

**CONNECTED
VEHICLE/INFRASTRUCTURE
UNIVERSITY TRANSPORTATION
CENTER (CVI-UTC)**

**Applications of Connected Vehicle Infrastructure
Technologies to Enhance Transit Service Efficiency and
Safety**

Applications of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety

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Connected Vehicle/Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Abstract

Implementing Connected Vehicle Infrastructure (CVI) applications for handheld devices into public transportation transit systems would provide transit agencies and their users with two-directional information flow from traveler-to-agencies, agencies-to-traveler, traveler-to-vehicle, and vehicle-to-traveler. This information flow could improve the efficiency of services provided by the agency and enhance the safety of travelers and drivers. This project developed an architectural framework for two CVI applications: (1) an application for dynamic demand-response transit (DRT) services and (2) an enhanced traveler safety application that allows individuals to notify a transit vehicle that they are within a specified distance of the vehicle's current stop location. A limited simulation was performed to evaluate the potential of using this location information with respect to a transit vehicle to provide flexibility for that vehicle to remain at a stop for a limited time, minimizing passenger wait time and exposure to potential safety issues, specifically during night operations. An annotated bibliography of resources used for this study is also provided.

Acknowledgements

The authors recognize the support that was provided by a grant from the U.S. Department of Transportation – Research and Innovative Technology Administration, University Transportation Centers Program and to the Virginia Tech Transportation Institute.

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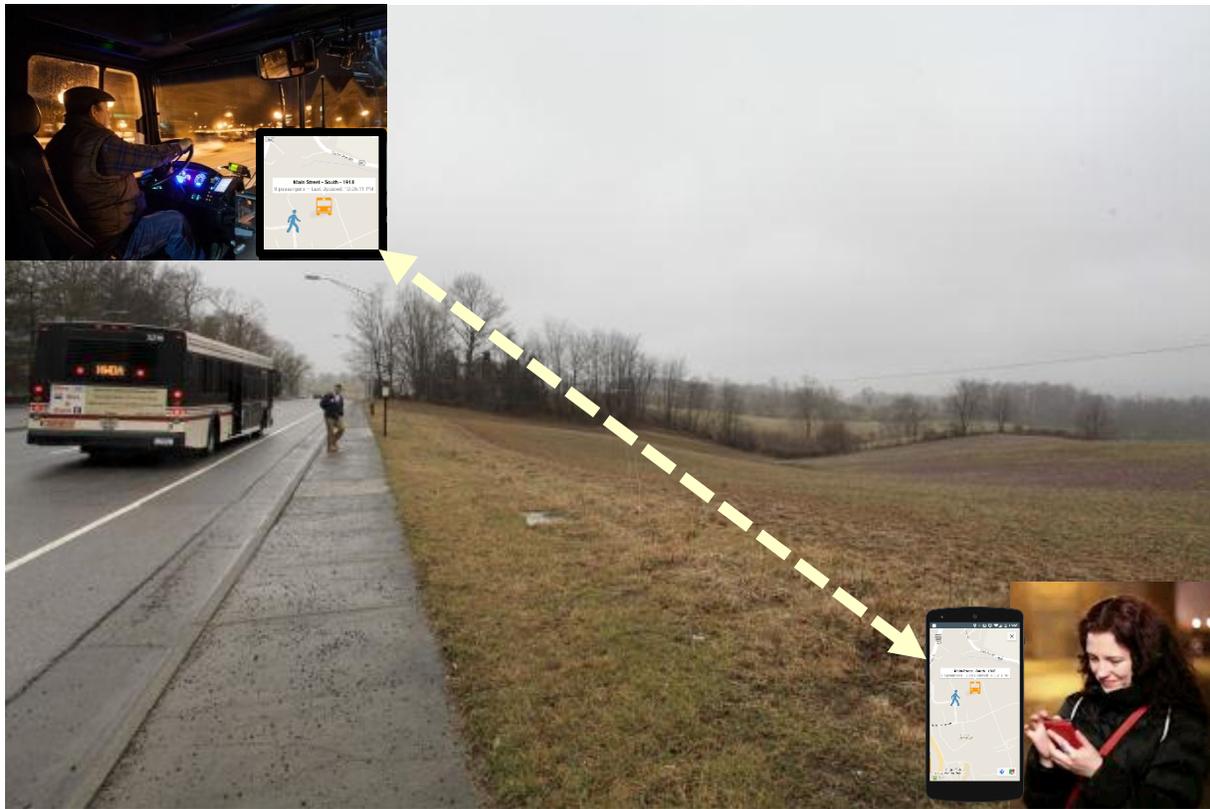


Figure 1. Enhanced traveler safety application.

Introduction

In 2013, Virginia Tech and Morgan State Universities were awarded a project to apply connected vehicle (CV) technologies to public transportation with the goal of making public transportation operation more efficient and productive through responsiveness to the immediate travel needs of the public. The approach was to identify incremental ideas that would lead to gradual changes in transit operations at different levels of demand. The scope was modified in 2014 when project leadership at both universities changed.

The redefined scope was to research and develop two beta applications: a dynamic demand-responsive transit routing and scheduling application primarily for use in small urban areas and rural transit operations, and an enhanced traveler safety application—represented in Figure 1—based on the premise that if a transit driver knows the locations of travelers who are en route to a transit stop, the driver can wait a short time so that the traveler is not required to wait 20 to 30 minutes, or longer, for the next vehicle. Virginia Tech compiled an annotated bibliography based on the literature review for the project, developed a proposed architecture to support implementation of the two applications, and performed a limited simulation of the safety application to evaluate its potential use. Morgan State developed the prototype applications. This report details the work performed by Virginia Tech. The annotated bibliography is included in the appendix and is a useful resource for readers interested in CV infrastructure related to transit

operations and references related to the corresponding communication architecture. The proposed architecture required for the two applications and a description of the simulation related to the second application are presented in the following sections.

Background

Connected vehicle infrastructure (CVI) technologies consist of applications that use wireless technologies for the exchange of data between vehicles, roadway infrastructure, central services, and handheld devices. Currently, many transit agencies provide real-time operational information, including trip planning, routing, and scheduling, which typically consist of one-way information flow from transit agencies to travelers. This project considered two applications that use two-way communications, specifically between handheld and onboard devices.

These technologies provide many benefits that support enhanced safety, mobility, and environmental sustainability for transportation agencies, travelers, and the transportation industry [1]. The United States Department of Transportation Intelligent Transportation Systems Joint Program Office describes the benefits of CV technology to travelers, transportation agencies, and industry as follows:

Travelers are the primary beneficiaries. They will experience improved safety of travel, including reduction in fatalities, injuries, and the costs associated with crashes. Travelers will also benefit from real-time, multimodal information that will lead to more efficient and eco-friendly choices regarding travel routes and modal choices. For instance, informed travelers may decide to avoid congestion by taking alternate modes such as walking, biking, or public transit; by rescheduling their trip; or by taking alternate routes.

Transportation agencies benefit by being able to see and respond dynamically to conditions on the transportation network as they evolve and expand across all of the modes. Operators will have the tools to manage the multi-modal system more efficiently, saving fuel, and reducing environmental impact. For example, data generated by connected vehicles systems can provide transportation operations centers with detailed, real-time data on traffic volume, speeds, transit schedule status, parking availability, evolving weather conditions, and other roadway conditions. This information can be used to optimize the transit capacity, traffic signal timing or ramp meter operations, corridor management, incident and emergency response, variable speed limits, dynamic road pricing, road weather surface treatments, and improved real-time travel alerts and advisories, among others.

Industry benefits with the introduction of a new marketplace in support of connected vehicles technologies, applications, and new, creative products and services. A key component of each of the research programs described in this ITS Strategic Research Plan is the focus on catalyzing new markets and the assurance that resulting policy will support

market growth; in fact, successful connected vehicles adoption will rely upon the ability of private markets to efficiently bring products and services to consumers across the Nation.

Industry will also benefit from efficiencies delivered by connected vehicles deployments. Organizations that engage in freight and passenger transportation, in particular, will find that the seamless, real-time information enabled by wireless communication between vehicles and with infrastructure translates into greater economic productivity, administrative cost savings, and profits. System and operational efficiencies will be gained through real-time information on system conditions, routing recommendations, vehicle diagnostics, and fleet and capacity usage. Connected vehicle applications will also enable interoperable operations and real-time data sharing and exchange to facilitate automated screening, inspections, credentialing, and other processes. Further, for those organizations that provide information services, wireless technologies will deliver a more ubiquitous range of data sources for developing new applications and services. [2]

In this report, an overview of how CVI works is presented along with a summary of the communication technologies used in the implementation of CVI applications. This is followed by a general framework that supports these applications. A high-level architecture, which describes the communication flow between agency, travelers, vehicles, and roadside equipment (RSE), is presented, followed by a description of the framework's components. A more-detailed architecture for the two applications is then presented. This is followed by a description of the limited simulation of the enhanced traveler safety application and a discussion of the results of the simulation.

Method and Results

Architecture for Applications

The enterprise system of CVI is still evolving. The core enabler of CV applications is effective data communication. Communication networks, protocols, security, and messaging formats are fundamental to CV development, testing, and demonstration, and continue to be discussed and refined.

Currently, Dedicated Short Range Communications (DSRC) technology is the foundation of CV applications. DSRC is fast, secure, reliable, and not vulnerable to interference, which makes it an essential technology for safety applications. Applications that are not primarily concerned with providing safety benefits may rely on different wireless technologies, such as cellular, Wi-Fi, and Wi-Max. [3]

DSRC (5.9 GHz): DSRC operates on a dedicated 5.9-GHz band using the Wireless Access in Vehicular Environments (WAVE) protocol [4-6]. WAVE is defined in the IEEE 1609 standard and its subsidiary parts, which are built on the established IEEE 802.11 standards for Wi-Fi wireless networking [7]. SAE J2735 defines the standard message set [8].

DSRC delivers the high bandwidth and low latency needed for vehicle-to-vehicle (V2V), vehicle-to-interface (V2I), and infrastructure-to-vehicle (I2V) communications. A certificate management scheme provides security [4, 5].

DSRC is a relatively new technology, with only limited, proof-of-concept deployments. The most extensive thus far is the United States Department of Transportation's (U.S. DOT's) Safety Pilot program in Michigan to test V2V and I2V safety applications [9]. In addition, some private demonstrations of tolling applications by a DSRC system vendor have been provided to certain agencies.

Cellular services: Cellular communication services are widely available in the United States from several commercial vendors. The technologies underlying those services vary among providers, but all provide similar voice and data services through phone handsets and cellular data modems. Commercial services are generally marketed as 3G or 4G connections that differ primarily in the bandwidth (speed) that is theoretically available for each connection. Geographic coverage varies across providers, but all urban and most rural areas are served by at least one provider.

The ubiquity of commercial cellular services makes them valuable in vehicular environments for applications needing continuous connectivity over longer travel segments and trips. Smartphones now provide traveler information and entertainment options that were previously available only through AM and FM radio broadcasts. Cellular applications are increasingly being used for probe data collection and other telematics, especially on fleet vehicles. Bandwidth is generally sufficient for data-centric applications, though not necessarily for streaming video, and the networks are designed for secure transmissions. However, network latencies and the potential for a dropped connection prevent cellular from being suitable for safety applications that rely on real-time data exchange [5].

Commercial cellular services have been used in a variety of commercial telematics deployments and CV demonstrations. The California SafeTrip-21 Connected Traveler Field Test Bed Mobile Millennium project used standard 3G Nokia phones as probe data sources [10]. Cellular connections have been used for backhaul from RSEs in the Vehicle Infrastructure Integration (VII) California Test Bed, and as one option in the VII Proof-of-Concept (POC) Test Bed in Michigan [11]. OnStar has used a dedicated onboard cellular connection for many years, and Ford is using a Bluetooth connection to a driver's cell phone handset for its SYNC connection.

Wi-MAX: Wi-MAX is a relatively new wireless technology designed to provide high-bandwidth data communications over a wide area. As with any wireless network, the practical bandwidth is reduced at longer ranges, but connections of up to 10 miles are possible. The Wi-MAX standards (IEEE 802.16) support both fixed and mobile implementations.

Although Wi-MAX has been deployed in the U.S. by Clear Wire as a 4G commercial cellular service, it can operate in unlicensed spectrum and can be deployed as a private network. It was used for backhaul purposes as part of the VII POC in the Michigan demonstration test environment [12].

Wi-Fi: Wi-Fi networking equipment is widely available, inexpensive, and used in home, commercial, and industrial environments. The protocol for Wi-Fi communications is defined by IEEE 802.11 [7]. Bandwidth has increased substantially from the original protocol implementations, and the most recent standards provide connections comparable to wired connections.

Although Wi-Fi was not developed specifically for vehicle-to-X (V2X) communications, it has been used in some CV applications [5].

General Framework Architecture

The proposed architecture is based on current implementations from a wide range of transit services applications using CVI [13-25]. The approach is based on results from these studies, the National Intelligent Transportation Systems (ITS) Architecture shown in Figure 2, and the Connected Vehicle Reference Implementation Architecture (CVRIA) developed by the Research and Innovative Technologies Administration (RITA) shown in Figure 3 [13-15].

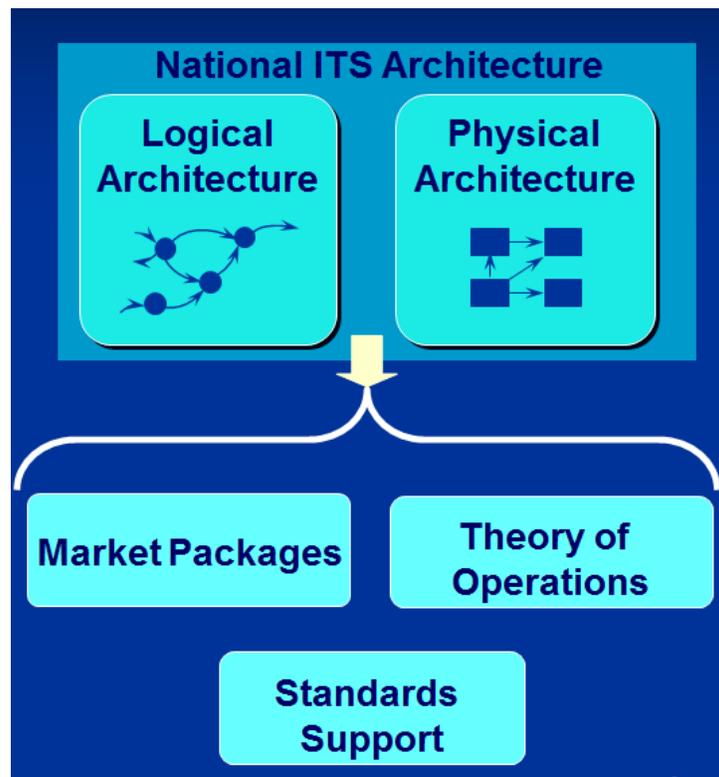


Figure 2. National ITS Architecture (Source: [14]).

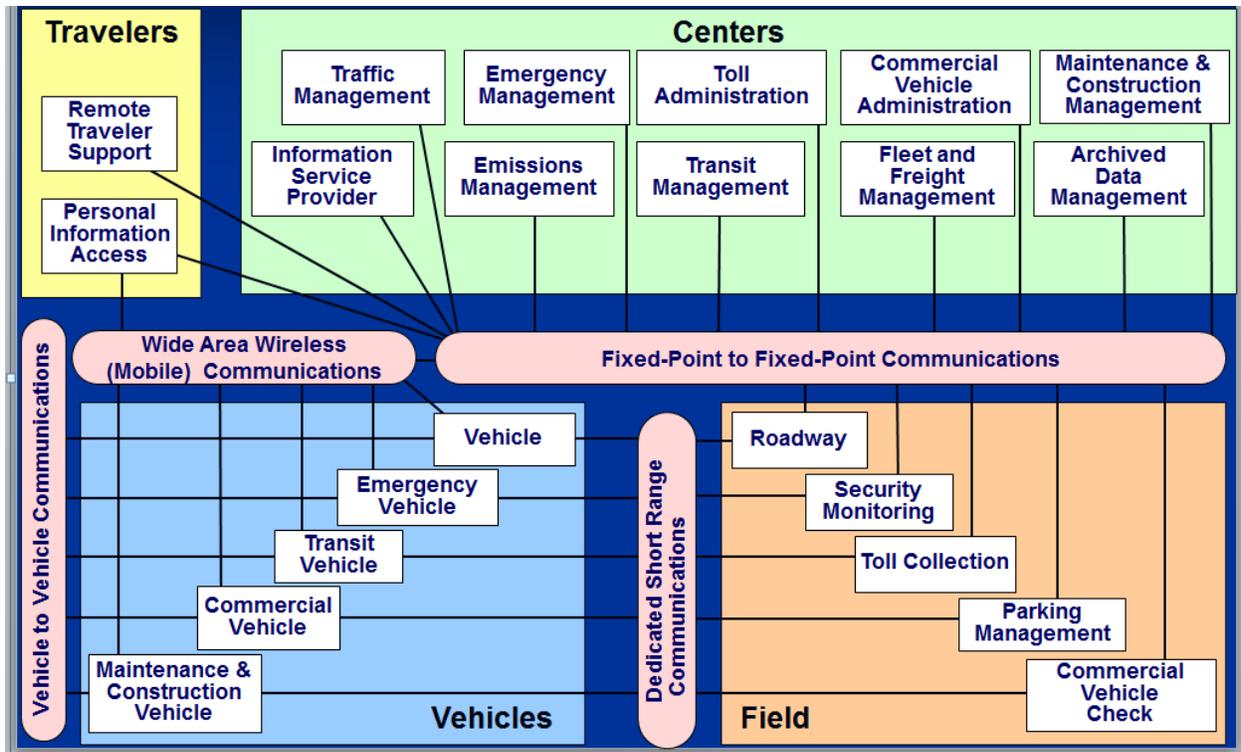


Figure 3. Subsystem diagram of the ITS Architecture (source: [14]).

Figure 4 provides a conceptual high-level framework for this study, showing communication flow among four entities: traveler, agency, vehicles, and RSE. As displayed, two-way communication occurs between traveler and agency (person-to-agency/agency-to-person [P2A/A2P]), agency and RSE infrastructure (agency-to-infrastructure/infrastructure-to-agency [A2I/I2A]), and vehicle and RSE (V2I/I2V). Further, there is one-way communication flow between traveler and vehicle (person-to-vehicle [P2V]) since the location of a traveler may be detected by a vehicle, and between RSE and traveler (infrastructure-to-person [I2P]) to provide the traveler with both bus and traveler arrival time at the stop.

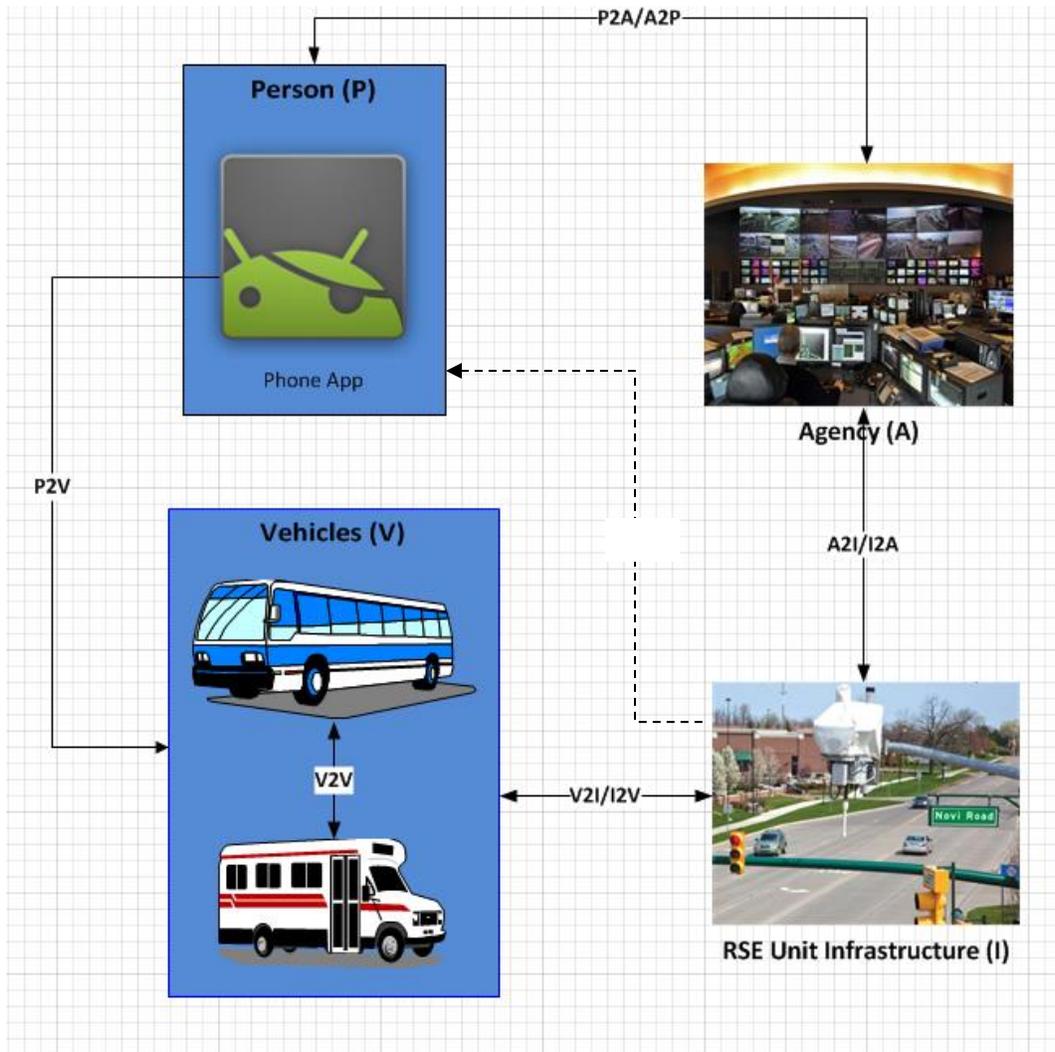


Figure 4. Overall general high-level framework representing this study

Figure 5 shows the system architecture in more detail. This architecture includes the four entities shown in Figure 4, as well as detailed information about the services provided along with their communication flow lines. The Dispatch Travel Center (DTC) represents the agency and some of the services that are available. Communication lines represent the type of communication technology that can be implemented among the four entities. For example, cellular communication technologies can be used to communicate traveler-to-agency (P2A) origin-destination information. In the following sections, the four entities are discussed in more details.

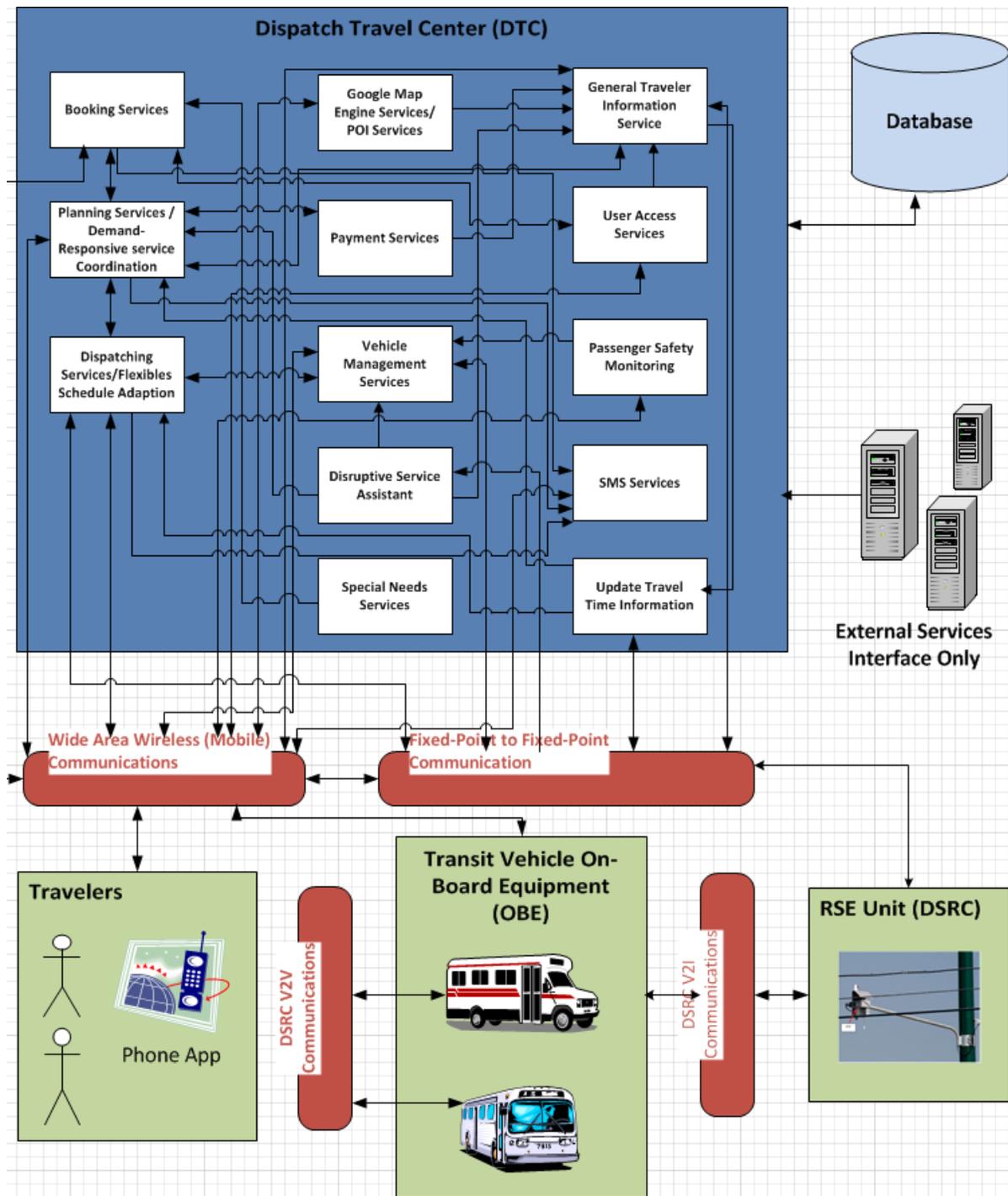


Figure 5. Detailed high-level architecture showing DTC services and communication flow lines.

DTC: The DTC system represents an agency and services that are available for travelers. Regardless of the type of scheme implemented and the specific choices underlying the operational models adopted, the operation of a demand-response transit (DRT) service is usually organized such that the traveler communicates with the DTC booking service, requests pick-up and drop-off, departure time, service negotiation, and schedule confirmation. The DTC typically includes

several integrated software systems supporting the management of the DRT service, including traveler request handling, trip booking, service planning, vehicle dispatching, vehicle communication, and system data management.

The communication system is usually based on public or private long-range wireless telecommunication networks, which support communication and information exchange between the DTC and the DRT vehicle, as shown in Figure 5. Onboard systems installed on the DRT vehicles provide the driver support functionalities during vehicle operation, and can include dynamic journey information, route variations, traveler information, and driver/dispatcher messages. Fixed-point to fixed-point communication using Ethernet wireless bridges is another communication medium for information exchange between the DTC and RSE units, and can include updating travel information, user information, management services, and dispatching services. Finally, DSRC communication systems are used for delivering low latency and highly reliable data communication among vehicles and RSE units.

Services provided by the DTC are implemented through an integrated system of software applications that share an enterprise database. External Web services can also be accessed, as shown in Figure 5, to gather weather, traffic, or other needed information from other agencies or operational services.

Travelers: The term “traveler” is applied to any user of transportation services. Travelers can use their personal devices and computers to access and use services provided by a transit agency. Mobile applications can be provided to book a trip, access schedule information, view trip options, pay for a service, obtain general traveler information, receive confirmation, and access many other services provided by the agency. Travelers may also agree to provide their Global Positioning System (GPS) location to an agency so that the transit vehicle is aware of their presence near or at a stop. The communication system would typically be through a cellular device such as a smart phone or other personal navigation device [26, 27].

Onboard equipment (OBE): Onboard equipment (OBE) is installed on transit vehicles such as buses to provide data input, processing, storage, and communications. For example, an OBE can collect ridership numbers and support electronic fare collection. Other functions of an OBE include supporting traffic signal prioritization, communicating with RSEs to improve schedule adherence, and providing automated vehicle location. An OBE can use both DSRC and cellular communication systems, depending on the type of service or application. Safety applications typically require fast communication using DSRC communications, while mobility applications can use the more ubiquitous cellular communication technologies. [26-28]

RSE: RSE units relay messages between nearby vehicles, other RSE units, and the DTC using DSRC. The hardware requirements for an RSE include a processor, data storage, and secure communications. An RSE may be a permanent installation alongside a roadway or a temporary

one used to facilitate traffic management for a special event, construction, or a traffic incident. [29]

Applications

Two applications were considered for this study: (1) dynamic DRT and (2) traveler enhanced safety. For the DRT application, transit users send their origin and destination information to the agency, and the agency uses that information for dynamic routing and scheduling, primarily for small urban and rural areas. GPS data from the handheld device provide the location of travelers, supporting dynamic routing of transit vehicles to pick up travelers more efficiently (especially when they are not where they are expected to be) and saving transit travel time. The architecture for this application is given in Figure 6.

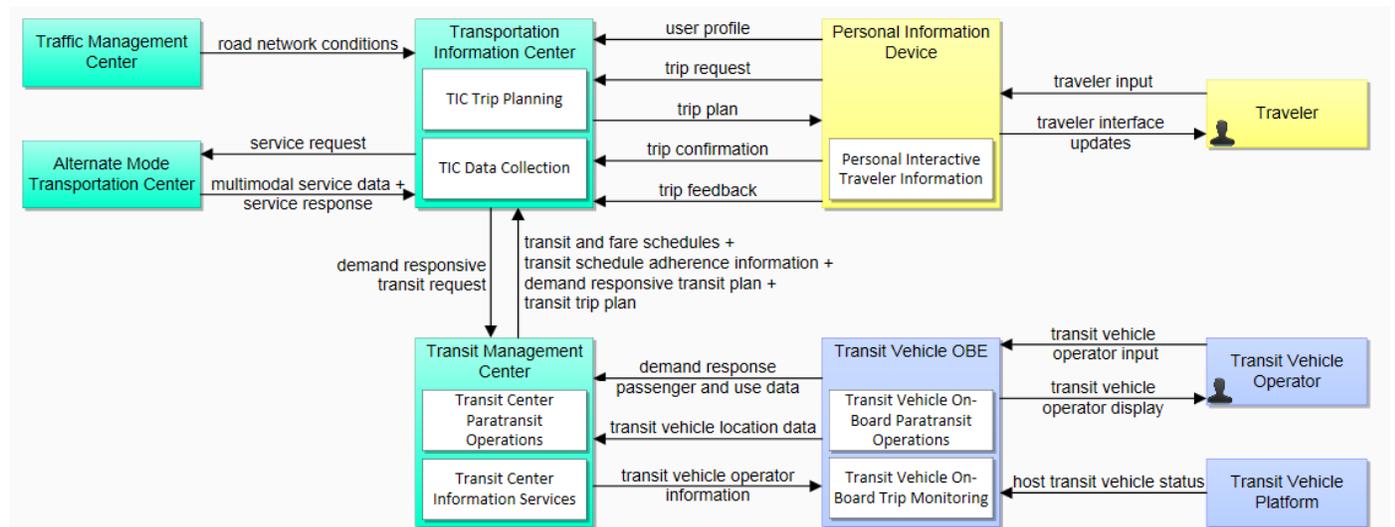


Figure 6. System architecture for dynamic DRT.

For the enhanced traveler safety application, traveler and vehicle communication and location are exchanged either through the agency or RSE so that traveler and driver are aware of the other’s location and time to reach the transit stop. Figure 7 provides the architecture for this application.

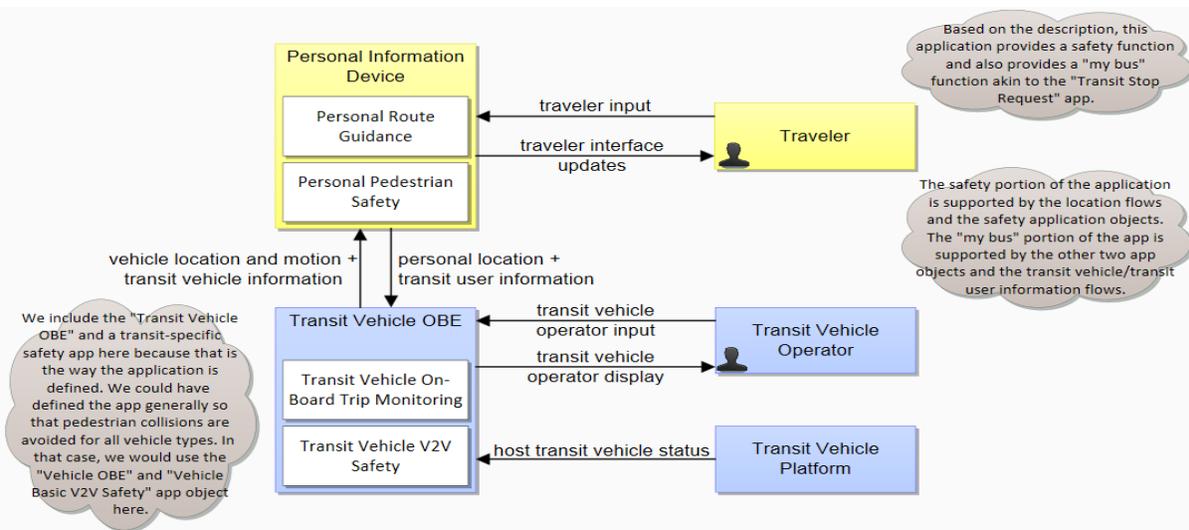


Figure 7. System architecture for the enhanced traveler safety application.

There are two distinct functional requirements for handheld devices. The first requirement is to provide communication between the device and the agency, vehicle, and/or transit stops. The second requirement is to request the user's agreement to submit his or her geographic location.

For the first application, the user can send his or her origin and destination information to the agency, and the agency can use that information for DRT routing and scheduling as shown in Figure 5. GPS data from the device provide traveler location for both applications.

The first requirement uses the Dynamic Transit Application in the CVRIA. The physical presentation of the application is shown in Figure 5. With DRT, a user submits a travel request to the transit agency using an app. The transit agency processes the request, coordinates with in-service vehicles and other requests, and provides an itinerary to the user. As conceived, DRT is an extension of current technologies such as computer-aided dispatch, automated vehicle location, and automated scheduling software. [26, 30, 31]

To support the second application, the Transit Pedestrian Indication application in the CVRIA architecture is used. The physical presentation of the application is shown in Figure 6. The Transit Pedestrian Indication application will alert pedestrians when a transit vehicle is in the vicinity through alerts on their portable devices. The app also provides vehicle operators with notifications about patrons waiting for transit service. Systems to prevent collisions between transit vehicle and pedestrian can also be supported by the app. [27]

Simulation of Enhanced Traveler Safety Application

The premise of the enhanced traveler safety application is that when a traveler is en route to a transit stop and is within an acceptable time window, a driver can hold the vehicle at the stop to wait for the traveler. This option would be available only during non-peak service, and primarily during times when traveler safety is a concern, such as when the traveler would need to wait long

periods in the dark or when few other people are in the vicinity. In consultation with Blacksburg Transit (BT), an urban-suburban bus line based in Blacksburg, Virginia, a commuter route was identified to test the application. This route provides only one trip each way and primarily serves regular customers, who use the route to travel to work in the morning and return home in the evening. However, because the application prototype was not available, a simulation was performed to test the concept.

The simulation was developed for the BT commuter service route 241 Commuter. Only the stops in Blacksburg shown in Figure 8 were included in the analysis. These stops serve travelers returning home in the evening, representing the time when the application would be used.

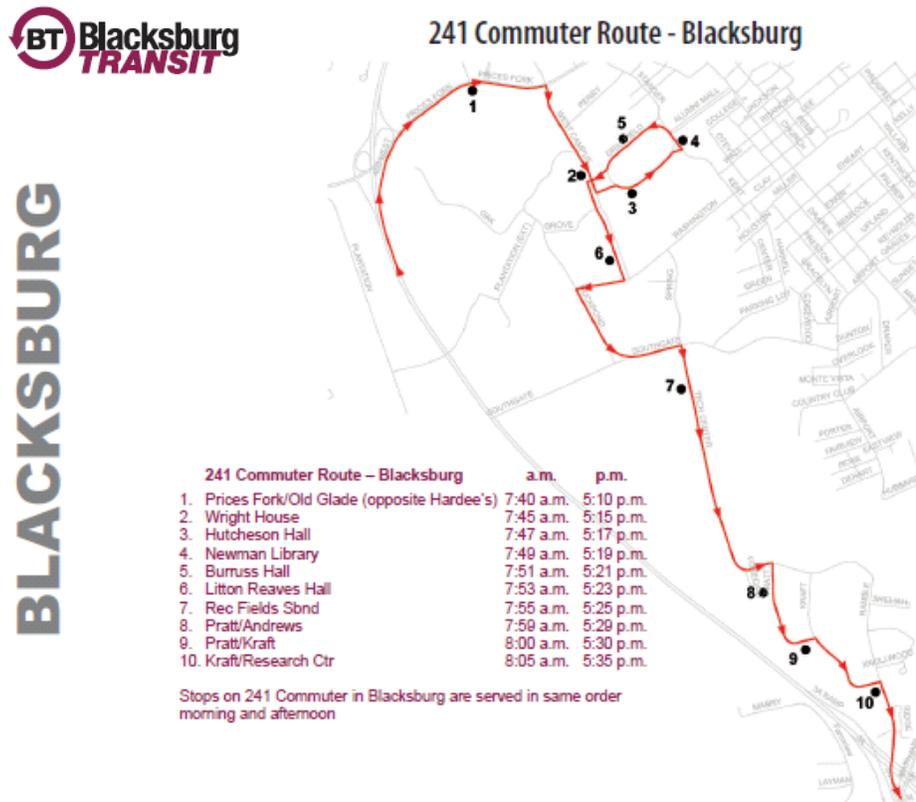


Figure 8. Transit stops used in simulation.

The analysis consisted of establishing travel time buffers using Network Analyst in ArcGIS for (1) the transit vehicle as it approaches each transit stop and (2) potential travelers approaching any transit stop. For the transit vehicle, the bus route was modeled as one-way segments using the existing road centerlines from the Blacksburg Geographic Information System (GIS). Travel times were calculated based on the posted speed limits. The resulting travel times, in seconds, were linearly associated to the segments approaching each stop, as shown in Figure 8. Travel times associated with travelers were modeled as polygon buffers also associated with road segments around each stop, and are shown in Figure 9. Although the buffers do not account for buildings, they provide useful boundaries for the simulation.

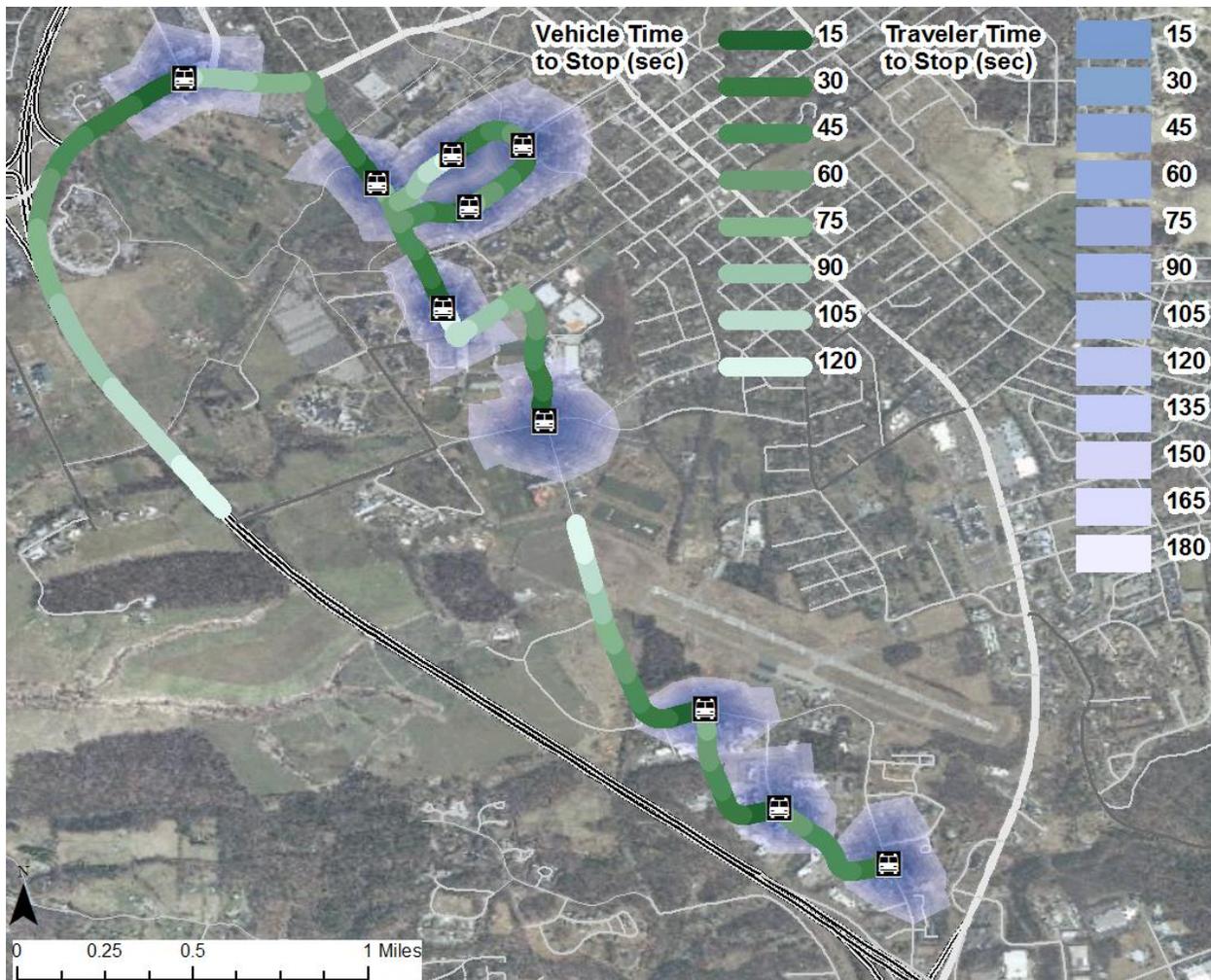


Figure 9. Traveler and vehicle travel times for simulation.

Maximum travel times were set to 180 seconds for travelers and 120 seconds for the transit vehicle. The difference is the time the vehicle would wait. All values are representative and require additional analysis to determine what limits should be used in an operational environment. Input about on-time performance and acceptable wait times would also need to be obtained from each transit agency.

Because both travel times are referenced to the transit stop, the simulation was formulated with the RSE being the link between traveler-to-vehicle and vehicle-to-traveler. When a traveler enters the outer buffer, the GPS location from the handheld device is received by the RSE and passed to the vehicle's OBE along with the traveler's time to stop. Similarly, when the vehicle crosses the linearly referenced outer buffer location on the route, its GPS location is sent to the RSE, which passes it to the handheld device with the vehicle's estimated time to stop. An assumption for this approach is that the traveler selects the shortest path, generally following the road network to get to the stop.

The goal of this simulation was to show proof of concept and to identify potential problems, so the results are qualitative as opposed to quantitative. For stops that were far enough apart (greater than the maximum travel time established for the traveler)—stops 1, 6, 7, 8, 9, and 10 in the simulation—the information between vehicle and traveler accomplished the goal of the application. However, as modeled, the system did not distinguish between closely spaced stops for travelers that were within buffers of multiple stops. The logic for the vehicle worked because travel time to the stop is always associated with the next stop on the route. As the red arrows in Figure 10 show, a traveler could enter the outer buffer at intersections of stop buffers.

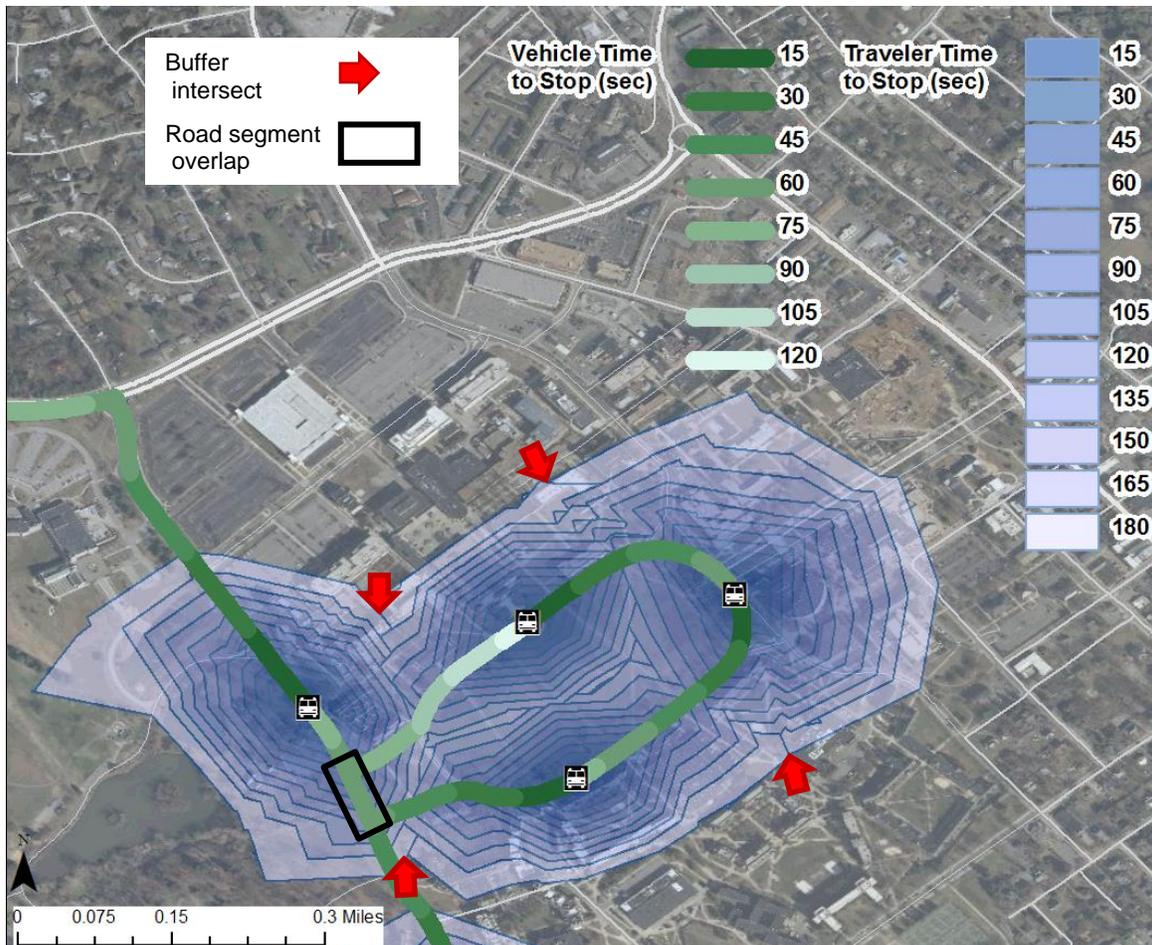


Figure 10. Issues raised in simulation.

Without additional logic, each corresponding stop would receive the traveler location and would send it to the vehicle, which would then display either information from the “first” stop, or alternately, from between stops. Similarly, the traveler would receive information from multiple stops. Another issue that occurred involved the road segment shown in the black box. Although the route is one-way, the vehicle traverses this segment twice: once as it enters the Virginia Tech Drillfield loop and again when it leaves the Drillfield loop. Again, the vehicle information is correct and the travel time values for both the vehicle and traveler could be correct. However, the

location of the vehicle that is transmitted to the traveler could be interpreted incorrectly. The traveler could see the bus's location as it is leaving the Drillfield and interpret it as entering instead.

Conclusions and Recommendations

This project resulted in an annotated bibliography of references related to CVI standards, a system architecture, and transit applications. A large-scale architectural framework was developed and used in the development of a more-detailed architecture for two specific CVI applications: a dynamic DRT for small urban and rural areas, and an enhanced traveler safety application that provides a transit driver with the location of travelers who are en route to a transit stop, allowing the driver to wait a short time, thereby reducing travelers' exposure to potentially unsafe conditions at night or in isolated locations. A limited simulation was performed on the enhanced traveler safety application to identify potential issues associated with the prototype design.

The annotated bibliography provides a useful resource for others interested in CVI for use in the transit industry. It was compiled in 2014 and should be updated with more current research results and guidelines associated with improved technologies and equipment.

Although rudimentary, the architecture in this report gives a framework for building applications that enhance two-way communication between drivers and travelers. It is conceptual and is designed to generically map communications and linkages between components that make up the applications. Additional development is necessary to expand what has been presented into something that is implementable as a proof of concept.

The simulation of the enhanced traveler safety application exposed some limitations in the initial design—specifically, problems related to routes with closely spaced transit stops. The concept is valid but additional logic is necessary to ensure that information provided to both the driver and traveler is consistent and unambiguous.

Appendix

Annotated Bibliography

The annotations for this bibliography are presented below. The annotated categories for category type include: Transit Connected Vehicle Research Overview, Connected Vehicle Infrastructure Deployment, Electronics and Mobile Communication Technologies, National ITS Architecture, General Cross Enterprise Architecture, Single Transit Agency Service Architecture, and Transit Application Specific Architecture.

- Category type: Listed
- Type of article/paper/study/report: Listed
- Type of mode or system: Listed
- Survey results included: Yes/No
- Benefit/Cost information included: Yes/No
- Lessons learned provided: Yes/No
- Contact information provided: Yes/No

Transit Connected Vehicle Research

Spencer, J. L. *Transit Connected Vehicle Research*. U.S. Department of Transportation / Research and Innovative Technology Administration (RITA), 2015.

Web Page:

http://www.its.dot.gov/factsheets/transit_connectedvehicle.htm#

Category:	Transit Connected Vehicle Research Overview
Type of article/study:	Article
Type of system:	Transit
Survey results:	No
Benefit/cost information:	Yes
Lessons learned:	No
Contact information:	Yes

Applicability:

The article contains general information about connected vehicle research programs.

Summary:

In this web page, the author highlights the importance of Transit Connected Vehicle Research Programs. The author discusses why connected vehicle technologies are needed and their impact on safety, mobility, and the environment. The author presents a brief background on how connected vehicles work when developing safety and non-safety applications, and the communication technologies that are used (i.e. dedicated short-range communications [DSRC]). The author suggests high-priority applications that can improve safety, mobility, and the environment.

Transit Connected Vehicle Infrastructure Deployment Approaches and Potential Issues for State and Local Transportation Agencies

AASHTO Connected Vehicle Infrastructure Deployment Analysis. American Association of State Highway and Transportation Officials (AASHTO), Research and Innovative Technology Administration (RITA). Publication Number: FHWA-JPO-11-090, 2011.

Web Page:

<http://www.its.dot.gov/index.htm>

Category:	Connected Vehicle Infrastructure Deployment
Type of article/study:	Report
Type of system:	Any
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

The article contains information about connected vehicle infrastructure deployment methods and management.

Summary:

This report was developed by the American Association of State Highway and Transportation Officials (AASHTO) Connected Vehicle Working Group with support from the U.S. DOT. The purpose of the report is to explore infrastructure deployment approaches and potential issues for state and local transportation agencies, primarily from a state DOT perspective. The report covers connected vehicle applications of most interest to the states, current state and local programs underway, deployment readiness in the vehicle market, aftermarket devices and communications, the magnitude of effort to upgrade the nation's signal controllers with Dedicated Short Range Communications (DSRC) capabilities, and a set of deployment scenarios with corresponding strategies and actions for state and local transportation communities.

National Intelligent Transportation System (ITS) Architecture

National Intelligent Transport Systems (ITS) Architecture. U.S. Department of Transportation / Research and Innovative Technology Administration (RITA), 2013.

Web Page:

<http://www.iteris.com/itsarch>

Category:	National ITS Architecture
Type of article/study:	Live Document and Framework
Type of system:	Transportation
Survey results:	No
Benefit/cost information:	No
Lessons learned:	No
Contact information:	Yes

Applicability:

The National ITS Architecture is a live document which provides a common framework for planning, defining, and integrating intelligent transportation systems.

Summary:

The National ITS Architecture provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.). The architecture defines the functions (e.g., gather traffic information or request a route) that are required for ITS, the physical entities or subsystems where these functions reside (e.g., the field or the vehicle), and the information flows and data flows that connect these functions and physical subsystems together into an integrated system. The National ITS architecture is a living document, which documents the evolution of ITS systems and any new innovations in the transportation field. The goal is to standardize all system integration of intelligent transportation systems.

Key Concepts of the National ITS Architecture

Key Concept of the National ITS Architecture. U.S. Department of Transportation / Research and Innovative Technology Administration (RITA), 2013.

Web Page:

<http://www.iteris.com/itsarch/documents/keyconcepts/keyconcepts.pdf>

Category:	National ITS Architecture
Type of article/study:	Live Document and Framework
Type of system:	Transportation
Survey results:	No
Benefit/cost information:	No
Lessons learned:	No
Contact information:	Yes

Applicability:

Reference document that explains certain terminology and concepts related to the National ITS Architecture.

Summary:

This document explains the essential terminology and concepts needed to understand, navigate, and use the National ITS Architecture. The concepts and terms explained in this document are: User Services and User Service Requirements, Logical Architecture, Physical Architecture, Equipment Packages, and Service Packages.

Connected Vehicle Reference Implementation Architecture (CVRIA)

Connected Vehicle Reference Implementation Architecture (CVRIA). U.S. Department of Transportation / Research and Innovative Technology Administration (RITA), 2014.

Web Page:

<http://www.iteris.com/cvria/index.html>

Category:	National ITS Architecture
Type of article/study:	Live Document and Framework
Type of system:	Transportation
Survey results:	No
Benefit/cost information:	No
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Live document and framework of applications, an active website that is regularly updated to document applications that have been defined by various connected vehicles programs in areas such as mobility, safety, environment, and support systems.

Summary:

The Connected Vehicle Reference Implementation Architecture (CVRIA) website, which is an extension of the National ITS Architecture, includes stakeholder engagement and development of an integrated standards strategy and action plan. The content of the CVRIA is based on the existing connected vehicle documents, including Concept of Operations, System Requirements, Standards, etc. The purpose of the CVRIA project is to produce a reference implementation architecture of the connected vehicle systems as the basis for integrating the connected vehicle systems into the National ITS Architecture, and to provide interface information needed for standardization of planning.

CVRIA is comprised of four views: enterprise, functional, physical, and communications.

Enterprise viewpoint describes the relationships among organizations and the roles those organizations play within the connected vehicle environment. Functional viewpoint describes abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements.

Physical viewpoint describes physical objects (systems and devices) and their application objects, as well as the high-level interfaces between those physical objects. Finally, the communication viewpoint describes the layered sets of communications protocols that are required to support communications among the physical objects that participate in the connected vehicle environment. In our study, we will follow the CVRIA standard and only present the physical viewpoint within a brief description of the functional viewpoints.

The Agency for Flexible Mobility Services

Ambrosino G., Ferrari A., Volo N., Masson B. *The Agency for Flexible Mobility Services “on the move,”*
Final report, 2004.

Web Page:

http://www.transport-research.info/sites/default/files/project/documents/20090112_191123_11203_FAMS_Final%20Report.pdf

Category:	General Cross Enterprise Architecture
Type of article/study:	Report
Type of system:	Demand Responsive Transport (DRT)
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

E-business (business-to-consumer [B2C], business-to-business [B2B]) Flexible Mobility Services.

Summary:

In Europe, in 2004, the FAMS project, which stands for Flexible Agency for Demand Responsive Collective Mobility Services was created, and essentially aimed at experimenting with concepts for a Flexible Agency enabling coordinated provision of DRT (demand responsive transit) services in an area. FAMS has innovated solutions for DRT planning and operation by the implementation and trial of the Flexible Agency. Existing DRT management tools have been adapted and made interoperable within an e-Business collaborative environment. This allows cooperation amongst transport service suppliers, and the operation of a new service value chain, which in turn has allowed different transport operators to benefit from a shared IT infrastructure, services for the management of the Flexible Services they are individually offering, the FAMS service operator to have a global view of travel needs and of the service offer. As a result, these service providers can ensure the best match between users' demands and available services, and provide the opportunity for DRT and Flexible Transport users and users' groups to benefit from a unique service center that is able to serve their travel needs in the most integrated and best possible way.

Advanced Traveler Information System Study

Advanced Traveler Information System Study. Cambridge Systematics, I. E. P. A., LLC, The Schapiro Group; AECOM; Kimberley-Horn and Associates, Inc., 2009.

Web Page:

http://www.morpc.org/trans/advancedtravelerinfo_finalreport.pdf

Category:	General Cross Enterprise Architecture
Type of article/study:	Report
Type of system:	Advanced Traveler Information System
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Advanced Traveler Information Systems and Applications (B2B and B2C Architecture and web services.)

Summary:

The Mid-Ohio Regional Planning Commission (MORPC) has hired Cambridge Systematics to study the feasibility of a Central Ohio Advanced Traveler Information System (ATIS) that would display all regional travel-related information so that travelers can make informed decisions about the best transportation mode, route, time, and costs for each trip. This literature is a report documenting the results of the feasibility study and provides a comprehensive implementation plan for the system. It also outlines the study approach, provides an overview of the proposed system, provides an overview of the phasing, organization changes, and timeline recommendations needed to ensure a successful system, and provides an overview of the costs associated with deployment, roll-out, and ongoing operations.

The overall proposed architecture of the system was presented showing ATIS web services using a “data gatherer” approach. The interface at <http://www.ohgo.com/> allows users one-stop access to device interfaces (cameras, highway advisory radio, traffic speed, DMS, etc.) through the Buckeye Traffic ATIS website, which gathers information such as point data, geometric data, meta data, text, links, etc. from different web services available at organizations such as Central Ohio Transit Authority (COTA), Ohio State University, the City of Columbus, etc.

Southern California Regional ITS Architecture

NET et al., *Southern California Regional Its Architecture, Southern California Regional ITS Architecture*; Ventura County Regional ITS Architecture. 2005.

Web Page:

http://www.scag.ca.gov/Documents/VenturaCounty_2005Update_ver4_0.pdf

Category:	General Cross Enterprise Architecture
Type of article/study:	Report
Type of system:	ITS
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public transportation systems advanced technology applications and integrations.

Summary:

The Southern California Regional ITS (Ventura County) project seeks to capitalize on years of investment in transportation technology by identifying the interfaces and paths that will make it possible to integrate many systems in the future. The system is designed to share information among many organizations invested in ITS or infrastructures. Real time traveler information can also be shared in addition to vehicle tracking information location using AVL devices. The study provided a framework that is firmly based on existing ITS systems and included a vision for future deployment of integrated ITS applications in the Ventura County that will yield continuous benefits.

The Southern California Regional ITS Architecture is a document that can be viewed as a process to be maintained, revised, and validated as needed over the years. Most importantly it utilizes and is consistent with the National Architecture, whose purpose is to foster interoperability and permit an exchange of traffic, transit, and traveler information between regions, states, and throughout the county.

Enhancing the Rider Experience: The Impact of Real-Time Information on Transit Ridership

Enhancing the Rider Experience: The Impact of Real-Time Information On Transit Ridership, Florida Department of Transportation. National Center for Transit Research at the Center for Urban Transportation Research, University of South Florida. 2005.

Web Page:

<http://www.nctr.usf.edu/pdf/576-15.pdf>

Category:	Single Transit Agency Service Architecture
Type of article/study:	Report
Type of system:	Advanced Public Transportation Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public Transportation Systems / Advanced Technology applications.

Summary:

The objective for this project was to evaluate how ready access to wireless networks and real-time information affects transit system ridership as well as the rider's experiences.

Advanced Public Transportation Systems (APTS) technologies are used to improve the efficiency and effectiveness of public transportation operations, vehicle maintenance, and administration. These technologies include a wide range of computer databases, software and hardware, as well as vehicle devices such as mobile data terminals (MDTs) and global positioning satellites sensors, and automatic vehicle location (AVL) systems. Another set of applications geared towards information dissemination, Advanced Traveler Information Systems (ATIS), plays an important role in improving the convenience, safety and efficiency of travel by assisting travelers with pre-trip and en-route travel information.

Real-time information is accessed through a variety of media, including dynamic message signs (DMS) at stops and stations, kiosks (at bus shelters, office buildings, shopping centers, and other locations), cable television, personal digital assistants (PDAs), the Internet, and telephones.

The Flexible Bus Systems Using Zigbee as a Communication Medium

Iqbal, R., K. Y., Ichikawa, T. *The Flexible Bus Systems Using Zigbee as a Communication Medium*. New Technologies, Mobility and Security (NTMS), 4th IFIP International Conference, 2011.

Web Page:

<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5720601>

Category:	Electronics and Mobile Communication Technologies
Type of article/study:	Paper
Type of system:	Advanced Flexible Bus (DRT) Systems
Survey results:	No
Benefit/cost information:	Yes
Lessons learned:	No
Contact information:	Yes

Applicability:

Public Transportation: DRT Systems / Advanced Technology applications.

Summary:

The paper describes a research study on The Flexible Bus Systems (FBS) using Zigbee as a communication medium. The Flexible Bus System is a demand responsive transit (DRT) system, which is more efficient and convenient in the sense that it entertains passengers' demands and gives bus locations in real time. The real time synchronization of The Flexible Bus System makes it information rich and unique as compared to other DRTs. The Flexible Bus System is a system that can replace Traditional Bus Systems while providing more flexibility and efficiency. This paper discusses the use of wireless technologies in Flexible Bus Systems and how to make the system more reliable using the short-range wireless technology Zigbee.

Based on this research, the use of Zigbee for communication between the Buses and the Bus Stops greatly reduces the total cost of the system. Everything is connected to the Control Centre, which is the brain of the system. The Control Centre and Bus Stops are connected through the internet, and Buses and the Control Centre are connected to each other through Bus Stops. All the system elements (Buses, Bus Stops and Passengers) are updated with the latest information.

Personalized Demand-Responsive Transit Systems

Cayford, R. and Yim, Y. B. Y. *Personalized Demand-Responsive Transit Service. Research Reports*, California Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies (UCB), UC Berkeley, California Path Program Institute Of Transportation Studies University Of California, Berkeley, 2004.

Web Page:

<http://escholarship.org/uc/item/29j111ts#page-1>

Category:	Transit Application Specific Architecture
Type of article/study:	Report
Type of system:	Advanced Flexible Bus (DRT) Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public Transportation: DRT Systems / Advanced Public Transit Systems.

Summary:

In this paper, Smart DRT Feeder was proposed. This is a system that collects transit riders from neighborhoods and takes them to transit stations. This system will use APTS (Advanced Public Transit System) technologies to make the feeder service convenient and reliable. The concept is very simple. When demand is high, Smart Feeder will use the fixed-route fixed schedule service. When demand is low, it will use the on-demand service. For the on-demand service, customers will use an automated dial-a-ride system or the Internet for making a reservation or receiving a confirmation. Feeder vehicles will be equipped with Automated Vehicle Location (AVL) and on-board wireless computer Devices. The first part of this paper describes the results of a user survey on the demand for and on the desired characteristics of a Smart Feeder system for the city of Millbrae. The second part of the paper describes the resulting design and implementation of the automated dial-a-ride system that will be used for the demand responsive transit service.

The system uses an automated phone-in system for reservations, computerized dispatching over a wireless communication channel to the bus driver, and an automated callback system for customer notifications. User requests for pickup are collected and a computerized scheduling system acts as a broker between the multiple user requests and the transit agency to determine the optimal departure time and route that minimizes customer wait time and maximizes the number of passengers per trip. The system requires no dispatchers and operates in real time without requiring advance reservations Shuttle operations rely on advanced public transit system (APTS) technologies. These include an automated vehicle location (AVL), advanced traveler information system (ATIS), and automated dial-a-ride (ADART) system. The schedule synchronization between transit modes will be done by coordinating real-time arrival/departure of transit modes through advanced communication systems.

Design and Implementation of a Traveler Information Tool with Integrated Real-time Transit Information and Multi-modal Trip Planning

Zhang, L., Kun Zhou, J. L., et al. Design and Implementation of a Traveler Information Tool with Integrated Real-time Transit Information and Multi-modal Trip Planning, *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2215, 2011.

Web Page:

<http://trjournalonline.trb.org/doi/10.3141/2215-01>

Category:	Transit Application Specific Architecture
Type of article/study:	Paper
Type of system:	Advanced Traveler Information Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	No
Contact information:	Yes

Applicability:

Public Transportation: Real-time Traveler Information System.

Summary:

In this literature, a multi-modal traveler information application, PATH2Go, was developed to improve the accessibility and quality of real-time traveler information and to make transit a known and viable choice for travelers. It was developed for a field test on the US-101 corridor, in the San Francisco Bay Area. PATH2Go integrates a web-based multi-modal trip planning tool that uses real-time information of available transit, traffic and parking availability, a web-based search tool that finds real-time transit arrival and schedule information, and a mobile application that provides personalized en route transit trip information. PATH2Go integrates these major components of traveler information into one platform and therefore makes it easier for travelers to access real-time information.

Implementing Vehicle Infrastructure Integration (VII): Real World Challenges

Sharafsaleh, A., VanderWerf, J., Misener J., Shladover, S. Implementing Vehicle Infrastructure Integration (VII): Real World Challenges. *Intellimotion: California PATH's Quarterly Newsletter*. 14 no. 1: 12.

Web Page:

http://www.path.berkeley.edu/sites/default/files/documents/IM_14_1.pdf

Category:	Transit Application Specific Architecture/ Connected Vehicle Infrastructure Deployment
Type of article/study:	Article
Type of system:	VII Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public Transportation: Connected Vehicle Applications.

Summary:

This article (California Path newsletter) discusses the real world challenges involved in the implementation of Vehicle- Infrastructure Integration (VII). The article highlights the challenges associated with the deployment of VII systems in a test bed environment in California. It stress the importance of understanding the practical aspects of installing, operating and maintaining the VII communications infrastructure when developing plans and cost estimates for large-scale national VII deployment. Lessons learned from the initial VII California test bed development and operations were provided in the hope that they can contribute to decisions about VII design and development.

Traveler Information Systems and Wayfinding Technologies in Transit Systems.

Jackson, D. W., Burger, C., Cotton, B., Linthicum, A., Mejias, L., Regan, T., Filosa, G. *Traveler Information Systems and Wayfinding Technologies in Transit Systems*, U.S. Department of Transportation (U.S. DOT) Research and Innovative Technology Administration (RITA) John A. Volpe National Transportation Systems Center 55 Broadway/Cambridge, MA 02142: 139. 2011.

Web Page:

http://www.fta.dot.gov/documents/MMTPS_Final_Evaluation_Report.pdf

Category:	Transit Application Specific Architecture
Type of article/study:	Report
Type of system:	Transit Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public Transportation: Transit System Technologies.

Summary:

The purpose of the study is to provide federal guidance to transit agencies on current and future trends in the application of traveler information technologies as a means to expand transit agencies' deployments of these tools, which may result in an increase in transit ridership. The study provides a technology evaluation of the industry and traveler benefits associated with transit wayfinding (the process of reaching a destination in a familiar or an unfamiliar environment) and route information technologies. The study also identifies challenges experienced by transit agencies in the implementation and use of wayfinding technologies and tools. One challenge depicted in the study is the implementation of communication technologies. In addition, other challenges were discussed, including legal challenges, institutional challenges, and technical challenges (data and system integration, GPS technologies, real time data, etc.). The study proposed a list of recommendations and lessons learned.

Instant Mobility Use Case Scenarios Definition & Analysis Preliminary Report

Kompfner, P., Li, Y., et al. *Instant Mobility Use Case Scenarios Definition & Analysis Preliminary Report*. Europe, European Commission, 2011.

Web Page:

<http://cordis.europa.eu/fp7/ict/netinnovation/deliverables/instant-mobility/instant-mobility-d31.pdf>

Category:	Transit Application Specific Architecture
Type of article/study:	Report
Type of system:	Transit Systems
Survey results:	Yes
Benefit/cost information:	Yes
Lessons learned:	Yes
Contact information:	Yes

Applicability:

Public Transportation: Transit System Technologies.

Summary:

The authors aimed to characterize five lead scenarios selected for analysis for their important potential of enhancement with Future Internet (FI). These scenarios are: multimedia travel made easy; the sustainable car; collective transport 2.0; trucks and the city; and online traffic and infrastructure management. This report document provides a detailed description of each scenario and each service in those scenarios, as well as the interactions and service combinations in each scenario. For each service, an end-to-end service chain, service capability, components of each service, actors and their roles and data flow are provided, and will form a base for functional and non-functional requirements of FI technologies in subsequent phases of the project

IEEE 802.11p

IEEE Standards Association. IEEE 802.11p: IEEE Standard for Information technology – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY).

Web Page:

<https://standards.ieee.org/findstds/standard/802.11p-2010.html>

Category:	Electronics and Communication Technologies
Type of article/study:	Encyclopedia
Type of system:	Communication Systems
Survey results:	No
Benefit/cost information:	No
Lessons learned:	No
Contact information:	No

Applicability:

The page contains general IEEE 802.11p protocol information.

Summary:

IEEE 802.11p is an approved amendment to the [IEEE 802.11](#) standard to add **wireless access in vehicular environments** (WAVE), a vehicular communication system. It defines enhancements to 802.11 (the basis of products marketed as [Wi-Fi](#)) required to support Intelligent Transportation Systems (ITS) applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). IEEE 1609 is a higher layer standard based on the IEEE 802.11p.

Dedicated Short Range Communications (DSRC) Message Set Dictionary.

Dedicated Short Range Communication (DSRC) Message Set Dictionary. SAE International, 2009.

Web Page:

http://standards.sae.org/j2735_200911/

Category:	Electronics and Communication Technologies
Type of article/study:	Standards
Type of system:	Communication Systems
Survey results:	No
Benefit/cost information:	No
Lessons learned:	No
Contact information:	No

Applicability:

The page contains information about DSRC messages' SAE standards.

Summary:

This SAE Standard specifies a message set, and its data frames and data elements specifically for use by applications intended to utilize the 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE, referenced in the document simply as "DSRC"), communications systems. Although the scope of this Standard is focused on DSRC, this message set, and its data frames and data elements have been designed, to the extent possible, to also be of potential use for applications that may be deployed in conjunction with other wireless communications technologies. This Standard therefore specifies the definitive message structure and provides sufficient background information to allow readers to properly interpret the message definitions from the point of view of an application developer implementing the messages according to the DSRC Standards.

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