vehicle to infrastructure communication to support the CV application to facilitate multimodal winter travel. Moreover, a coincident necessary change is enhanced server capacity to assimilate and quality-check the mobile data collected by connected vehicles and other fixed detectors and output route-specified weather and road condition advisories.

4.4 New System Concept

This section describes the background, operational policies and constraints, description of the new system, affected personnel (users), and the required support environment.

4.4.1 **Description of the Proposed Applications**

4.4.1.1 CV Applications for Winter Transit Operations

As stated in previous parts in this report, state and local transportation departments and transit agencies try to maintain normal transit service operations even when facing winter weather events. The transit operation strategies are made according to local winter transit plans and rely heavily on experienced transit operators or supervisors. In decisions making, gathering accurate road weather information critical. RWIS is the extremely useful for collecting road weather data, including pavement temperature, pavement status, wind speed, and precipitation amount, etc. however, RWIS is installed on fixed sites and can only gather point-specific road weather data. Route-specified road weather data, which is more important for identifying road weather conditions, is hardly collected.

CV application in winter transit operation concept will change this situation by providing expanded road weather data from connected vehicles. City fleet vehicles, transit vehicles and other voluntary private vehicles will provide road weather connected vehicle data to traffic departments and transit agencies to help them to make optimal decisions for route-specific transit operations strategies. Once made the resulting decisions are provided to transit vehicles drivers. Figure 10 provides a schematic of how the application could operate.

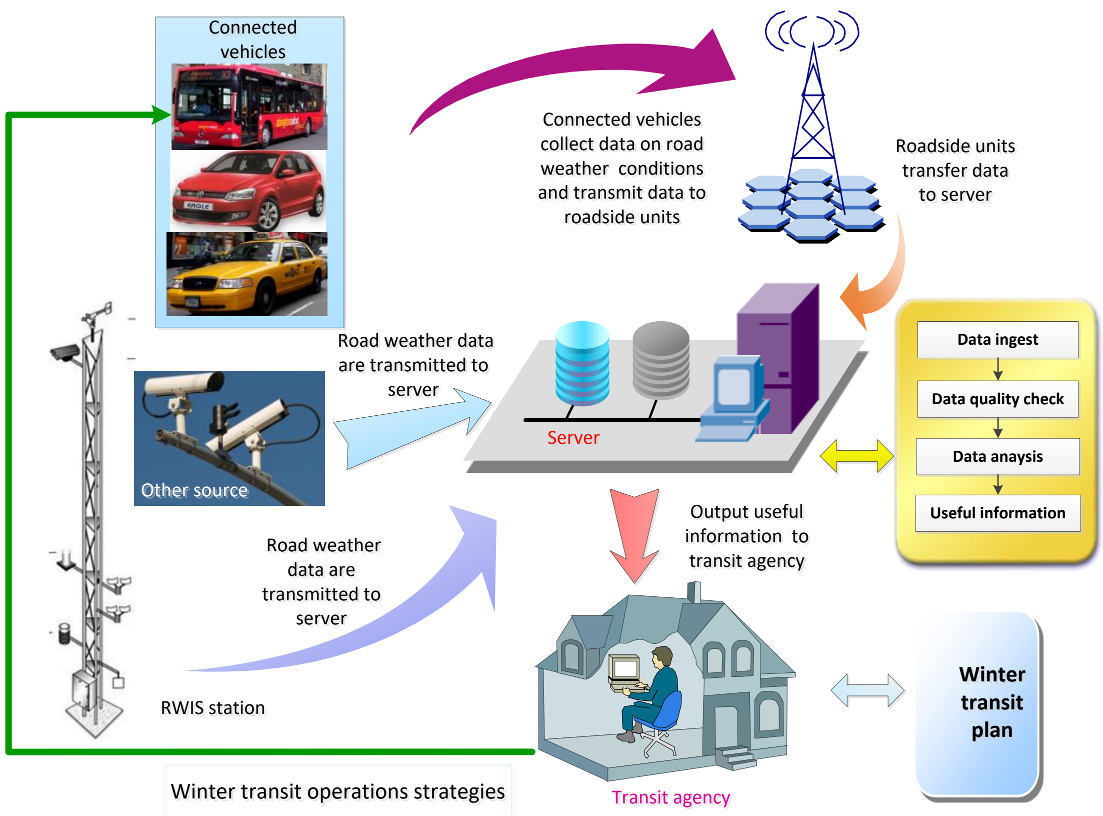

Figure 10: Schematic of CV application in winter transit operations

4.4.1.2 Multimodal Commuter Winter Travel Advisories and Warnings

At present, travelers can access various traveler and road weather information from many different sources and providers. State DOTs normally provide important information on traffic incidents and delays; work zones; and the impacts of severe weather events, such as road closures caused by winter storms or flooding. Transit agencies will provide transit route information, such as reroute, route delay or route cancellations resulting from winter weather events. Multimodal commuters can obtain this information through a series of means, such as 511 systems, agency websites, and infrastructure-based displays (digital message signs) and smartphone apps. Public agencies also distribute the information through traditional media including radio and television broadcasts. With the growing use of information technology and social media, those are also options for transferring road weather information.

Generally, the significance of information received by travelers is dependent on accuracy and timeliness of collected road weather data. Currently, route-specific road weather data collection is not well implemented. The capability to obtain road weather information from connected vehicles will noticeably improve this situation. Raw data gathered from connected vehicles, RWIS and other sources will be integrated, processed and analyzed in servers, which can generate useful road weather information that will be transferred to traffic management centers and transit agencies. On one hand, transit agencies can generate transit route information that can be transferred to traffic management center. On the other hand, the traffic management centers can distribute route information and short time alerts and warnings that are deduced by algorithm immediately. Figure 11 describes the schematic of CV application in multimodal commuter winter travel advisories and warnings.

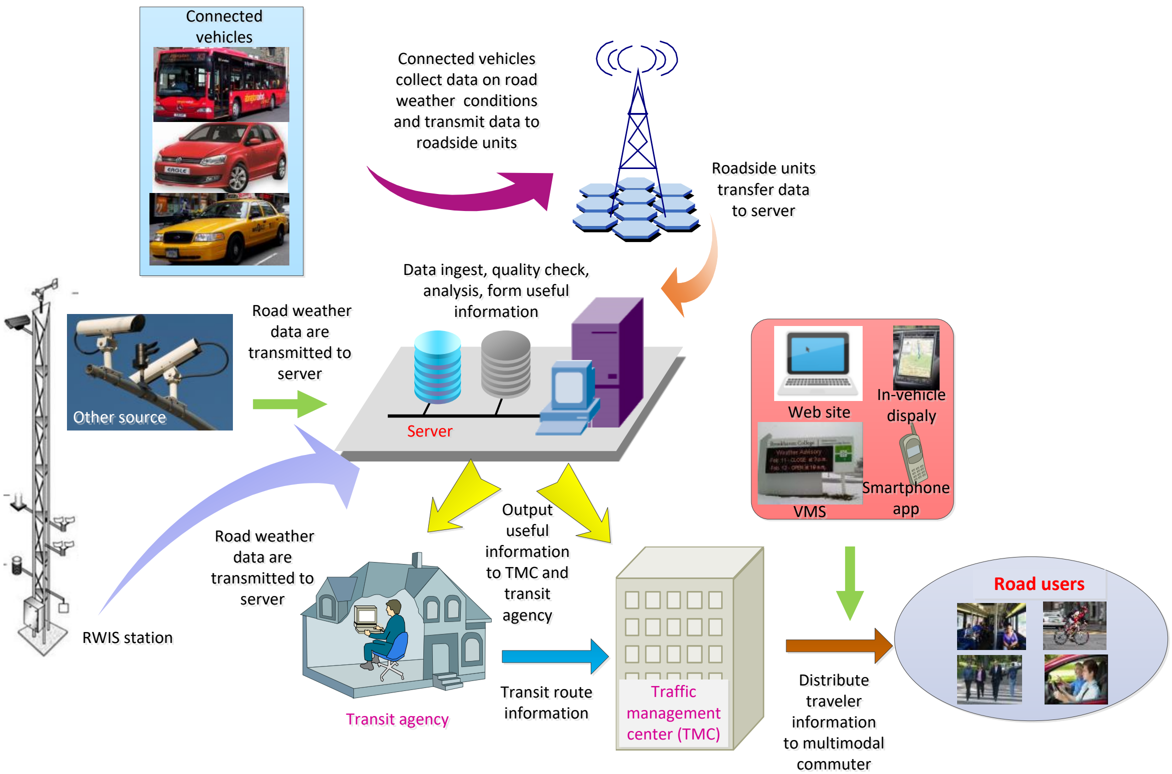

Figure 11: Schematic of CV application in multimodal commuter winter travel advisories and warnings

4.4.1.3 Subsystems for CV applications

Each of these CV applications requires various subsystems:

Data collection subsystem:

This subsystem is made up of the connected vehicles, with their associated onboard equipment and road weather information system (RWIS), other detection equipment (such as cameras, sensors) and the required roadside infrastructure. The connected vehicles involved are mainly city fleet vehicles, transit vehicles and voluntary private vehicles that will provide the data from CAN-Bus and sensors mounted on them.

Data processing subsystem:

Connected vehicle data are first transmitted to roadside units, then to a server which also accepts data from RWIS, traffic and other observation sources. The server will ingest, check and process the data gathered from different sources and output route-specified road weather data that will be available to the transit agency. The information needed includes:

- Weather data: air temperature, barometric pressure, and dew point.

- Road weather data: pavement temperature, friction and salinity.
- Other data: average vehicle speeds, ABS activation events, and vehicle stability and traction control activation events
- Deductive data (from server algorithms): pavement condition, visibility, precipitation.

Information Generation Subsystem

Data outputs from the server will be also provided specifically for transit agencies; thus transit route information will be generated. Additional decision support tools may also be developed for transit operators and supervisors who use the detailed roadway segment-specific data that is newly available from the connected vehicle data sources and the server.

Data transmission subsystem:

Connected vehicle data are communicated to roadside units via direct short range communication (DSRC). The data will be transferred to data severs through wireless or General Packet Radio Service (GPRS).

User interface subsystem:

Transit operators will interact with the winter transit operation system. Ancillary decision support tools may be developed that use the route-specified road weather data from the connected vehicle data sources and data server. Advanced techniques will be required to transfer the enhanced operation strategies back to transit vehicles and transit drivers.

Various user groups will access the multimodal commuter advisories interface through a series of means, such as smartphones, websites, in-vehicle display, infrastructure-based displays (DMS) and social media.

4.4.2 **Operational policies and constraints**

This section described the potential operational risks and constraints.

Data availability

The effectiveness of this application is based on the availability of connected vehicle road weather data. That means sufficient transit vehicles, city fleet vehicles and private cars are equipped with sufficient onboard or external equipment. Appropriate roadside units are also required. Additional research is needed to identify the levels of transit vehicles and city fleet vehicles CV penetration needed to obtain sufficient data for the application, and the appropriate spatial resolution of the roadside units. Finally it supposes traffic departments and transit agencies would like to deploy connected vehicle devices and other external sensors into the vehicles.

Server function

Poor quality data or poorly-functioning algorithms will yield inadequate route-specific road weather information and only hinder decision support for transit operators. Thus data processing of server function requires additional research to improve the algorithm precision.

Data processing function

As stated, the concept assumes the development of new algorithms to quickly analyze the road weather data to produce short time advisories and warnings for multimodal commuters. In addition, it also describes the other information processing system that is used to generate transit operation information. With this environment, additional development and research are required.

Interfaces to other systems

Users can access the advisories and alerts through a variety of means including public websites, phone hotline, and private phone APP. The development of suitable interfaces will be required to adapt the existing systems.

Personnel knowledge

Lack of training and knowledge for various involved personnel will result in limited use of connected vehicle road weather information.

Deployment coverage

In this concept, it requires an adequately dense network of roadside units with appropriately geographic coverage to collected connected vehicle road weather data. This will be especially important in areas of complex terrain or where information on short roadway segments is desired.

4.4.3 **Modes of operation**

There are three typical modes of operation for this application.

Normal mode

With the normal operation mode, the CV in winter transit operation application is available during all winter weather events. All the objects of the application can function normally.

Degraded mode

In the degraded operating mode, some of the objects of the application are not functioning properly or may not be available. For example, some onboard equipment or sensors may not be functioning, limiting the data sources.

Maintenance mode

During maintenance mode, some subsystems are not functioning or may not be available as expected. This mode is analogous to Degraded Mode; however, it may be possible to bring the subsystems back into operation during maintenance mode, if needed.

4.4.4 **User classes and other involved personnel**

Transit vehicle drivers

The drivers of these vehicles will be passive participants in the collection and communication of the identified connected vehicle road weather data. However, these vehicle operators will be intended recipients of the information that the CV environment generates. Operators of these vehicles will interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events. (Hill, 2013)

Transit operators

This group of users will interact with system outputs. They will use the decision support tools to make winter transit operation plans based on winter transit operation guides and experience and then direct the actions of the transit drivers.

Traffic management center personnel

The TMC personnel will provide travel advisories and warnings and transit route information from the application for the public through 511 system or other phone-based systems or agency websites.

Motorists

All the motorists will be the intended recipients of the information. They can access the travel advisories and alerts through a variety of devices on pre-trip or en-route.

Transit passengers

This group of users will receive travel advisories and transit route information from TMC which can assist to select proper trip modes, trip route, and trip time and so on.

Pedestrians and cyclists

Pedestrians and cyclists will receive travel advisories and alerts through smartphone app, social media, etc.

4.4.5 **Support environment**

The CV application in winter transit operation concept will operate within the whole connected vehicle system. The system requires the utilization of connected vehicle onboard equipment, other special sensors and DSRC roadside unit or other wireless communication system, such as cellular and GPRS, access to the certificate management entities defined for the CVS; and suitable data communications backhaul. (Hill, 2013)

It is assumed that the systems operating with data server will be deployed coincident with data processing and communication systems required to operate the existing system within state and local agency facility. Hence, suitable systems administrators, system maintenance, and IT personnel will be required if the system is operational.

An appropriate communication infrastructure will be necessary for the transit operators to direct transit vehicles' drivers. Also an appropriate communication infrastructure will be necessary to distribute travel advisories and alerts to multimodal commuters.

4.5 Operational Scenarios

This section provides the use case diagram of the two applications.

4.5.1 **Scenarios for CV application in winter transit operations**

In this scenario, connected vehicles including city fleet vehicles, transit vehicles and voluntary private vehicles provide road weather and traffic data for server as well as RWIS and other detectors. The server analyzes these data combining with algorithm models and outputs route-specific data to transit agencies. Advanced operation strategies are obtained by winter transit guide plus transit operators' experience. Finally, the recommendations are sent back to transit vehicles via in-vehicle display. Figure 12 shows scenarios for CV application in winter transit operations.

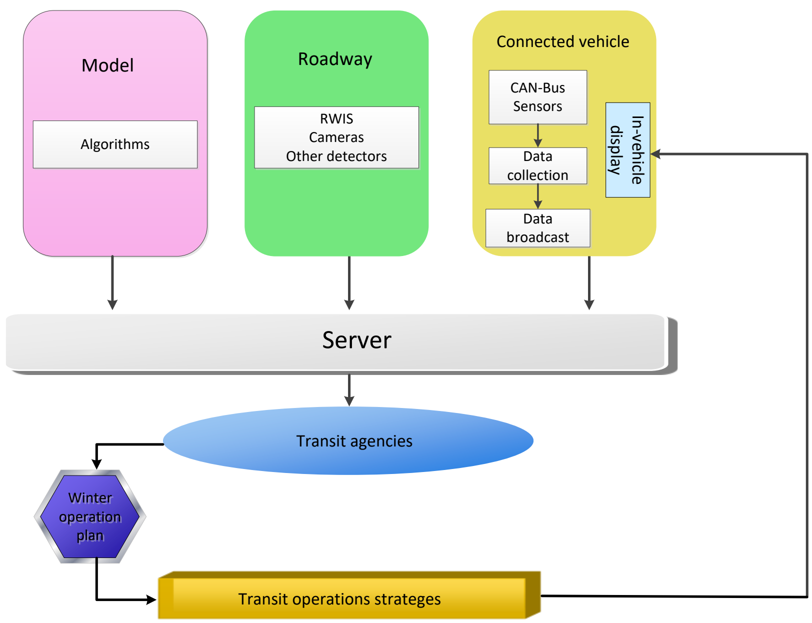

Figure 12: Scenario for CV application in winter transit operations

Step 1: Connected vehicles including city fleet vehicles, transit vehicles and voluntary private cars broadcast road weather data to server through roadside units.

Step 2: RWIS, cameras and other sensors communicate data to server using wireless.

Step 3: Algorithm models are sent to server in order to process data.

Step 4: Server ingests data, executes quality check, and generates route-specified data and transfers outputs to transit agencies.

Step 5: Transit operators or supervisors get the route-based data and make decisions on transit operation strategies according to winter transit plan and their experience.

Step 6: Approved transit route plan are disseminated to an in-vehicle display in transit vehicles. Then transit drivers implement actions.

4.5.2 **Scenarios for CV application in multimodal commuter winter travel advisories and warnings**

In this scenario, connected vehicles including city fleet vehicles, transit vehicles and voluntary private vehicles provide road weather data for server as well as RWIS and other detectors. The server analyzes these data combining with algorithm models and output advanced road segment information to transit agencies and traffic management center. Traffic management center send the travel advisories and transit route information to users through information distribution system. Figure 13 describes the scenario for CV application in multimodal commuter winter travel advisories and warnings.

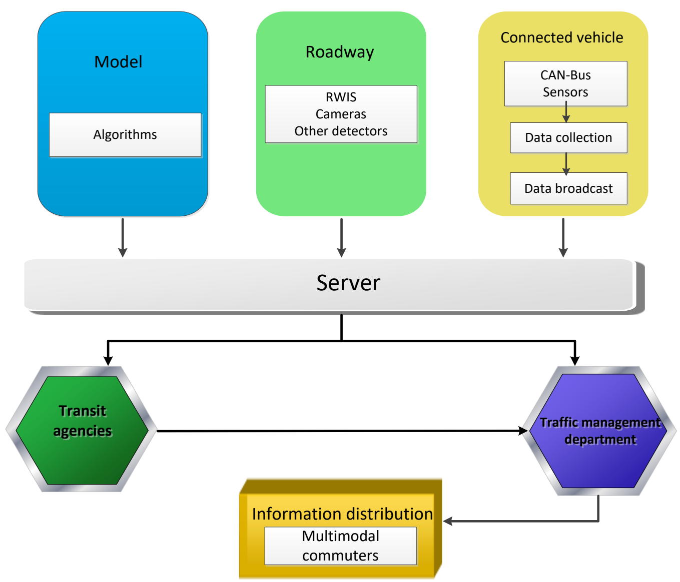

Figure 13: Scenario for CV application in multimodal commuter winter travel advisories and warnings

Step 1: Connected vehicles including city fleet vehicles, transit vehicles and voluntary private vehicles broadcast road weather data to server through roadside units.

Step 2: RWIS, cameras and other sensors communicate data to server using wireless.

Step 3: Algorithm models are sent to server in order to process data.

Step 4: Server ingests data, executes quality check, and generates route-specified data and transfers outputs to traffic management center and transit agencies.

Step 5: Traffic management center distributes alerts generated from server and transit route information from transit agencies to commuters such as passengers, drivers, pedestrians and cyclists through information distribution system.

4.6 Summary of Impacts

Generally, the CV application to facilitate multimodal winter travel is expected to enhance the quality and timeliness of road weather information provided to transit operation decision-makers and commuters in the region.

4.6.1 **Operational impacts**

From the operational impacts perspective anticipated impacts of the new system are as follows.

1) Need connected vehicle infrastructures deployment, operation and maintenance.

2) Requirement of in-vehicle devices such as onboard equipment and special sensors in transit vehicles, city fleet vehicles and voluntary personal cars.

3) Development to data collection sources in connected vehicle environment.

4) Enhancement to data processing system in server and traffic management center when ingesting, fusing and analyzing data from a variety of different source.

5) Demands to new operational procedures including new winter transit operations procedures and new traffic management procedures related to commuters' advisories and warnings.

6) Changes to the transit agencies to incorporate CV data into social media, website and various app platforms.

7) Need for additional training on involved personnel such as transit operators, transit staff and bus drivers in the use of the new systems.

4.6.2 **Organizational impacts**

From organizational impacts perspective, several impacts are identified, as follows.

1) Communications among public agencies. The applications describe extended communication among local transportation agencies, such as transit agencies and traffic management centers. Potential interaction between traffic management department and emergency department is also indicated.

2) Communications with private enterprises. In the CV applications for multimodal commuter advisories and warnings, the route-specified weather information, transit route information and travel advisories will be distributed to users via phone apps that are developed and conducted by private sectors.

4.6.3 **Impacts during development**

Impacts during development phase of the proposed applications may include meetings on the new system, system design, test and verification as well as training on drivers.

4.7 Analysis of the New System

This section provides a summary of the advantages, disadvantages/limitations, and alternatives and trade-offs considered.

4.7.1 **Summary of improvement**

The proposed CV applications to facilitate multimodal winter travel are intended to enhance safety, mobility and public agency efficiency in winter. The anticipated improvements are as follows:

1) Providing improved weather and road conditions to drivers, cyclists, and pedestrians will result in reduced crashes and fatalities.

2) Distributing information about current and forecasted road weather conditions and transit route information to multimodal commuters will enable commuters to make better trip plans, such as selecting trip modes, trip time, trip route, and cancelling trip, etc.

3) Enhancing the ability of transit agencies to maintain the highest level of services during adverse winter weather will improve safety and mobility of passengers.

4) Generating accurate, location-specific, real time information about weather and road conditions for transit agencies will enable transit operators or supervisors to make better decisions on transit route operations such as reroute change, route cancel, router delay as to produce high agency efficiency and productivity.

4.7.2 **Disadvantages and limitations**

Although CV applications can bring a series of benefits for multimodal winter travel, there are also some aspects needed to further improve.

1) It is necessary to increase the density of connected vehicles equipped with onboard equipment and additional sensors, encourage more personal cars to engage in CV network to gather mobile data, which will assist transit agencies to obtain sufficient road weather data as to generate more accurate information on road weather conditions and traffic conditions.

2) It is critical to improve server capabilities and performance to be able to handle data processing requirements and develop appropriate algorithms to transform raw connected vehicle data and other road weather and traffic data to advanced and actionable information.

Chapter 5. Summary and Conclusions

5.1 Summary and Conclusions

This research reported has provided the current state-of-the-art of CV technology for multimodal winter travel, results of a transit CV survey, and developed the Concept of Operations for improving winter transit service and multimodal commuter winter travel advisories. The significant findings include:

1) Winter road condition assessments using CV technology, particularly AVL and automated plow-mounted cameras, has been demonstrated and will likely be more widely implemented by state DOTs for two reasons: winter road maintenance decision-making and providing traveler information and advisories.
2) Transit CV applications have limited development and pilot testing.
3) Transit agencies are generally excited about the potential of CV technology to improve winter transit operations, but have some reservations regarding driver distraction, safety consequences, and the cost.
4) Two application areas of CV technology for improved multimodal winter travel are:
    a. CV applications in winter transit operations--- mobile road weather-related data and traffic flow data will be collected from CV technology enabled city fleet vehicles, transit vehicles and private vehicles through CAN-Bus, AVL, and sensors mounted on the vehicles. These route-specific data will be combined with point data from road weather information system (RWIS), traffic loop data, and traffic cameras. After data processing and analysis, road segment weather and traffic information will be analyzed by transit operators to provide real-time and forecast route information.
    b. CV applications in multimodal commuter winter travel advisories and warnings---the road segment weather information and transit route information will be shared to multimodal commuters through a Smartphone App to allow commuters to select proper trip behavior (trip time, trip modes, trip routes, etc.).

5.2 Directions for Future Research

This project has laid the foundation to address the innovative use of CV technology for improving multimodal winter travel. Future phases of this project are suggested to include pilot transit and bicycle/pedestrian CV technology applications to compare transit operations efficiency and the costs and benefits of the CV solution. In addition, a case study with a Municipality Transit Authority may be desirable to calibrate a simulation model for expanded, city-wide transit CV scenarios to optimize mobility during inclement winter weather. To this end, it may be necessary to use mobile tablet or smartphone devices with custom programs for transit vehicles and bicycle or pedestrian commuters and collect data related to travel speed, bus-stop-waiting duration, and distance between transit/bike/pedestrian interactions.

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Appendix A: Survey – CV for Winter Transit

SURVEY: **CV FOR WINTER TRANSIT OPERATIONS**

This 10-question survey is being conducted to assess priorities for transit applications of Connected Vehicle technologies to improve safety and mobility during winter. Please share your current experience and your opinions on the usefulness of new technologies

At the end of the survey you will be asked whether you want to be included in a drawing for one of four $25 Amazon gift cards. If so, you'll need to provide your name, email, address and phone number.

This research is being conducted by the Center for Advanced Multi-modal Mobility Solutions & Education, a Tier 1 University Transportation Center funded by the US Department of Transportation. This survey is voluntary and you may choose to not participate. If you have any questions about the survey or research project, please contact Dr. Xianming Shi at Xianming.shi@wsu.edu or Phone 509-335-7088.

Q1. What transit agency, city, or county are you affiliated with? Please provide your name and either email address or phone number.

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Q2. How do winter storms currently affect your operations? (check all that apply)

☐ Route delays
☐ Changed or cancelled routes
☐ Snow build-up at stops
☐ High labor needs for snow removal and salting
☐ Icy tracks
☐ Other (please describe) ____

Q3. How do you communicate to passengers/users when winter storms cause delays or cancellations?

☐ Large notice on main page of website
☐ AVL/live map showing bus locations on website
☐ Smartphone App
☐ Social media alerts (Facebook, twitter, etc)
☐ Local news station
☐ 511
☐ Other ____

Q4. Which of the following information might be beneficial during winter storms to improve operations?

☐ Pavement condition (bare, wet, snow-packed, icy, etc)
☐ Pavement and air temperature
☐ Precipitation type (snow, sleet, etc) and amount (heavy, moderate or light)
☐ Visibility
☐ Wind speed and direction
☐ Road friction / grip
☐ Other (please describe) ____

Q5a. Do you currently use any of the above information during winter storms?

○ Yes, skip to Q5b

○ No, skip to Q5c

Q5b. What are your current methods of obtaining the information?

☐ RWIS (road weather information system) maps and websites
☐ Weather forecast websites
☐ Weather stations in the city
☐ 511
☐ Other ____

Q5c. Why not?

☐ Not enough staff
☐ Don't have access to current data/information
☐ Wouldn't use the information to change operations
☐ Not necessary
☐ Never considered looking for this information
☐ Other (please describe) ____

Q6. Connected vehicle (CV) technology can provide information about real-time, location-specific weather data (windshield wiper status indicates rain or snow, traction control system activation can indicate icy roads, cameras can show road condition, etc).
How useful do you think CV weather data will be to improve safety and mobility of winter transit operations?

○ Extremely useful

○ Moderately useful

○ Slightly useful

○ Neither useful nor useless

○ Slightly useless

○ Moderately useless

○ Extremely useless

Q7. The following 6 topics are potential application areas for Transit Connected Vehicle programs:
Pedestrian Warning Application for Transit Vehicles: communications to provide warnings to transit vehicles of a pedestrian's presence in the roadway – either in a crosswalk or outside of the crosswalk.
Bus Stop Warning Application to alert nearby vehicles and pedestrians: communications to alert nearby vehicles or pedestrians of the presence of a transit vehicle at or near a bus stop.
Left Turn Assist Warning Application: communications to drivers performing unprotected left turns to judge the gaps in oncoming traffic and to inform them of hazards to completing a safe left turn.
Forward Collision Warning Application: alert and then warn drivers if they fail to brake when a vehicle in their path is stopped or traveling slower.
Blind Spot Warning/Lane Change Warning Application: warn drivers when they try to change lanes if there is a car in the blind spot of an overtaking vehicle.
Angle Collisions at Intersections Warning Application: warnings to drivers at signalized intersections, at intersections equipped with stop signs, highway rail intersections (HRI), or light rail intersections.
How useful do you think each application will be for improving safety and mobility during winter?

	Very Useful	Useful	Slightly Useful	Not Useful
Pedestrian Warning Application for Transit Vehicles	O	O	O	O
Bus Stop Warning Application to alert nearby vehicles and pedestrians	O	O	O	O
Left Turn Assist Warning Application	O	O	O	O
Forward Collision Warning Application	O	O	O	O
Blind Spot Warning/Lane Change Warning Application	O	O	O	O
Angle Collisions at Intersections Warning Application	O	O	O	O

Q8. How concerned are you about the following issues related to CV technologies for transit operations during winter storms?

	Very Concerned	Moderately Concerned	Slightly Concerned	Not Concerned	Don't Know
Safety consequences of equipment failure or system failure	○	○	○	○	○
Legal liability for drivers/owners	○	○	○	○	○
System security (from hackers)	○	○	○	○	○
Data privacy (location and speed tracking)	○	○	○	○	○
Interacting with non-connected vehicles	○	○	○	○	○
Learning to use connected vehicles	○	○	○	○	○
Increased distractions for drivers	○	○	○	○	○
System performance in poor weather	○	○	○	○	○
Drivers will rely too much on the technology	○	○	○	○	○

Q9. Please share any comments/thoughts regarding Connected Vehicle technologies for improving safety and mobility of transit during winter storms.

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Q10. Thank you! Do you want to be entered into a drawing for a $25 Amazon gift card? If yes, provide your name, email, address (personal or work address) and phone number. There will be at least 4 gift cards and up to 10% of completed responses.

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