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An Overview of Vehicle-to-Infrastructure Communication Technology

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Abstract: As a part of solutions to reduce problems associated with transportation in cities, technologies can have noticeable impacts. Due to efficiency and low costs, innovative transportation technologies can reshape and improve human's transportation. This research aims to explore Vehicle-to-Infrastructure communication technology (V2I) and its benefits to safety, mobility, and environment. In addition, it explores the planning aspect of deploying V2I technology and its opportunities, challenges and concerns, and implication to communities. The research will also look at several case studies including pilot projects that have been taking place in the United States and studies that have been done to have a better understanding of the current situation of V2I technology and its future needs.

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List of Abbreviations

ATT – Average Travel Time

DSRC – Dedicated short-range communications

FHWA – The Federal Highway Administration

FMCSA – Federal Motor Carrier Safety Administration

FRA – Federal Railroad Administration

FTA – Federal Transit Administration

GPS – Global Positioning System

ITS JPO – Intelligent Transportation Systems Joint Program Office

NYDOT – New York department of transportation

NHTSA – National Highway Traffic Safety Administration

OBU – On-Board Unit

ODE – Operational Data Environment

PKI – Public Key Infrastructure

REL – Reversed Express Lane

RSU – Roadside Units

SCMS – Security Credential Management System

THEA – Tampa Hillsborough Expressway Authority

3M – Minnesota Mining and Manufacturing company

USDOT – United States Department of Transportation

V2I – Vehicle-to-Infrastructure

WYDOT – Wyoming Department of Transportation

Chapter 1: Introduction

Background

The world is evolving quickly and one important aspect of this evolution is technology. The combination of knowledge, process, skills, and techniques is the successful key of the technology. Its primary goal is to make our lives easier by increasing our safety and saving our time and efforts. Due to the convenience and efficiency provided by technology, many aspects of our lives have changed significantly. As technology evolves, many things around us are either going to change or stay as they are but with enhancements. Technology developers will not stop trying to upgrade and move our lives into different levels. One of the important aspects of life that technology has been improving on is mobility. It is much different how people moved between places in the past compared to today because of technology.

Transportation is an important aspect of people's lives. The mobility of people is considered to be one of the most important issues around the world. People's mobility behavior has economic, social, and environmental impacts. Therefore, governments aim to create transportation plans that suit the government's goals and objectives. Technology developers have been creating devices and programs to solve transportation problems. For example, autonomous vehicles have been created for safer driving, Global Positioning Systems (GPS) help identify the location of vehicles, and smart traffic lights detect traffic volume to adjust traffic light timing. Technology has affected the way governments plan, operate, design, and build a transportation system. Governments and developers are combining their efforts to create solutions that suit their needs and open new doors for improvements.

As the population grows, the use of the city's infrastructure increases. It is possible that a city would face problems related to the environment, safety, and economy because of the state of its transportation system. One of the major problems cities face is the increasing number of automobile users. It has become a challenge and expensive to improve the transportation infrastructure to meet future needs. The increase of automobile users would likely impact the city negatively in terms of environment, safety, and mobility. It can reduce the air quality, threaten pedestrian's safety, create congestion, and increase travel time. Most of these cities have been using solutions such as policies that prohibit driving cars in certain areas, diversifying mobility modes, and building unfriendly vehicle environments. However, these solutions can sometimes be very costly. Some cities that do not have a strong economic base are introducing the concept of the smart city by using new technologies to reduce the impact of the problem they are facing.

The U.S. Department of Transportation has created a technology named Vehicle-to-Infrastructure (V2I) that connects a system with moving vehicles to surrounding infrastructure using high speed internet. The purpose of V2I technology is to reduce automobile accidents, support general mobility, and conserve energy through sharing information with automobile users (U.S. Department of Transportation, 2018). Drivers would receive information such as speed changes, emergency situations, and pedestrians crossing warnings. This idea and effort is a collaborative initiative spanning the Intelligent Transportation Systems Joint Program Office (ITS JPO), Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Federal Motor Carrier Safety Administration (FMCSA), Federal Railroad Administration (FRA) and the

National Highway Traffic Safety Administration (NHTSA) (United States Department of Transportation, 2018).

Purpose of the Study

Purpose Statement

The purpose of this study is to explore and explain Vehicle-to-Infrastructure (V2I) technology, its applications, and benefits in the aspects of mobility, safety, environment.

Rationale of the Research

As cities grow and populations increase, maintaining viability of a transportation system to handle the transportation demand increases could be costly. Exploring transportation technologies would help find solutions to solve or reduce a specific problem in transportation. As the automobile is the major mode of travel in most countries, V2I technology aims to regulate drivers' experiences to reduce the negative impacts on general mobility, the environment, and safety. Exploring V2I technology and its applications helps create solutions that enhance overall mobility, reduce the chances of accidents, and protect the environment.

Research Questions

1. What is V2I technology?
    - What is the definition and goals of V2I?
    - How it works?
    - What are the needs of V2I?
2. How much does it cost?
    - What is the cost of building and implementing it?

- What are sources to fund V2I projects?

3. What kind of services will it provide?
    - Who are the targets and parties need to be involved?
    - What are the benefits V2I will provide?
    - Can this technology handle heavy usage?
4. How will it enhance mobility, safety, and the environment?
    - How can V2I adapt changes in traffic timing phase, speed adherence, and weather conditions?
    - Why does V2I need to cover all types of travel users?
5. What opportunities V2I technology will bring to local governments and communities?
    - How regulating automobile drivers' behavior enhance other travel modes?
    - How will V2I technology change the components of cities?
6. What effects will V2I apply on city design?
    - What are the impacts on zone ordinance?
    - What affects are going be laid down on land use regulations?
    - What are the effects of V2I on streets design, regulations, and standards?
7. What are the possible planning challenges and concerns V2I could bring to local governments and communities?
    - What are V2I policies regarding vehicle and personal privacy?
        - How to increase the acceptance rate of sharing data of communities?

        - What is the role of local governments in protecting the system and users' privacy?
        - Can the collected information be hacked?
    - What social aspects would be affected when the technology is deployed?
        - How balancing transportation ensures the equity of the users?
        - What possible public health issues would V2I create?
8. What are the implications when a city fully depend on V2I technology?
    - What transportation and land uses policies can be placed to adapt with future changes?
9. How is V2I technology going to be implemented?
    - What is the process of implementation?
    - What steps need to be taken to ensure the stability of the technology?
    - Who needs to be involved in the process and why?

Chapter 2: Literature Review

Introduction

As cities grow in population, the infrastructure needs to grow. One of the impacted aspects of a city is transportation. Transportation is an important aspect in a city. Problems affecting mobility in a city lead to negative impacts on the city's economy, environment, and society. In general, automobiles are the most heavily used mode of transportation in most cities. As automobile users increase, problems related to mobility, environment, and safety get bigger. In 2017, automobile accidents in the United States reached almost 6.5 million accidents and resulted in 37,133 fatalities and 2.7 million injuries (National Highway Traffic Safety, 2019). These problems could be solved or reduced by applying policies, supporting one mode of travel over another, and supporting projects such as public transit. Technology can also help solve or reduce these problems by using high tech equipment, the internet, and platforms which is a system consisting of hardware devices and an operation system that provides the environment to run applications, and program of processes (Roscoe & Lyles, 2000). Because of the efficiency and lower costs gains of technologies, some cities have started using advanced technologies to address multiple issues related to transportation.

One of the technologies the United States Department of Transportation (USDOT) has been developing is Vehicle-to-infrastructure (V2I). It is a technology that links drivers of automobiles to surrounding infrastructures to improve safety and efficiency. USDOT believes that V2I can be one of the solutions cities can use to improve their transportation infrastructure. Additionally, automakers are building new vehicles using various technologies such as low-cost sensors, low-power high-capacity

processors, cloud computing, and improved wireless connectivity that allows the vehicle to be connected and interactive.

V2I technology has been defined and described in different approaches and scopes. In this chapter, federal offices publications, transportation journals, research conducted by universities, and technology institutions' publications will be used to explore V2I technology and answer the research questions of what is V2I technology? How much does it cost? What kind of services will it provide? and how will it enhance mobility, safety, and the environment?

V2I Definition

The U.S. Department of Transportation defines Vehicle-to-Infrastructure technology as "technologies that capture vehicle-generated traffic data, wirelessly providing information such as advisories from the infrastructure to the vehicle that inform the driver of safety, mobility, or environment-related conditions" (U.S. Department of Transportation, 2013, p. 1). As vehicles move, the infrastructure gathers their speed, location, and size, and provides helpful information to drivers, as two-way communication, to increase safety, enhance mobility, and notify about environment condition. The 3M Company, formerly known as Minnesota Mining and Manufacturing company, operates in the field of safety and consumer goods and similarly defines V2I as a wireless exchange of data between vehicle and road infrastructure via hardware, software, and firmware (3M, 2015).

The Significance of V2I

The main purpose of V2I technology is to reduce automobile accidents, support general mobility, and conserve energy through sharing information with automobile users (U.S. Department of Transportation, 2018). Another important aspect about V2I is cost. In terms of the safety, mobility, and environemental benefits that V2I offers, the cost is considered to be low. As V2I techonology offers multiple benefits to change the future of transportation, it is considered to be one of the key elements of an intelligent transportation system that leads to more opportunities, such as autonomous vehicles. Siva R. Narla (2013) stated that V2I technology is one of the technolgies that helps drivers to take their trip safely and efficiently. Moreover, it will help designing and building autonomous vehicles. Having all technologies and tools tested will help finding the needs for the future and improve the process of developing driverless vehicles.

V2I Potential Applications

V2I technology works by installing several safety, mobility, and environmental applications that can be applied to infrastructures. These applications can interact with multiple targets such as drivers and pedestrians to deliver information that can help the user to make better decisions related to mobility, safety, and interaction with environmental conditions. V2I potential applications include (Bhat, 2017):

- Potential Safety applications: Ensure the safety of pedestrians, inform about sharp curves, unclear pedestrians, traffic signals, stop signs, and dangerous areas that inform and ensure the safety of drivers and others.

  - Red Light Violation: Provides drivers approaching a signalized intersection an alert when a driver may violate the red light.
  - Pedestrian in Signalized Crosswalk Warning: Alert vehicles to a possible presence of pedestrians in a crosswalk.
  - Oversize Vehicle Warning: Uses external measurements to alert drivers of weight and height limits.
  - Curve Speed Warning: Informs drivers that there is an upcoming curve and suggested speed.
  - Stop Sign Gap Assistance: Alert drivers when it is unsafe to enter an intersection with no traffic lights but STOP-signs.
  - Stop Sign Violation Warning: Based on vehicle's speed, the driver will be alerted if he/she may violate a stop sign.
  - Work Zone Warning: Alert drivers about upcoming work zones and in which lane.
- Potential Mobility applications: Creates better speed environment, efficient signal phases, smooth flow, better engagement with public transportation, and real-time data map.
  - Intelligent Traffic Signal System: Uses automobile data to improve signal operations.
  - Traffic Signal Priority: Give specific vehicles or transit vehicles the priority at one or series of signalized intersections.
  - Smart Parking: Provides users with real-time location of parking lots.

    - Reduced Speed Warnings: Inform drivers about suggested speeds in specific areas at specific times.

- Potential Environmental applications: Provides drivers with real-time data related to hazards, creates eco-friendly driving environment with less consumption of fuel.
    - Hazards Warnings: Inform drivers and pedestrians about upcoming hazards in specific areas.
    - Spot Weather Impact Warnings: Inform drivers about real-time data about weather events in specific locations.
    - Eco-Friendly Signal Operations: Operations include changes in traffic signal timing and priority to decrease greenhouse gases.

As the technology improves, V2I technology applications can be modified to be adjusted with certain situation. As the technology evolves, applications' hardware and firmware could be changed to improve its overall process.

Infrastructure Needed for Deploying V2I

Conceptually, V2I technology deployments will need to be integrated with intelligent system equipment to allow the communication between vehicles and infrastructures (Figure 1). Placing devices on infrastructures depends on the locations of the devices, distances between them, and the size of the area. These requirements are (Center for Automotive Research, 2017):

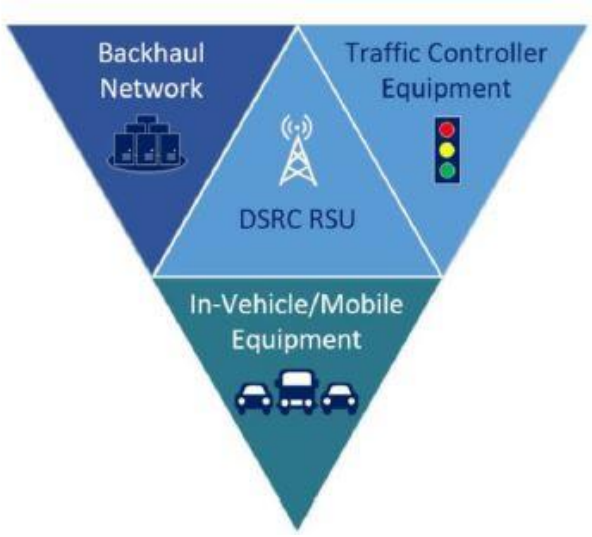

Figure 1. The Conceptual Diagram of V2I / Source: USDOT

- **Roadside Units**: Units that transmit and receive data from vehicles by using Dedicated short-range communications (DSRC).
- **Traffic Signal Controllers**: Devices that generate the signal phase and timing and transmit it to roadside units.
- **Management Center**: Collects, processes, analyze data generated from infrastructures.
- **Backhaul Communication**: Internet that links the main platform to the devices.
- **Traffic Sensors**: Sensors that can locate and detect vehicles and pedestrians.
- **Nomadic Device**: Devices carried by pedestrians, bicyclist, or wheelchair user to inform vehicles.
- **On-board equipment**: Devices in the vehicle to communicate with roadside units.

- **Security Credential Management System (SCMS)**: A security system that manages encryption to facilitate trusted communication.
- **Algorithm**: A sequence of well-defined, computer-implementable instructions, and set of rules to perform a computation.

Security

The National Highway Traffic Safety Administration and its partners have developed a security system and applied Public Key Infrastructure (PKI). PKI is defined as a combination of software and encryption tools that enable users to protect the security of their communications and data transactions on networks using public and private cryptography (U.S. General Services Administration, n.d.). The V2I system consists of:

- A Security Credentials Management System (SCMS) that issues, distributes, and revokes security credentials for devices operating in the system.
- Devices with valid certificates.

However, Jadaan et al. (2017) states that hacking the system is possible. Any system would have gaps that can be used as a door to the system. Nevertheless, governments deal with this problem by upgrading the firewall from time to time to hide these gaps.

Costs of Deploying V2I Technology

Because of the options that can be chosen, costs vary. In addition, with companies' competitions and technology evolution, these prices may change in the future. The cost of deploying V2I is consists of main components prices and desirable V2I applications prices. There are main requirements need to launch V2I applications,

hardware and software. These prices were taken from previous experiences of pilot implementations, information from hardware vendors, and records collected by USDOT for their cost database (Hourdos, 2019). Table 1 shows V2I main requirements' costs and annual maintenance costs:

Table 1.

Estimated Cost of Main Components of V2I for One Street Segment (300 meter)

Components	Price Range	Annual Maintenance
Roadside units	$1,200-$3,300	$250
Field Computer	$500-$1,200	$85
Traffic Sensor	$7,000-$10,000	$280
Pedestrian Sensor	$400-$800	$60
Environmental Sensing Station	$10,000-$35,000	$2,250
System Integration	$91,000-$111,000	$10,000
Total	$110,100-$161,300	$12,925

Note: Data are from John Hourdos (2019, August).

Table 2 shows V2I applications costs in detail. A variety of applications were chosen to give an estimation of the overall cost of an application. The overall cost of the V2I technology depends on the quantity needs, software and hardware future improvements.

Table 2.

Estimated Cost of V2I Applications

Applications	**Deployment** Quantity	**Equipment**	**Installation**	**Software**	**Annual Maintenance**
Curve Speed Warning	1 Intersection	$5,000	$5,000	$100,000	$11,500
Reduced Speed Warning	1 Intersection	$5,000	$5,000	$100,000	$11,500
Upcoming Zone Work Warning	1 Intersection	$5,000	$5,000	$100,000	$11,500
Pedestrian in Signalized Crosswalk warning	1 Intersection	$10,000	$10,000	$100,000	$11,500
Spot Weather Impact Warning	1 Spot in a Location	$30,000	$20,000	$7,000	$3,500
Intelligent Traffic Signal System	30 Intersection	$200,000-$400,000	$200,000-$400,000	$260,000	$82,000

Source: Data are from John Hourdos (2019, August).

Privacy

Privacy is considered to be one challenge to the users while being in control from a third party (Hourdos, 2019). The system or the platform can be built with customized options that ensure the confidentiality of the users without using personal information about vehicles and drivers. Directives that have been established by USDOT in regard to privacy:

- Establish data ownership. Whoever owns the vehicle, owns the data generated by that vehicle.
- In order to get the data, a secure consent from the owner is required.
- The V2I system will not collect or save any personal data about drivers.
- The V2I system will not be tracking specific owners, drivers, or passengers.

Challenges

As V2I offers many benefits, it also has multiple challenges. Challenges related to hardware, software, and process that need to be addressed (Mahmood, 2020). Some of these challenges are:

- **Updated Software inside the vehicle**: It is important to have updated software of the system in the vehicle. Otherwise, the vehicle may not interact with surrounding infrastructures.
- **Diversity of Smart Devices**: The market offers multiple types of one device. Creating communication device standards would reduce the chance of not working together.

- **Data Protection**: It is important to protect generated information from RSU. Protecting them would protect the users' privacy.
- **Main office System Breakdown**: In some cases, the system that collects, analyzes, sends messages can face a breakdown. Ensuring the stability of the system is a priority so the process can operate properly.

Smartphones

Smartphones became an essential device in most people's daily lives. Due to the services it provides like visual texting and calling, location detector, a source for news, and camera, it can play a major role with V2I technology to maximize the benefits for users (Sharma et al., 2016). Newer smartphones such as the iPhone 7-11, Samsung Galaxy S7-20, and Google Nexus 6-9 have more services that can help interacting more with V2I. These services are GPS, accelerometer, magnetometer, and gyroscope. They can be used to determine potential risks such as crashes and hazards. A device with these services can function as a platform to develop multiple solutions for users' safety. A smartphone can function as:

- Sender: Record information such as path direction, speed, and GPS and send it to the surrounding infrastructure to process future warnings.
- Processor: Many phone applications that can save received information and analyze them for future decision making.

Federal Aid of V2I Equipment and Operations

The Federal Highway Administration (FHWA) stated in 2015 that a number of V2I activities are eligible for federal aid funding. Several programs are offered from

FHWA such as safety, mobility, congestion mitigation, and air quality (FHWA, 2015). The aid covers equipment, installation, maintenance, and operational costs. The applicants of local governments should meet the requirements that prove the need for applying the technology. V2I applications that are included in the program are:

- Safety Applications
- Mobility Applications
- Congestion Mitigation and Air Quality

Chapter 3: Research Methods

This research focuses on answering research questions on V2I technology and its relation to planning. To do that, the literature on V2I technology, its applications, and basic components, is discussed. Moreover, the research proceeds with presenting five case studies on V2I technology and exploring planning journals to have better and detailed overview of the technology and its relation to planning.

V2I technology is expected to deliver multiple benefits regarding safety, mobility, and environment. The selected cases studies in the research were picked to elaborate what level has V2I reached in the deploying process and how the technology is going to achieve the targeted benefits. The research focuses on five case studies and consists of three pilot deployments and two studies. The three pilot deployments are conducted by the USDOT and local department of transportations of New York, Florida, and Wyoming to determine the Impact of V2I on automobiles' safety and mobility. All selected pilots are still in progress started in 2015 and are still in progress; they aim to be finished in late 2021. It is hoped that it will help to understand the readiness of V2I and test how V2I will reach targeted objectives. The main goal of these pilots is to reduce transportation issues related to automobiles such as traffic crash rate, pedestrians' safety, and the efficiency of the public transit. Each pilot has different justifications of deploying V2I technology. Wyoming has deployed the technology to increase users' safety and enhance the overall mobility for individual and commercial vehicles in the I-80 corridor. Manhattan, NY and Tampa, FL have safety and mobility issues that require regulating the usage of automobiles. The two studies were conducted by the University College Dublin and the Transportation Research Institute in Houston, TX to test V2I technology process in

achieving mobility and environmental benefits using specific algorithms. Both studies were done in different locations and streets designs to text how would the technology work in different circumstances.

The information used in all the pilot were collected from the USDOT, as well as the local transportation departments. Additional information was collected from related journal articles.

Introduction

The idea of V2I technology is relatively new and still in the beginning stage. The expectation of the technology is to change the shape of transportation and improve travel modes that are not efficient and not fully safe. The USDOT had made efforts to make the technology happen. It conducted several meetings with technology institutions, automobile companies, and local departments of transportation to develop the idea. Moreover, several technology companies have already made tests regarding technical features of the technology. After the developing stage, the USDOT planned for the deployment of V2I technology in the most needed areas; the deployment will be expected to deliver a better understanding of the technology, how to work it properly, and other changes related to policies and regulation. In addition, multiple transportation institutes and universities have conducted several studies and small-scale tests conform of the expected benefits.

Case Study: Wyoming, I-80 Corridor

Introduction

The V2I pilot by USDOT and Wyoming DOT is on I-80 in Wyoming. I-80 (402 miles) is considered to be one of the busiest corridors in the region. The corridor handles an average of 32 million tons of freight deliveries annually. Truck volume is 30-55% of the traffic on an annual basis. The corridor mix of private and commercial vehicles can result in deadly crashes during heavy use seasons. The interstate also has difficult environment and terrain. During the winter season, when the wind speed and gusts gets up to 30-65 mph, the crash rate increases to be 3 to 5 times the summer rate, resulting in 200 truck crashes in 4 years that led to road closures. The pilot is still in progress and officials didn't release the results on the pilot.

The pilot vision is to focus on the needs of the commercial vehicles. Wyoming Department of Transportation (WYDOT) and USDOT are focusing on enhancing mobility and improving safety by developing a new communication system that links road and travel information to commercial truck drivers along the 402 miles of I-80 in the state (Gopalakrishna et al., 2016). The project is being deployed through three phases. Phase one finished the concept development in 2016. The pilot has also finished phase two of the project deployment in August 2018. Finally, phase three is still in the progress and will be finished in October 2020. This link leads directly to a live map of the pilot. https://wydotcvp.wyoroad.info/CVM/.

Partners:

The Wyoming Department of Transportation has created a team for deploying the pilot to achieve its vision. This team consisted of the:

- United States Department of Transportation.
- Wyoming Department of Transportation and its departments:
    - Traffic Management, Telecommunications, Highway Patrol, Maintenance, GIS, IT, Contracts, and Public Affairs Office.
- Inner City Fund (ICF) International to create the overall program management support, performance support, and evaluation.
- Trihydro to create the system design, application development, and monitoring.
- University of Wyoming to help with evaluation.
- McFarland Management to coordinate all performance management and evaluation activity for the pilot.
- Vendors for On-board units, Road-side units, Sensors, and hardware and software development.

Study Area:

The pilot will take place in the I-80 corridor (Figure 2). Roadside units were installed at different locations based on spatial and temporal implications. The collected information will be managed from the main office at Cheyenne, Wyoming.

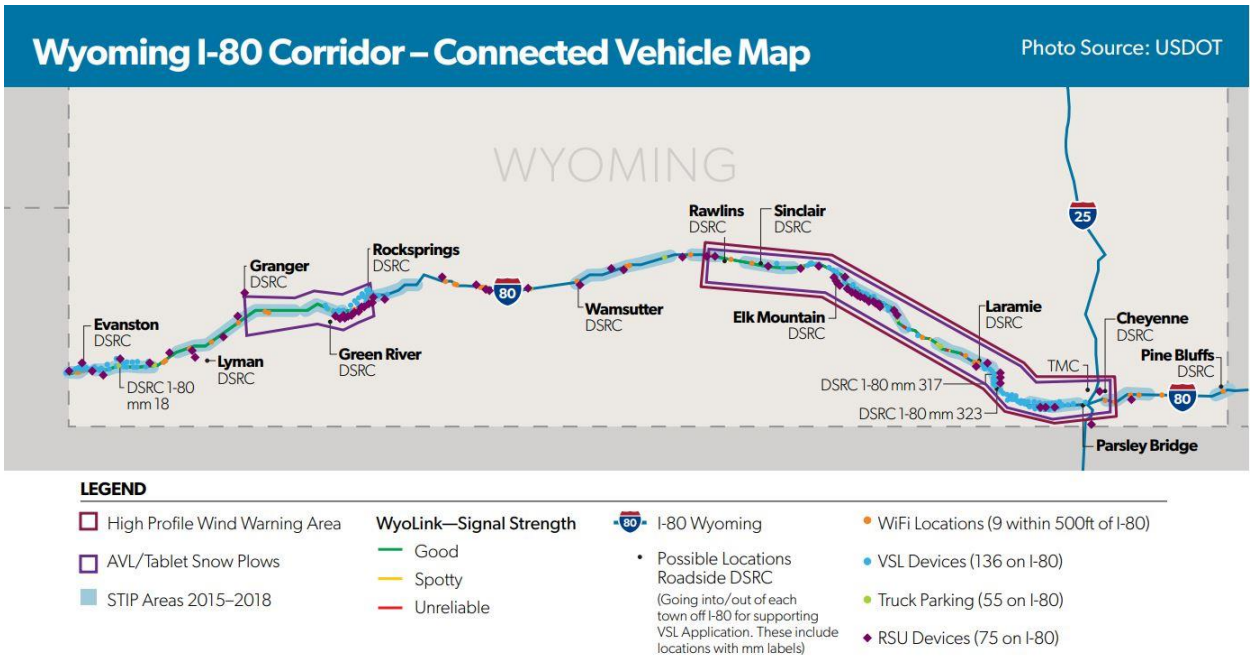

Figure 2. Study Area of Connected Vehicle Pilot in Wyoming / Source: USDOT

Wyoming System

WYDOT created a system that links vehicles to the main system via DSRC and GPS (Figure 3). In addition, they created a Data Management Plan to save and manage collected data throughout the connected vehicle pilot project. The data collected will be available to the University of Wyoming and the Department of Transportation. V2I technology is being used for spot weather impacts warnings, work zone warnings, and speed adherence. Below is a list of tools that helped V2I technology during the pilot project (Gopalakrishna et al., 2017).

Wyoming Connected Vehicle System consists of five sub-systems:

- Roadside Units (RSU).
    - Physical roadside units that include DSRC connectivity, application support, and data storage.
- Operational Data Environment (ODE).
    - The Operational Data Environment sub-system receives information and shares them between the system and the vehicle.

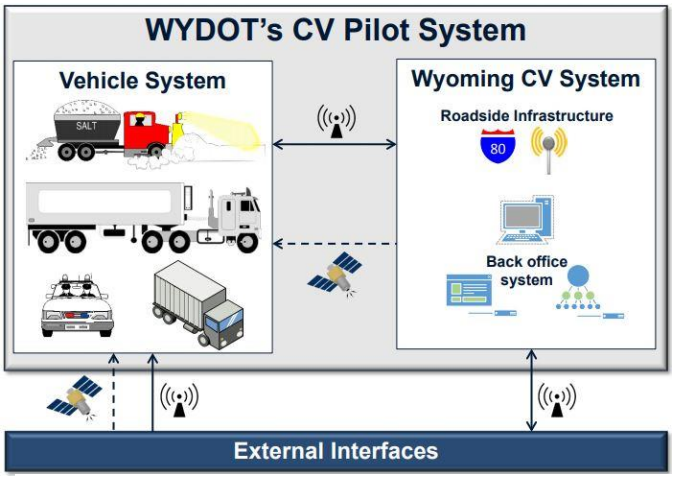

Figure 3. Wyoming Connected Vehicle System Concept / Source:

- Pikalert System.
    - Pikalert System provides alerts regarding adverse weather condition along I-80.
- Data Broker to analyze data.
- Data Warehouse.
    - Stores overall collected and analyzed data.

The pilot consists of:

- 75 Roadside units.
- 150 commercial trucks.
- 100-150 Private vehicles.
- 100 WYDOT fleet.

V2I Applications:

To achieve the goal of maintaining safety on I-80, V2I safety applications were applied to have a better observation of the corridor conditions. Wyoming focused on the reasons for crashes on I-80 (Table 3) and applied safety applications to reduce the overall rate of crashes.

Table 3.

Vehicle-to-Infrastructure Applications in Wyoming

V2I Application	Purpose
Work Zone Warnings	Notify of work zone ahead
Spot Weather Impact Warning	Notify of weather changes and hazards
Distress Notification	Notify a distress status that requires assistance
Forward Collision Warning	Notify of impending collision
Situational Awareness	Notify relevant downstream road conditions

Source: USDOT, 2016

Goals of the pilot:

- Improve road weather condition reports:
    - Increase reports by 30% after the test.
- Driving behavior.
    - 80% of drivers would take actions after receiving an alert.
- Speed adherence:
    - 20% improvement of adjusting to the recommended speed.
- Crashes:
    - 25% reduction of vehicles involved in a crash.

- 10% reduction of truck crash within work zones.
- 10% reduction of truck crash.

Challenges:

- Wireless connection between equipment is unreliable.
    - The wireless connection between infrastructure devices isn't efficient to send or receive data between the system and RSU. With the difficult weather, technical problems can affect and slow down the process This issue would affect the aimed goal of increasing report messages to drivers.
- The size of the study area needs a higher level of maintenance.
    - As the I-80 corridor is a massive area to deploy V2I technology that require multiple advanced devices to be installed within the corridor, it needs a higher level of maintenance, especially in the winter season. To make V2I work properly, nonworking devices need to be fixed.
- Storage Capacity has limited the amount of data collected.
    - The local office controlling the system must have adequate storage to fit the needs. As the number of users may increase, the storage needs to increase as well.
- The number of participants is considered to be low. The I-80 corridor is considered to be a major use corridor, but many participants are unaware of the V2I project. Unlike commercial trucks that usually use the corridor and have been notified of the project, individuals who rarely use the corridor would also impact the study. There would many participants whose vehicles don't have OBU. Thus, it is important to notify all users locally and nationally of the ongoing project to have better results.

Opportunities:

- Applying V2I technology on the I-80 corridor would introduce multiple benefits to the safety and the economy. As the corridor is heavily used by commercial trucks, there could be multiple economic projects along the road. For example, projects such as warehouses to load goods and factories to make it faster to deliver for nearby cities.
- The V2I project can increase the safety level of small cities and towns located nearby I-80. It can reduce crash rates, create adequate speeds for travelers' vehicles to move, and help with developing new regulations regarding safety.

Lessons Learned:

- The technical problems have led to complexity in V2I notifications. For example, some of the work zones on the I-80 corridor has broken RSU nearby, and drivers would receive wrong warnings about upcoming work zone. WYDOT has needed to redesign the system to adapt for broken devices.
- To increase safety level, the WYDOT suggested increasing effectiveness by adding speed reduction warnings along with weather notification. It is possible that not every driver would reduce speed based on weather notification.

Case Study: New York, New York

Introduction

The New York Connected Vehicle Pilot Deployment is the largest deployment of connected vehicles to date. Local officials aim to eliminate injuries and fatalities due to traffic crashes. Vehicles include taxis, buses, commercial trucks, and other city vehicles.

Officials' expectations are reducing overall crashes, controlling speed, and assisting pedestrians (Talas et al., 2016). The pilot started in 2016 after finishing the concept development and still in progress of in the deployment which will finish in August 2020. The pilot will then beyond the deployment and finish in November 2021. The pilot's time frame can be accessed through this link https://www.cvp.nyc/project-status.

Partners:

The New York Department of Transportation team consists of:

- United States Department of Transportation.
- New York Department of Transportation (NYDOT).
- JHK Engineering to design and manage the system.
- Cambridge Systematics to handle performance measures.
- KLD Engineering for NYC infrastructure integration.
- Security Innovations for securing the system and ensure data privacy.
- University Transportation Research Center for support and training.
- Vendors for On-board units, Road-side units, Sensors, and hardware and software development.

Study Area:

The pilot is taking place in 1st, 2nd, 5th, and 6th avenues covering 310 signalized intersections. In addition, the major cross-town street, consisting of 14th, 23rd, 34th, 42nd, and 57th streets, and Flatbush Avenue in Brooklyn (Figure 4).

Figure 4. Study Area of Connected Vehicle in New York, New York / Source: USDOT

System Concept:

Figure 5 shows the connection between the main office system and targeted travel modes. The roadside unit is considered to be an important element of the system. It links the users with system. As the information starts from the users to the roadside unit, it moves to multiple directions such as data collection, traffic control system, and advanced transportation controller (Figure 5).

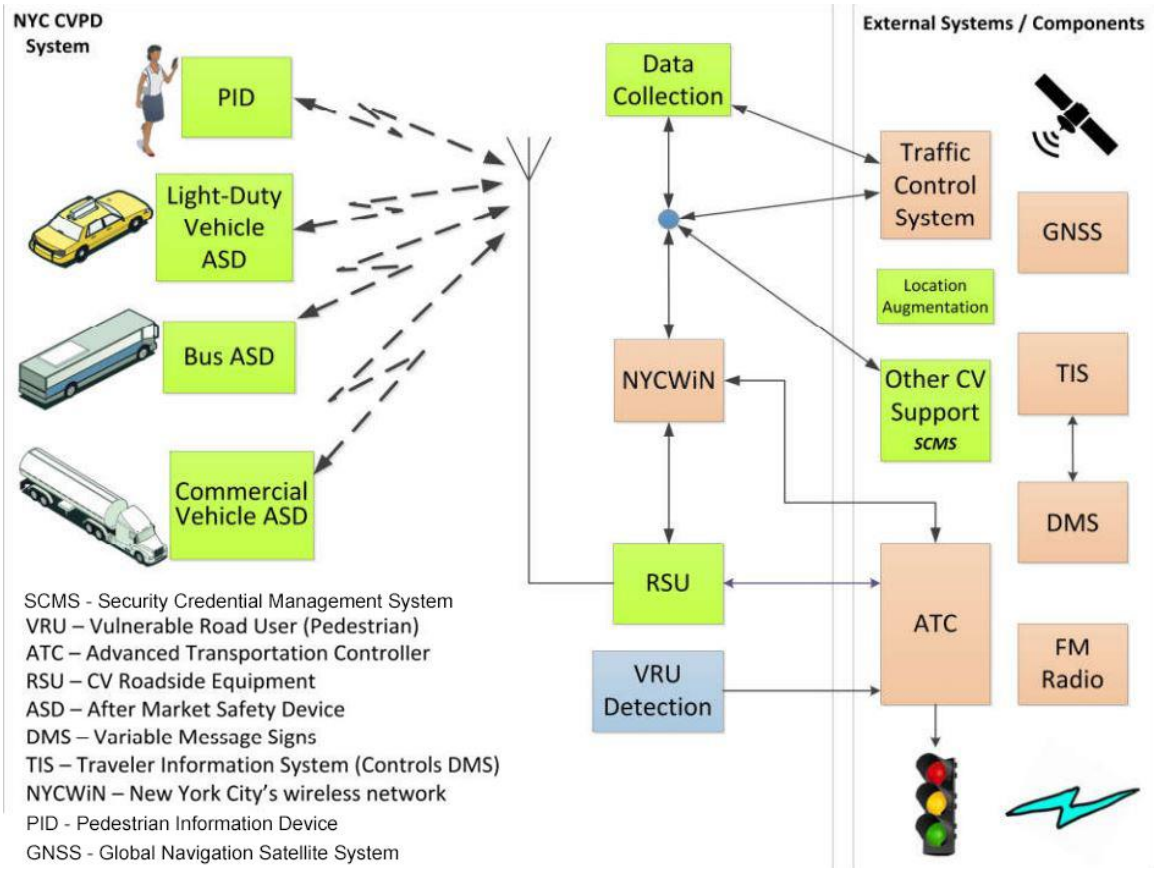

Figure 5. New York Connected Vehicle System Concept / Source: USDOT

V2I Applications:

The New York Department of Transportation and The United States Department of Transportation are using V2I technology, along with DSRC, to manage speeds, red light violation warnings, reduce vehicle crashes, and manage system operation (Table 4). The city has been installing RSU, approximately 8,000 and OBU in vehicles, and 353 of roadside units (Talas et al., 2018).

Table 4.

Vehicle-to-Infrastructure Applications:

V2I application	**Purpose**
• Speed adherence • Work Zone • Curve Speed adherence	To Control Speed along arterials, curves, and work zones.
• Red Light Violation Warning	To avoid rare-end and right-angle crashes.
• Oversize Vehicle Compliance	To avoid vehicle-to-infrastructure crashes.
• Emergency Communications and Evacuation Information.	To spread information for situations that are in need for changes in travel patterns.
• Pedestrian in Signalized Crosswalk	To avoid vehicle-to-pedestrian crashes by alert drivers.
• Mobile Accessible Pedestrian Signal	To assist visually challenged individuals crossing intersection.

Source: USDOT, 2016

Goals of the pilot:

- Improve work zone safety.
- Reduce fatalities and injuries from vehicle crashes.
- Reduce speed and intersection adherence to suggested speed.
- Improve mobility for public transit.

Challenges:

- Because it is deployed in a dense area, the range of RSU will overlap. DSRC range is approximately 300 meters and the block spacing is approximately 70 meters. This can affect the progress in achieving all targeted goals.
    - Overlapping ranges of RSU would create mix results to the receivers and they could end up with wrong notifications. For example, automobile driver would receive multiple notifications of pedestrians crossing in different locations. One potential solution is to change and separate the locations of RSU to fully cover Manhattan's street segments without interference.
- New York is known for its urban canyons which create a challenging environment for GPS technology.
    - The grid design in Manhattan can cause problems to the GPS system. V2I fully depends on the locations of the users, and false locations would affect the process and generate wrong messages to drivers.
- Privacy is considered one aspect of the challenges. It can limit the type of data that needs be collected.

  - Additional type of data would raise concerns on the collection process. Residents of Manhattan have to register their vehicles to be able drive with the city. The local government of Manhattan apply this regulation to reduce automobile users from outside the city. The V2I project would help monitor the use of automobiles inside Manhattan by collecting vehicle and personal data. Limiting personal data collection wouldn't help the technology to do this service.

- The size of system, the number of vehicles, and roadside units needs more maintenance support.
  - Since the V2I system, RSU, and OBU are new in field of technology, it has limited maintenance vendors. In addition, the size of the study area and number of vehicles, that can be increased, require maintaining the devices to stabilize the process. It is expected to have multiple technical issues at the beginning of the V2I deployment process. These issues would help develop V2I devices to fit the needs with fewer mistakes.
- The deployment of V2I increases the safety of pedestrians. The involvement of pedestrians in the V2I process is necessary.
  - Since Manhattan, NY is known as one of the most tourists places in the United States, it is expected to have many visitors who will move around the city and uses public buses for far destinations. It is important to include these visitors and provide incentive for them to download the application and enable location option to be counted in the V2I system.

Opportunities:

- The deployment of V2I would increase the safety of the pedestrians. The local government can offer multiple plans to improve and support the safety of tourism, on-street festivals for instance.
- Regulating drivers' behaviors would improve the quality of air for pedestrians. Applying Eco-friendly V2I applications in a dense place such as Manhattan would lower the rates of harm from automobile emissions.

Lessons Learned:

- The city already faced a couple of challenges regarding privacy and technical issues. It is important to include technical, vendors, and legal personnel in stakeholder meetings to address the requirements of the connected vehicle deployment.
- Manhattan, NY has to provide multiple options to determine the locations of users. Since the grid design create issues with the GPS system, it is urgent to develop the system to avoid locations mistakes. Developing the GPS system could be done by updating the speed of internet and enhance the coordinate system to adapt to specific areas such as Manhattan.

Case Study: Tampa, Florida

Introduction

Drivers, pedestrians, and transit users in downtown Tampa, Florida face daily transportation challenges. During the rush hours, commuters using the Lee Roy Selmon Expressway's Reversible Express Lanes deal with delays and, usually, rear-end crashes.

In addition, the increase of vehicles, pedestrians, and bus users creates conflict. This conflict of transportation modes is creating challenges for mobility, safety, and the environment. The United States Department of Transportation and the Tampa Hillsborough Expressway Authority are combining efforts to complete the pilot that started September 2015 and aims to finish in 2021. The pilot has also finished phase two deployment in August 2018. Finally, phase three is still in the progress and is scheduled to be finish in October 2020. The goals of the pilot are to prevent crashes, enhance traffic flow, improve transit trip times, and reduce emission in the downtown area (Talas et al., 2016).

Partners:

The Tampa Hillsborough Expressway Authority's team consists of:

- United States Department of Transportation
- Florida Department of Transportation
- Hillsborough Area Regional Transit (HART)
- HNTB, Howard Needles Tammen and Bergendoff.
- University of South Florida Center for Urban Transportation Research
- Siemens
- Brandmotion
- Global-5 Communications

Study Area:

Downtown Tampa is bordered by Ybor Channel (Cruise Ship and Commercial Port Channel) to the east, Garrison Channel (local waterway) to the south, Florida Avenue to the west, and Scott Street to the north (Figure 6).

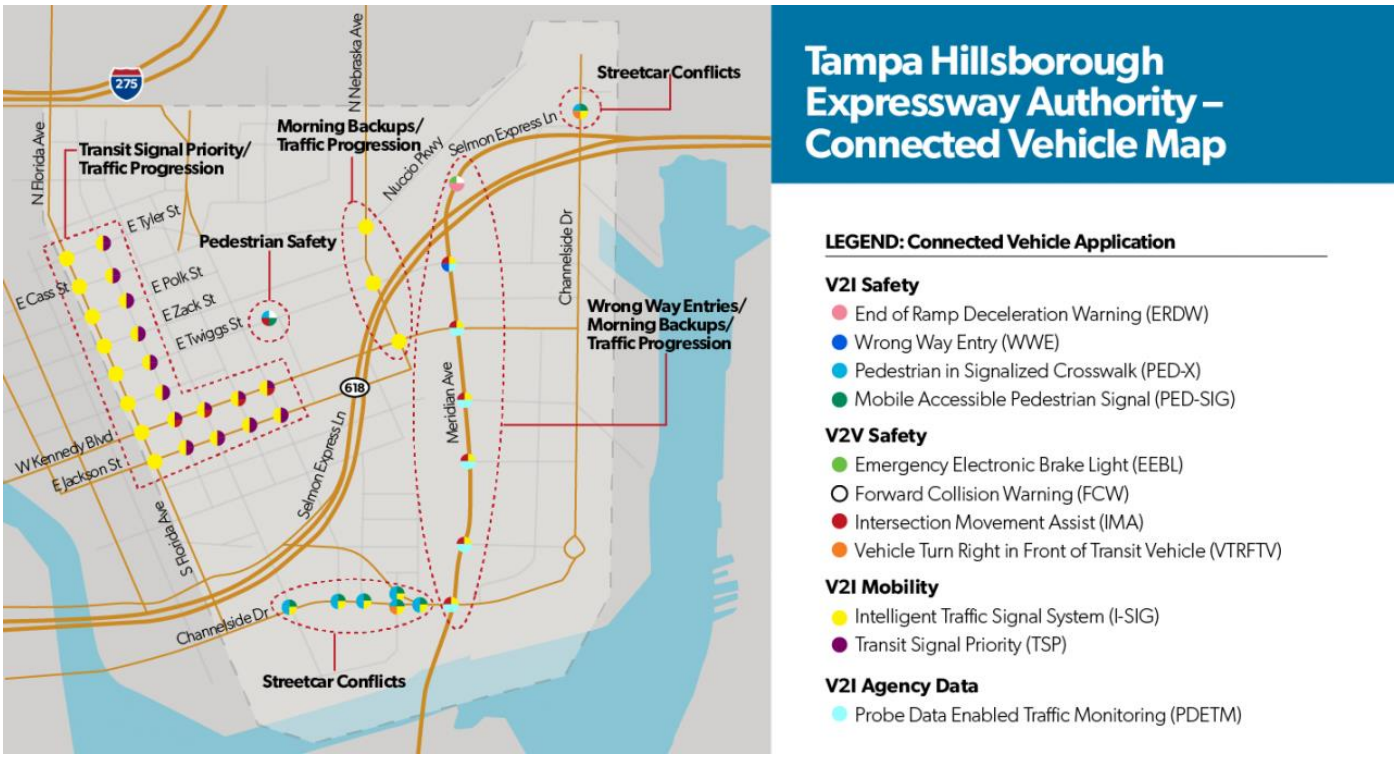

Figure 6. Study Area of Connected Vehicle in Tampa, Florida / Source: USDOT

System Concept:

Similar to New York and Wyoming pilots, Figure 7 shows how data is being transformed from vehicles via DSRC, Smartphone device via WIFI to the roadside units and then to the Traffic Management Center.

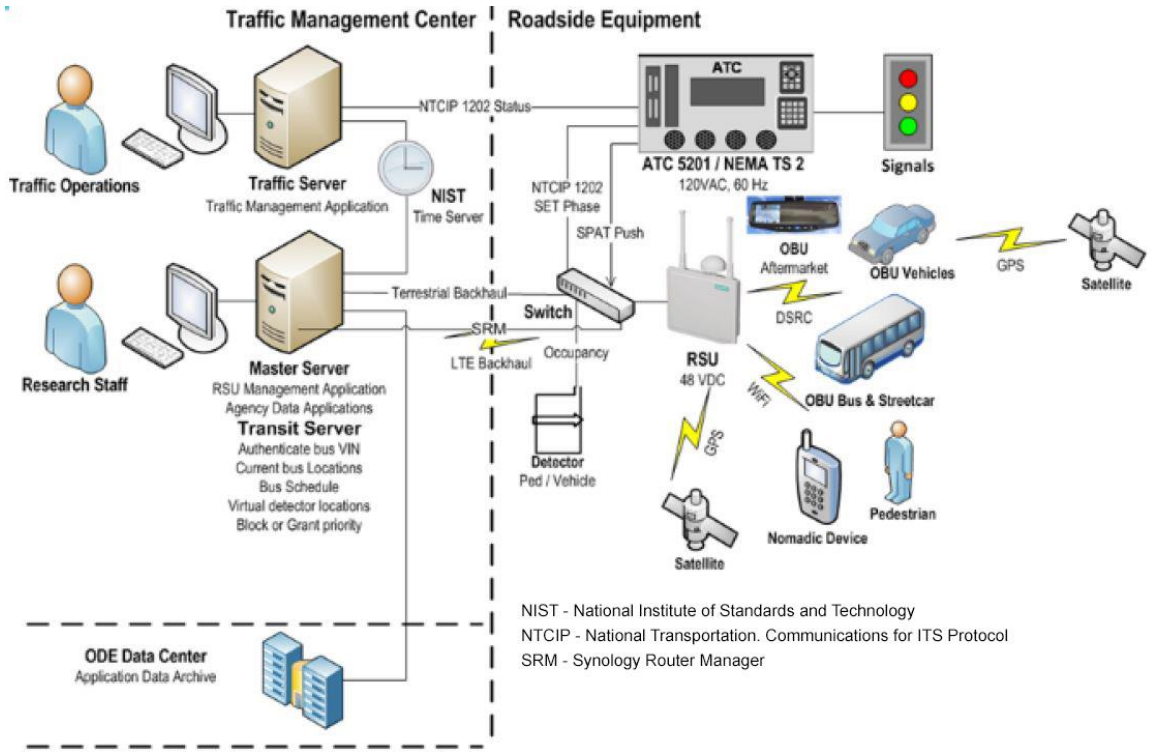

Figure 7. Tampa, FL Connected Vehicle System Concept / Source: USDOT

Tampa Hillsborough Expressway Authority (THEA) pilot consists of:

- More than 1,000 privately owned vehicles.
    - The count will more likely continue to increase because the pilot team will provide the necessary equipment for the vehicle if the owner wants to voluntarily participate in the pilot.
    - 10 Buses.
    - 48 roadside units.

- 500 application downloads by pedestrians.

V2I Applications:

Table 5 shows the V2I used applications in Tampa, Florida for vehicles and pedestrians. They were focused on resolving the conflict of different modes of travel (automobile users, pedestrians, and transit users) (Johnson et al., 2017).

Table 5.

Vehicle-to-Infrastructure Applications:

Vehicle	Pedestrians
End of Ramp Deceleration Warning	Pedestrians in Signalized Crosswalk
Wrong Way Entry	Mobile Accessible Pedestrian Signal System
Signal Priority (transit)	
Intelligent Traffic Signal	
Emergency Communication and Evacuation Information	

Source: USDOT, 2016

V2I application End of Ramp Deceleration Warning is being used in Reversed Express Lane, Wrong Way Entry is being used at the intersection of Twiggs Street and Meridian Avenue, Pedestrian in Signalized Crosswalk along Channelside Dr. and East Twiggs St., Mobile Accessible Pedestrian Signal along Channelside Dr. and East Twiggs St., Intelligent Traffic Signal System is being used in every intersection that has roadside units, and Transit Signal Priority is being used in East Jackson St.. The way V2I technology connects with pedestrians is by smartphones. Pedestrians point the

smartphone to the direction they want to cross and presses the “Cross” button to notify the roadside units. The combination of V2I application reflects the need to balance travel modes.

Goals of the pilot:

- Reduce morning peak-hour delays and rear-end crashes on the Lee Roy Selmon Expressway’s Reversible Express Lane.
- Reduce vehicle/pedestrians conflict at a busy mid-block crosswalk near the Hillsborough County Courthouse.
- Improve traffic flow by supporting traffic signal optimization.
- Improve transit trip times by giving the traffic signals priority in the Marion Street Transitway.
- Efficient flow of traffic exiting the Reversed Express Lane (REL) into the downtown.
- More efficient management of intersections to improve transit travel reliability and general traffic.

Challenges:

- Low participants installing OBU, even with incentives. Even after recruiting participants, it is important to continue to engage them in order to support their ongoing participation.
    - As the Tampa’s study area is considered to be important for employment, residence, and tourism, it is encouraged to communicate with the public

about the project. More participants means more feedbacks and high level of awareness, and enthusiasm.

- Similar to previous pilots, Tampa has been facing technical problems regarding installing OBU.
    - Due to the limited vendors, the local government had to hire nonprofessional labors to install OBU into automobiles, which led to notable communication problems.
- General constructions complicated the progress of building V2I.
    - Road and building constructions have delayed installations of RSU and traffic sensors. Other projects interfered and delayed the project for several days.
- Some roadside units received more notifications than others which require a complete search and test of new roadside unit hardware.
    - Because of technical problems, some of the used RSU devices were inefficient and did not work constantly, and THEA had to look for new vendors.

Lessons Learned:

- The area's special events and new projects would create different ways of managing mobility in downtown.
    - It is important to have an early idea of future plans happening within the area of the V2I pilot. It would help the system to adapt to future route changes and traffic light timing.

- Because of the problems came with RSU that don't integrate with private vehicles, more tests will need to be done in future.
    - THEA is creating a process in which the deployment team has to collaborate with all vendors and automobile companies to ensure the integration process and the tests. As long as the deployment continues, more tests will be applied.

Case Study: Reducing Road Traffic Congestion

The University College Dublin has conducted a study in 2015 on reducing road traffic congestion by using V2I communication technology (Djahel et al., 2015). The goal of the study is to reduce congestion while avoiding stoppings through an improved coordinated and controlled acceleration/deceleration of vehicle and an increased awareness of surroundings. To have better results, the study was done in four different traffic loads (120 vehicles /km^2, 240 vehicles /km^2, 360 vehicles /km^2, 480 vehicles /km^2).

Approach:

The proposed approach was to make traffic lights equipped with RSU communicate with vehicles approaching, giving them the traffic light cycle. Thus, drivers can decide which action to take in order to cross the road intersection with minimum delays while avoid stopping. The model was based on priority mechanisms to manage V2I and Vehicle-to-Vehicle (V2V). V2I was used as a Traffic Light Control (TLC) that broadcasted information to the vehicles coming into the road segment that it controlled.

Study Areas:

The study took place in Bunker Hill in Los Angeles (Figure 8) and in the lower part of Manhattan, New York (Figure 9). Both locations were picked because they have differences in their layouts. New York tends to have narrower streets and one-way system, whereas Los Angeles has wider streets with many two-way streets.

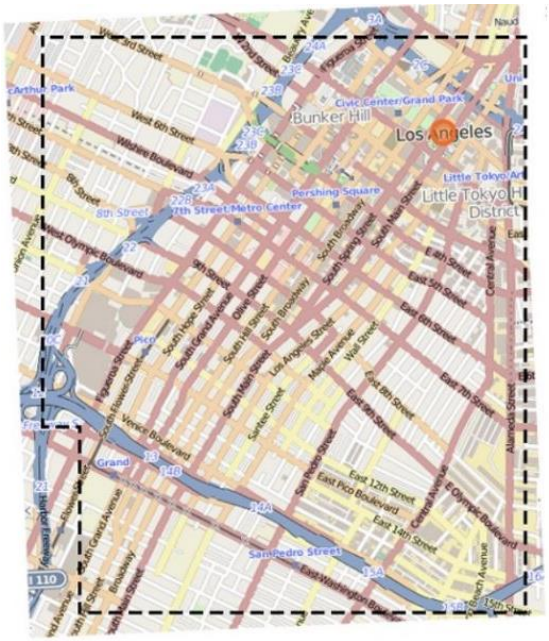

Figure 8. Bunker Hill, Los Angeles. Source: Djahel et al., 2015.

Figure 9. Lower Manhattan, New York. Source: Djahel et al., 2015.

Operation:

The operation consists of several steps, and each step results in several recommendations to each vehicle to take the appropriate action such as changing lane, decelerating, and accelerating. Vehicle's GPS, local sensors, and the information collected from TLC will help set the recommendations. The model is based on Belief-Desire-Intention of vehicle. Belief means current condition of a vehicle such as current

speed, position, and the distance to the traffic light. Desires refers to the objectives to take actions. Intentions reflect actions that the vehicle has chosen to do (Figure 10). As new information is received, a revision function updates the current beliefs. Based on new beliefs, an option generation function updates the desire. After that, an action generation function is used to deliberate the new intentions. Finally, a plan generation schedules the actions.

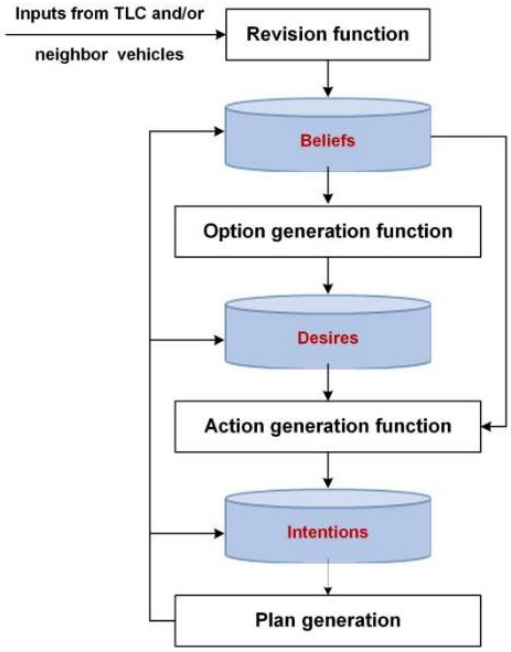

Figure 10. Belief-Desire-Intention vehicles Model. Source: Djahel et al., 2015

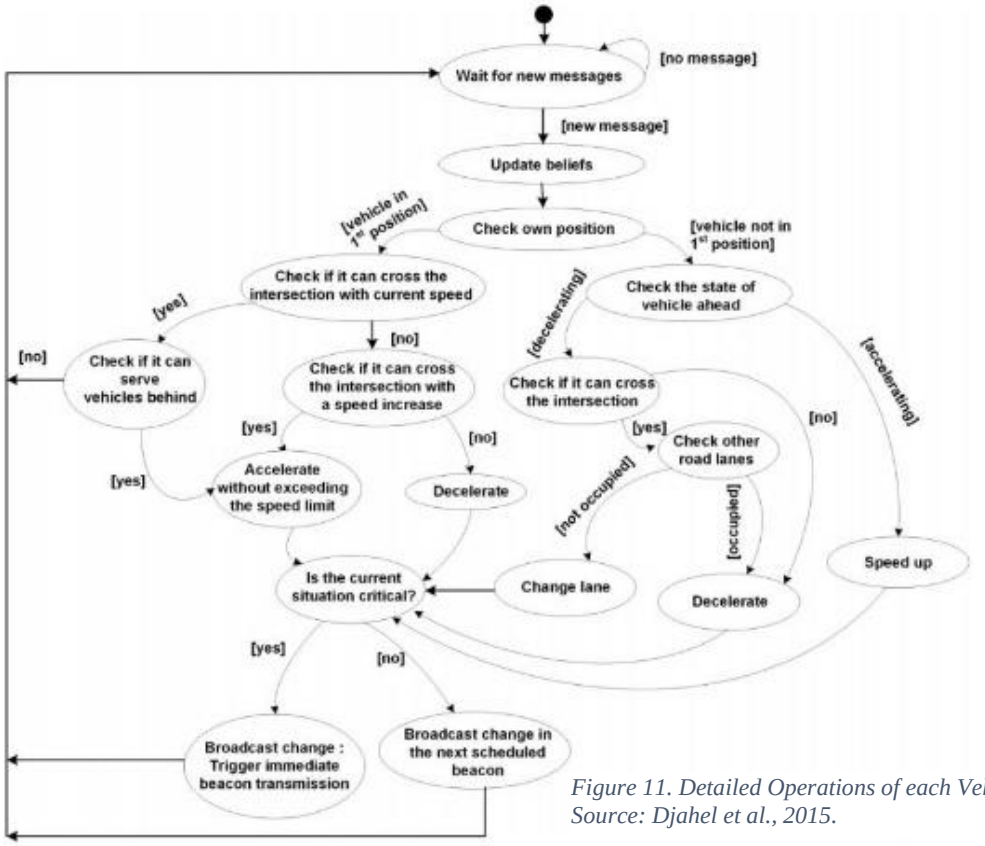

Figure 11. Detailed Operations of each Vehicle. Source: Djahel et al., 2015.

Figure 11 shows how the process operates. First, it updates beliefs about a vehicle to evaluate its objectives to go through the intersection or serving other vehicles. Based on the new objectives, the vehicle will decide either to accelerate, decelerate, or stop. Deciding to accelerate will generate mechanisms to adjust speed based on the distance to the intersection, remaining time of the traffic light, legal speed, and the distance between vehicles generated by V2V.

Test Results

The results were done by comparing Average Travel Time (ATT) and vehicles density of both proposed scheme (proposed algorithm) and the baseline scheme (regular daily operation). As Figure 12 shows, the study area in Los Angeles has recorded a significant difference between baseline scheme and the study scheme on ATT (reduction by 38%) at the highest simulated density (480/km^2). This means that proposed algorithm with V2I would work better on-peak hours. Similarly, the study in Manhattan has recorded a decrease of 28% on-peak hours (Figure 13). In conclusion, both studies with the proposed algorithm have

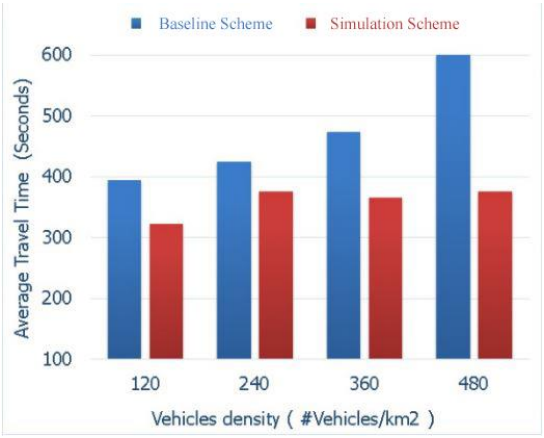

Figure 12. Average Travel Time in Los Angeles: our scheme vs. the baseline scheme. Source: Djahel et al., 2015

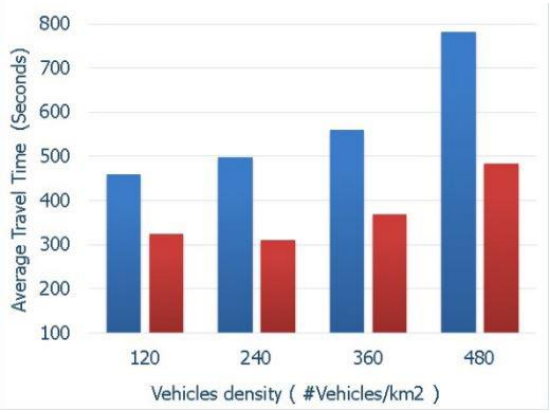

Figure 13. Average Travel Time in New York City: our scheme vs. the baseline scheme. Source: Djahel et al., 2015

recorded lower ATT than the baseline scheme (between 300-400 seconds in both study areas).

Lessons Learned:

- To have better understanding of the technology, the proposed approach need to be done in different locations with different streets designs to ensure efficiency.
- An up-to-date data collected post the test would increase the accuracy of the results by comparing before-and-after data collected in the study.
- An early study of the proposed algorithm has increased the success rate of the test.

Case Study: Using V2I to Reduce Air Emissions

The Innovative Transportation Research Institute in Houston, Texas has done a study in 2015 to test if vehicles connected to RSU would reduce air pollution (Li et al., 2015). According to the Environmental Protection Agency (2009), transportation has been the number one source of greenhouse gases emissions (approximately 28%). Vehicles' emissions include unburned Hydrocarbon (HC), Nitrogen Oxides (NO), Carbon Monoxide (CO), and Particulate Matter (PM) which is a mixture of solid particles and liquid droplets. V2I was used because it connects vehicles with infrastructures and sends safety messages to drivers so they can react properly. As V2I informs drivers, it provides safety, mobility, and environmental benefits. Smooth driving, as one mobility benefit, is considered to be a feature of Eco-driving. A vehicle emission decreases based on a certain range of speeds. Thus, V2I system can guide drivers to accomplish Eco-driving.

Scenario Design

A driving test is used to record different impacts of emissions with and without V2I. The scenario took place in a signalized intersection and a work zone. Thirty participants were recruited for the study.

Signalized Intersection:

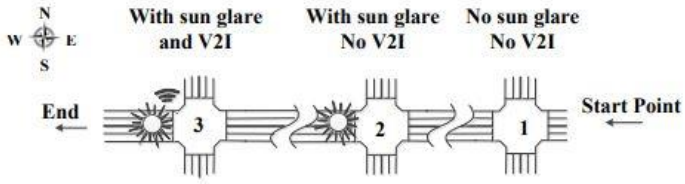

Figure 14. The Layout of the First Scenario (Signalized Intersection). Source:

1,000-meter track in an industrial area with three intersections is the first scenario (Figure 14). Posted speed is 45mph. Participants were required to drive through the intersection three times (no sun glare and no V2I, with sun glare and no V2I, and with sun glare and V2I). Drivers were able to receive audio messages about the real-time signal before approaching the intersection by 210 meters.

Work Zone:

Participants were required to pass the work zone twice. Post speed was changed from 45mph to 30mph when approaching the work zone.

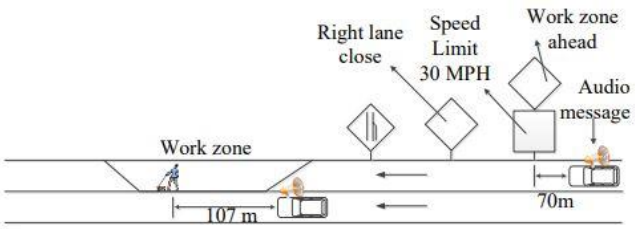

Figure 15. The Layout of the Second Scenario (Work Zone). Source:

Drivers were able to receive audio messages about 70 meters before the signs and 107 meters for traffic signs and risk warning (Figure 15).

Test Results

Measured emissions on first test, signalized intersection, resulted in Figure 16. As the chart shows, V2I with sun glare scenario has produced almost the lowest emissions rate of all types between all scenarios. The emission rates of CO2, HC, and NOx in the scenario S-V- (no sun glare and no V2I) at normal situation are 20%-80% higher than the others. Opposite to with sun glare and no V2I scenario, emission rates are lower.

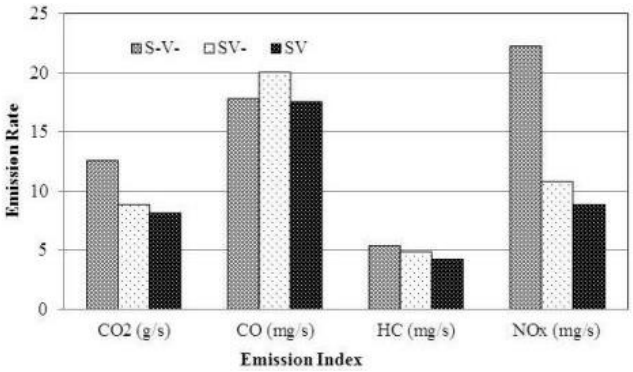

Figure 16. Vehicle Emissions Rates at Signalized Intersection Simulation Results. S-V- means no sun glare and no V2I, SV- means with sun glare and no V2I, and SV means with sun glare and V2I. Source:

In the work zone scenario, Figure 17 elaborates vehicles' emissions with and without V2I equipped while driving through the work zone. When V2I is equipped, all types of emission were reduced between 1%-25%. CO was reduced significantly, and CO2 HC, and NOx were reduced slightly.

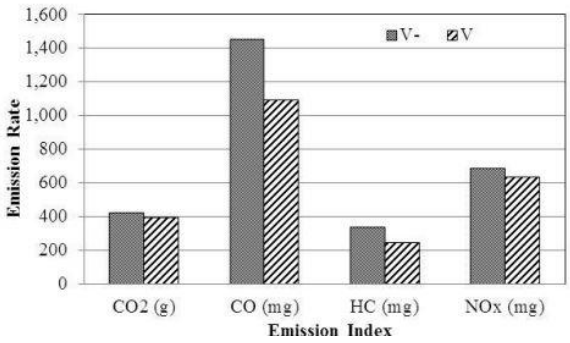

Figure 17. Vehicle Emissions Rates Work Zones Simulation Results. V- means no V2I, V means with V2I. Source:

Lessons Learned:

- The study shows how important it is to decide when to send the notification to vehicles so drivers can take actions.
- Involving other elements such as the sun glare enhanced the test's quality. In many cases, sun glare has been affecting people's vision in driving. Thus, V2I

technology improved drivers experience in the test by helping them in the decision-making process.

Conclusion

V2I technology provides multiple safety, mobility, and environmental benefits by communicating with vehicles to advice drivers to make better decisions. In USDOT pilots, V2I technology has been deployed to deliver solutions to reduce the effects of the conflict between automobiles and pedestrians, the high rate of automobile crashes in Manhattan, NY and Tampa, FL, and the accident and fatality rate, especially in the winter, within the I-80 corridor in the state of Wyoming. As the pilots continue, more participants are expected to be recruited to provide more accurate results and more feedback on V2I issues in the field.

Manhattan, NY and Tampa, FL, and Wyoming pilots are expected to fulfill their targeted goals by the end of 2021. However, they could face challenges that could impact the process to achieve targeted goals. One of major challenges these pilots have faced is the low number of participants. For example, many tourists driving in the study areas of Tampa and Manhattan were are unaware of V2I technology project and its equipment. Therefore, local governments need to spread the knowledge about V2I technology and its benefits and offer incentives to install temporary equipment into tourists' vehicles. Beside the presented pilots, the study that was done by the University College of Dublin also showed promising results in mobility using V2I technology. As Manhattan, NY and Los Angeles have high users of automobiles and different streets design, they were appropriate study areas to test the technology. The team has created specific algorithm to test the effects on drivers regrading acceleration and deceleration. From the environment

aspect, the study that was done by the Innovative Transportation Research Institute in Houston, Texas has shown that V2I technology would reduce the impacts of CO2, CO, HC, and NOx by 1%-25%. It is expected to have more effective rates on highways because of accelerations and decelerations rates and industrial areas because of the higher use of trucks.

Chapter 4: Discussion

Introduction

In general, technologies aim to enhance humans' lives, and humans' transportation can create issues if it doesn't get regulated. Mostly, people's choice of travel mode depends on how far the destination is, how comfortable it is, and the benefits from saving time and money. In most cases, as automobiles increase, it can affect the safety of people, reduce the quality of the air, and affect the way other travel modes operate. Governments try to reshape transportation to the way that fits the needs with minimum impacts. V2I technology helps connect vehicles with the surrounding infrastructure to create a system that supports mobility, reduces accidents, and conserves energy. It is considered to be a major tool to change the way transportation operates.

When USDOT agreed to do tests of connected vehicles, it was a reaction to challenges the United States is facing. Mobility challenges include higher travel time and increased congestion, safety challenges include high rates of crashes and deaths, and environmental challenges include more gallons of wasted fuel and an increase on OC2. Every connected vehicle pilot project USDOT is participating in focuses on problems that the local governments wanted to reduce. Wyoming is using safety and mobility applications to reduce accidents during heavy seasons. New York aims to eliminate injuries and fatalities due to traffic crashes by focusing more on safety applications. Tampa is focusing on reducing congestion and delays on Reversible Express Lanes and dealing with the conflict of increasing pedestrians, bus users, and drivers; mobility applications were put into place to reduce the impact.

Transportation Modes

V2I is a technology that can be used to regulate the overall mobility in a particular area or within a road. It is a system that informs drivers and pedestrians of potential accidents, weather conditions, violations and would reduce the chances of drivers making mistakes. People do mistakes while driving; these mistakes, such as increased speed, texting, and not focusing on driving, can be risky. V2I aims to reduce these mistakes by improving their awareness while driving. In addition, it maximizes the efficiency of other travel modes by giving priorities to different modes at different times and increases safety for all modes. One example is the state of Vermont. The state is considering V2I communication technology as a strategy to maximize the efficiency of all travel modes (Vermont Long-Range Transportation Plan, 2018). It believes that using V2I technology will lead to better transportation experience.

Both Tampa and New York pilots were conducted in downtown areas that are dense with pedestrians and vehicles. Both cases have declared that their problems include vehicle, pedestrians, and infrastructure crashes. Moreover, the increased number of automobile drivers has affected the time schedule of public buses. Therefore, buses were not able to operate properly. V2I technology was introduced to connect automobile drivers and inform them about potential accidents. It also gives the option to give priority to buses in signalized intersections to enable them to be on time. In terms of pedestrians, having the mobile application that connects them with the infrastructure around will put them in the system. Drivers will be notified when a pedestrian is going to cross so drivers can take appropriate actions to protect the safety of the pedestrians. It increases pedestrians safety while walking in a downtown such as Tampa’s that has a grid design,

which creates pedestrians and vehicles conflict at traffic intersections. V2I can be one planning solution to regulate automobile drivers and balance all travel modes. It can be considered as a beneficial technology to use in a transportation plan to reach specific goals.

Emissions in Urban Areas

Beside the safety benefits, V2I is also expected protected the environment. A city with mixed used development such as a downtown with a walkable environment can face a threat of CO2 emission from vehicles driving around the place. In a mixed used development area, conflict is expected between pedestrians and automobiles. One result from this conflict is pedestrians impacted by vehicles emissions.

USDOT conducted a field test in Anthem, AZ and applied Eco-Signal Operations that aims to decrease greenhouse gases and air pollution by reducing idling, reducing stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersection. Eco-Signal Operations that were used resulted in a 11% reduction in CO2 emission and fuel consumption. These applications are (Chang, 2015):

- Eco-Traffic Signal Timing: Optimizes the performance of traffic signals for the environment. The application collects information for vehicles such as location, speed, and emissions to adjust the traffic signal timing to reduce fuel consumption and emissions.
- Eco-Signal Priority: Consider vehicle location, type of vehicle, and speed to allow transit or freight vehicles approaching a signalized intersection to request signal priority.

Data Collection

It is important to have updated data about daily traffic, vehicle miles traveled, and travel time to have a better understanding of an area. V2I's system consists of multiple devices that collect data and transfer them to a memory to be saved and used for future uses. It captures real-time data of traffic, vehicle miles traveled and travel time on daily basis in a specific area. Data collected can be used to determine the existing and future needs such as additional parking spaces in most needed areas and updating policies regarding streets design and directions. Planners would have an exact and live data to study and analyze to get better and accurate results of an existing situations and future projections.

Conclusion

As planners develop plans for transportation, it is important to create a balance among transportation component, including vehicles, trails, pedestrians, buses, and bicycles, to increase accessibility, reduce travel time, reduce congestion, and protect the environment. As users increase in one travel mode, it can impact other travel modes negatively and reduce the process of reaching targeted goals by local governments, the increase of automobiles would increase health problems for pedestrians in dense areas such as downtowns for instance. Therefore, local governments would have to focus on solving current issues instead of focusing on future developments.

Chapter 5: V2I in Planning

V2I technology can be considered one of the most powerful technologies that can affect all aspects of communities. Due to the increase of automobile users that have affecting how transportation systems should operate, V2I technology can be one alternative solution to reduce the impact. As the increase of automobile users increase, it is possible that the concerns on safety, mobility, and environment increase. Planners need to think about what benefits the V2I technology offers to increase safety, enhance mobility, and protect the environment. More importantly, they need to focus on what changes will V2I technology bring to communities in terms of land use, transportation network, and the economy. The role of planners in adapting this technology would increase its success rate and maximize the benefits to communities. It is important to understand the relationship between humans and the built environment to create better systems that meet current and future needs, amend existing policies to adapt with new technologies, and plan for the future. Beside the opportunities V2I technology offers, it also raises challenges and concerns to communities that planners need to deal with. Many of these challenges and concerns can affect the city's design, impact the economy, and the social aspect of communities. This chapter focuses on answering research questions of What opportunities V2I technology will bring to local governments and communities? What effects will V2I apply on city design? What are the possible planning challenges and concerns V2I could bring to local governments and communities? What are the implications when a city fully depends on V2I technology? And how is V2I technology going to be implemented?

Opportunities

The idea of V2I technology is addressing problems related to the most used travel mode, which is automobile. Most cities around the world have become auto-oriented cities and focusing only on automobile and its infrastructures. This trend have led to supporting the automobile's industries the therefore the users of automobile. Thus, V2I technology have been developed to adjust that increase and reduce its consequences by connecting with automobiles. This connecting lay down opportunities to reduce negative impacts created by automobile and rebalance the transportation system (Crute et al., 2018), V2I opportunities include:

Improve Traffic Safety

Most automobile crashes happen because of human error. Many people tend to drive without being aware of surrounding vehicles, upcoming traffic signs and traffic lights. Thus, they become unintentionally involved in a crash. It has become necessary to involve technology to help drivers during their trips. As V2I technology sends messages to drivers, it is expected from drivers to follow the message immediately to be safe from upcoming events such as a work zone and pedestrians crossing an intersection (Crute et al., 2018). As the studies done in chapter 3 show, drivers act quickly when they received the message from the surrounding infrastructures. Informing drivers to be ready of possible crash would reduce the chance significantly. The concern is that people interaction with delivered messages is not guaranteed. Even though it may not cause a crash, but it can risky. It is important for automobile companies to create a noticeable inside warnings to ensure the clearness of warnings.

Increase Traffic Efficiency

As one of the main goals of the technology, V2I promise to positively affect the traffic efficiency. It aims to create safe driving environment by enhancing flows, harmonizing speeds, reducing congestions, and enhancing traffic light cycles. In addition, V2I technology with its applications help drivers to decide when accelerate and decelerate during their trip to minimize unpredicted and possible crashes. Daily traffic levels aren't the same. The morning shift is different from the afternoon shift for instance. Throughout collecting daily traffic levels for analysis, V2I system can adjust multiple aspects to fit every level of traffic. V2I technology's system take in consideration the number of automobiles in specific time, pedestrians, traffic light times, weather, and emergency to adjust speeds, suggest different routes for upcoming automobiles, and change different traffic lights timing (Crute et al., 2018). The technology can be used in areas that have a higher traffic rate such as Manhattan, NY.

Reduce Automobile Emission

Almost all of automobiles around the world run by fuel that burns inside the vehicle producing multiple types of emissions and harm the environment and the public health. The type of automobile, acceleration and deceleration, suggested speeds, and the weather are elements that can affect the process and the size of produced emissions. Beside the environment, emissions caused by automobile can endanger human's lives. When humans are exposed to automobile emissions, they would be threatened by respiratory diseases including asthma and lung cancer (Crayton & Meier, 2017). Areas where pedestrians are exposed to automobiles such as downtowns can be unhealthy and

unsustainable. Environmental applications fit in such areas to minimize the impact of automobiles' emissions. In addition, they can be used nearby hospitals and clinics to provide better environment and clear air for patients. In terms of zoning, the collection of data could be used to determine future locations of hospitals and industrial areas.

Improve Mobility for Pedestrians and Public Transit

In recent years, the increase of automobile has affected the overall mobility for pedestrians and public transit. Cities have focused on automobiles in the city design process which decreased the opportunities to plan for walkability and public transit. Cities have become auto oriented providing multiple parking options in land use, focusing on streets to improve access for automobiles, and decrease the safety and mobility needs for other travel modes. Therefore, people tend to use automobile rather than walking or riding the public transit. This process have laid disadvantages for pedestrians and public transit. It is difficult for low-level income population to purchase a vehicle or to ride a taxi daily. The emergence of V2I technology may change the priority of automobiles and rebalance all travel modes. V2I technology is expected to limit automobile interventions on pedestrians and public transit. Mixed land uses are expected to have a conflict of automobile users and other travel modes. The increase of automobile users would cause multiple negative impacts on pedestrians through exposing them to health concern, delaying on traffic intersections, endangering them in crosswalks, and taking more spaces for automobile needs such as parking lots rather than community or environmental needs. The role of V2I technology is to decrease these interventions by communicating with automobiles to inform drivers of pedestrians right-of-way and

process collected data to determine the actual needs of automobiles in specific areas (Sandt & Ownes, 2017).

A 2019 study done by NHTSA found that the age group of 50-59 years old has the highest rate of traffic fatalities (21%). They are the most endangered group from individual automobiles and light trucks crashes in the U.S. Almost 80% of these crashes happened in urban areas between 3-11:59 p.m. (NHTSA, 2019). As the numbers have increase from the last 10 years and more likely to increase in the future, applying V2I in urban areas has a high chance of reducing vehicle to pedestrians crashes and minimize the automobile risks.

The public transit, as second main travel mode, serves multiple categories of people who can own or drive automobile, low-income, people with disabilities, and young ages for instance. Negatively affecting the public transit such as buses would reduce these people's productivity and therefore their quality of life. As public buses share streets with automobiles, the increase of automobiles can cover the streets network making it hard for public buses to operate properly and move on schedule. Moreover, the lack of automobiles parking lots may affect public buses drop-off and pick-up points. As V2I mobility applications focus on automobile, they also support public buses by giving the right-of-way, prioritizing them at signalized intersections, and create harmony movements with automobiles. Additional potential applications that can be developed in the future would help public buses change routes based on the usage of streets, users' needs, and time schedules.

Beside impacting other travel modes, auto oriented design can be changed to be a design for multiple travel modes. Based on collected data, decreased demand on parking lots and gas stations in some cases would change the uses for other travel demands such as additional bike lanes and pedestrians facilities.

Parking Zones

Many land uses are required to have parking areas for automobile users. In some cities, parking has become an issue and there are not enough parking spots to fit the needs of the city's daily users. As V2I applications regulate automobiles drivers' behavior and balance travel modes, additional mobility applications can be developed to solve and reduce the problem of parking. Applications help drivers finding open parking spaces to save time. As V2I technology help automobile drivers, it can predict a potential parking space based on the route, the overall usage, the distance to the destination. Therefore, it may change the supply and demand for particular parking spaces (Elliott, 2017). In addition, throughout collecting data, V2I technology would produce real-time data on the parking usage and determine the shortage and the surplus of parking spaces. Planners can use V2I to study the current condition of parking areas and their usage to improve the zone ordinances for parking.

Permitted Building Forms

Collected data of vehicles in a particular area is important for shaping buildings (Henaghan, 2018). In dense places, such as downtowns, the need for on-street parking, drops-off, and pick-ups is usual. Based on collected data and V2I system advisory, planners can decrease or increase the square footage devoted to parking garages and on-

street parking. In addition, safety applications for pedestrians can reshape pavements. Traffic signal timing, vehicle to infrastructure and pedestrians accidents count, and pedestrians and cyclists densities would help developing new zoning ordinance for pathways and bike paths.

Land Use

As V2I technology aims for travel mode balancing, it protects pedestrians and bikers rights. It increases their safety by improving automobile drivers' awareness and supports their mobility by balancing the overall mobility and creating a better walkable environment. In addition to pedestrians, it supports the public transit by giving buses the priority in a signalized intersection to stay in schedule. Balancing travel modes would lead to converting unnecessary land uses such as unused parking garages and parking spaces to residential, commercial, and institutional uses to better serve local communities (Maurer et al., 2016). These changes on urban areas would create implications such as changes in densities.

Challenges and Concerns

Like many other technologies, applying V2I technology would reflect multiple challenges to planners to address. As planners navigate towards communities goals, they can use V2I technology to provide multiple benefits to the transportation network. To fully adapt the technology, local officials and planners are required to deal with challenges regarding increased VMT, privacy, the city's design, income sources, and social equity.

Privacy

Gaining people's trust may consider an issue in apply V2I. Privacy tends to be an important goal of local governments and planners need to ensure people's personal information. It is critical aspect and need to be maintained. As the technology develops around the world and people's lives are changing, many aspects of people's privacy can be affected. For example, social media is one of the most platforms that most people use daily. To be registered in social media websites, people are required to give their personal information for security and authenticity purposes. Educating people about V2I technology and its benefits, what type of needed information, how it's going to be collected, and most importantly for what purpose will elaborate how important it is to apply V2I technology.

V2I technology cannot operate properly without requesting information about vehicles. However, V2I can operate with requesting low level of personal data, meaning general information about the vehicle, such as location, automobile type, and weight, but not personal data, such as names and number of people in a vehicle. The biggest concern is to access people's locations. Not all people will accept showing their locations during their trips. To address this concern, local officials will have to explain the purpose of collecting people's locations for safety and mobility purposes and ensure the privacy by being accountable for any consequences.

A survey was done in 2018 by Otonomo, an automotive data services platform, regarding connected vehicle benefits. The target audience were a 100 automobile owners and new automobiles buyers. The survey's question focused on measuring the acceptance

of sharing data to gain the safety and mobility benefits offered by the connected vehicle system. Safety benefits include warnings about dangerous driving conditions, early detection of necessary maintenance, and faster response of an accidents. Mobility benefits include suggestion faster and efficient routs for gas station and charging stations, live-mapping, and available parking spots. Approximately 80% of the survey participants were very interested on gaining those benefits and share data. The result of the survey shows that there is a desire to improve the use of automobiles to have an efficient and safer mobility.

Glancy Stated (2012) that there are two types of privacy in vehicles. The first is type is a vehicle, such autonomous vehicles, that request all personal and vehicle data to process and analyze to make decisions. The second is a vehicle that interact with external network to provide information about weather, traffic signal, surrounding vehicles and pedestrians. Even though it requests low level of information, it tends to be risker than the first type because it deals with external network that can be a potential gap for the requested information to be leaked. It is a risky process that emphasizes the importance of creating a strong system that can protect vehicles' information.

Privacy Legislation

In recent years, many governments have begun enacting legislations to manage privacy in connected vehicles. For example, The United Kingdom and Germany have established privacy guidelines for On-board equipment and autonomous vehicles manufacturers to follow. China and Japan have also amended their privacy legislations to protect people's information and require customer consent and transparency from

automobile companies and network operators about the purpose, technique, and the use of data (Lim & Teaihagh, 2018).

In the U.S., several states have amended privacy legislation regarding autonomous and connected vehicles. Similar to V2I technology, autonomous vehicles also request personal information to process inside the vehicle to drive or to help the driver in making decisions. One of the common requirements in state legislation for autonomous vehicles is to make full disclosure to passengers regarding what information is being collected and for what purpose.

Even though USDOT have set policies on not collecting any personal information when applying V2I technology, V2I still have the option to allow collecting personal information. In some cases, collecting personal information for a specific type of V2I application may be optional for pedestrians and drivers to improve the decision-making process. However, this process can endanger people's privacy. In 2019, Booz Allen Hamilton, an information technology consulting company, developed six recommendations to connected vehicle stakeholders to increase the security of collected personal information. These recommendations include:

- Transparency: Create effective privacy policy on how the information is being collected, used, and shared.
- Choice: Obtain consumers agreements before collecting, using, and sharing their personal information.
- Respect for the Context: Limit the use of people's personal information to the reasons that are related to the proposed goals of the project.

    - Speed and location.

- Data Security: Protect personal information from manipulation and ensure security with the third party. In addition, allow consumers to change, update, and delete their personal information safely.
- Accountability: Create mechanisms to ensure that connected vehicle stakeholders are held accountable for any damage to people's privacy.

Potential for Increased VMT

V2I technology offers advices that can potentially increase VMT. In a dense place, V2I aims to reduce congestions, adjust speeds, and find more efficient routes for automobiles users. These benefits would lead to more travel demands on alternative routes in rush hour cases. Therefore, more congestions and emissions may increase despite the improvements in efficiency (Ganson, 2018). In addition, efficient mobility in automobile will more likely create more trips. Automobile drivers may have more interests in mobility benefits and drive more. While the expected impact from V2I is to slightly decrease automobile users by balancing travel modes, it is not guaranteed. This issue would require additional policies regarding the use of automobile in dense areas.

Impact on Public Health

Even though V2I technology can reduce air emissions, increase safety for pedestrians, and significantly decrease automobile crashes, it still can endanger people's lives. As V2I technology depends on specific algorithms to process decisions, potential errors in the proposed algorithm would threaten drivers and pedestrians' safety (Ganson, 2018). It is important to apply the appropriate algorithms and ensure the transmission of

algorithms for each daily event such as rush hours, special events, and regular daily traffic. Public health issues increase in areas with high densities, industrial areas, and areas with difficult weather environment. Beside mobility and safety applications, it is important to apply Eco-friendly applications in these areas to enhance the public health and increase safety. In addition, a total count on technologies isn't safe when it comes to controlling transportation system, especially if the system is breakable, has weak protection, and work unstably. The decision-making process can be damaged and create multiple false messages to drivers and unintendedly cause safety issues. Multiple problems can affect the way V2I system operate that can end up affecting people's health, safety, and welfare of drivers and pedestrians.

Social Equity and Access

Connected vehicle's concept is relatively new in transportation planning. V2I technology can improve people's opportunities to travel but impact equity negatively. In terms of cost, introducing V2I and its equipment can be costly to a community and will create issues regarding the cost of a vehicle. In addition, vehicles with no equipment would have to install On-board equipment in order to work with V2I technology. In this segment, V2I limits travelers who use automobile unless it has On-board equipment which means V2I technology favors higher income over lower income users. The impacted low-income population would not benefit from the technology. It could limit their access to their destinations. Darnell Grisby, the research director of the American Public Transit, stated (2017) that limiting the access to traveling opportunities would create pressure on public transit. Public transit, as the backbone of transportation for low income groups, can be affected by applying policies about vehicles being connected.

From another angle, communities differ in the most chosen travel mode and the cost of traveling. Thus, applying V2I will require more studies of communities, their income level, access opportunities, and the most favorable travel mode beyond just studying the transportation issues that V2I technology will be applied for.

Another aspect that has a high chance of impacting jobs is how V2I and help introduce autonomous vehicles faster. Deploying V2I technology shows many unknown issues in terms of specific details about OBU and RSU devices, technical issues, system performance, and developing algorithms. V2I experiments have speeded up the process for automobile companies to create autonomous vehicles faster than before. As autonomous vehicles make better results when connecting with surrounding infrastructure to help with driving, it can negatively impact the labor pool of a city (Schweitzer, 2016). Many jobs and occupations, such as taxi and bus drivers, would be on the raise in some centuries and autonomous vehicles can impact that raise by replacing people with robots. Goods delivers for instance is one the most impacted occupations that may disappear. Even though it may be more efficient, many jobs will be replaced with robots that limit income sources for people and increase unemployment rate.

Revenue Sources

Many cities have high revenue percentages from automobile violations such as running a red light and speed. When V2I technology is applied, violations are expected to significantly decrease because of the safety and mobility applications drivers will follow (Maciag, 2017). Even though it is a positive impact, it negatively affects local governments' budget. V2I technology is expected to reduce the need of traffic

enforcement. As automobile drivers receive notifications from V2I about efficient routes to take, red light signals, eco-friendly speeds, and parking options, the revenues from traffic citations, gas taxes, and parking would likely to decrease.

Implications on the Built Environment

As V2I technology will likely change the way people travel, it will have a profound impact on people's lives and the build environment. V2I open the door to reshaping the community by studying its behavior and its reflect on the build environment. As there will be a long transition period where other travel modes share the road with automobiles properly, it is important give attention to the process of change and its effects on the community.

Street Design

As the adaption of V2I technology increase in scale, it will likely to change the needs of roads and will increase the efficiency of automobile right-of-ways. As V2I technology collects data about daily traffic, it may give opportunities to change the design of streets. As some streets would have fewer drivers than what it has been expected, they can be redesigned to reduce lanes or change their sizes to meet its capacity (Sohrweide, 2018). Increasing the scale of area covered by V2I will cover multiple types of streets and vehicles. Beside individual automobiles, commercial trucks and industrial trucks can be covered and they can potentially impact the safety of automobile drivers. Planners can take in consideration the entrance road points where commercial and industrial trucks merge with individual automobile to improve the process of merging in and out of the road.

Signage and Signalization

The revolution V2I brings to the build environment may make changes on how the information is being delivered. Intersections are designed to have traffic lights and signs. As the technology move to digitally transform messages to drivers, traffic lights and signs can be removed or decreased (Crute et al., 2018). Automobile drivers would mainly depend on V2I to driver on roads and between intersections. In addition, the combination of automated and connected automobiles may revolutionize how intersections function and designed. Digitizing traffic and roads signs would make the process of street making easier and could help create urban spaces.

Redevelopment Opportunities

V2I efforts to reduce automobile crashes and increase accessibility and safety for other travel modes will lead to automobile users reduction. The automobile reduction will reflect multiple opportunities for new developments replacing auto oriented developments (Crute et al., 2018). As people move to choose other travel modes such as public transit and bikes as main travel modes, the unused parking spaces and garages can be replaced to serve the community. One example is university campus. As students find it safe to walk and efficient to ride the public transit, the university could replace parking garages to green spaces or missing amenity.

Applying V2I technology

Preparing for technology that could make rapid changes in communities would require preparations on all scales, federal, state, and local, regrading policies, laws, and regulations. As technologies have become highly considered to solve planning issues in

recent years, local government will need to address formal regulations on how technologies integrate with communities. Throughout studying the opportunities, challenges, and implications of V2I technology, planners would have primary ideas of the transition process. Examples include new approaches to redesign zone ordinance and developing new income sources. All suggested methods and tools by planners should take in consideration community goals to increase the success rate of applying the technology and maximize the benefits. The following process of applying V2I technology will move through several phases, starting with planning phase, implementation phase, and maintaining phase (Henaghan, 2018). Each phase require a period of time to be completed.

- **Planning Stage (12-18 months)**

The planning stage focuses primarily on studying the problem that justifies the use of V2I technology. It involves studies relate to the issue such as the community components, land use, economic impacts, and other factor that can be potentially impacted by the issue. The planning stage is very critical because it determines the scale of the impact and proposes the needs. In addition to defining the problem, the planning stage need to develop the following subjects:

  - Community vision and future goals.

    Local officials and planners would have to conduct several meetings with the residents and stakeholders to discuss future goals and proposed solutions. As cities differ in laws and regulations, planners meetings with the public regarding applying V2I technology can come up with decisions

that fit each community. For example, discussing the size of the deployment, privacy level, and future changes in land use.

- **Plan Making**
  - Comprehensive Plan

    Describe long-term goals and address potential changes regarding transportation network, land use, and the design of the build environment. In addition, introduce the technology and what benefits it can provide to the public.
  - Functional Plan

    Focuses on the issue and describe in detail how V2I technology will solve or reduce the impact. This step should include details about how V2I is going to be implemented, concept design, what applications will be used, the data collection methods, and how the information is going to be used. In addition, planners can set objectives to adapt with future transportation changes such as developing a plan to replace conventional signs and traffic signals with connected infrastructure covering all travel modes.
- **Time Frame.**

  Planners need to adjust community vision and goals with specific timeline to adapt and minimize the impacts. For example, it could be better to apply V2I technology in several steps to overcome unpredicted issues and prepare for the next wave of the deployment. Because it can make rapid

changes to communities, flexible timeline is encouraged to adapt with unpredicted challenges.

- Setting New Regulations and Standards

  Before next stage, planners should set necessary regulations and standards that help implementing the community goals for V2I technology. In general, the governmental policy making on V2I technology is still early stages. Planners can consider reviewing the community's regulatory systems to identify opportunities to maximize the community benefits.

  - Examples include:
    - Land use: Amend current land use regulations with more flexibility to accommodate new uses.
    - Street Standards: Replace vehicular level of service standards with all travel modes standards.

- **Implementation Stage (up to 20 months)**

  The implementation stage focuses on the readiness of the system to be deployed. After reviewing the integration process (including changes in the built environment and community awareness), suggested policies, the objectives, and time frame, the V2I project can be implemented through several levels to adapt with future changes.

  - Site Design and Development.

    Planners need to consider the community goals in the implementation stage. After applying V2I technology, several changes in the land uses and the build environment would be applied, and planners need to develop

strategies to maximize the benefits of the transition. Planners need to consider the following:

- Missing amenities such as open spaces and parks.
- Provide more accessibility for pedestrians and public transit.
- Increase/decrease density levels.
- Increase safety for pedestrians network.

- **Maintenance Stage**

Finishing planning and implementation stages of V2I technology requires maintaining the process of the project to ensure the quality and stability of the transition phase to fully connected vehicles. The maintenance stage also ensure the efficiency of V2I devices and the system to run the operation properly.

Conclusion

The deployment of V2I technology is expected to change and create new policies and regulations. It is important for federal, state, and local government to address legislations regarding land use and transportation to shape V2I future changes into methods to improve communities. Since nothing of future changes is definite, testing V2I technology in the built environment would create more evidences. Many problems at early stages still in progress to be solved. Moreover, problems include the increase of VMT and equity of travel still unresolved. Local officials and planners need to study alternative solutions beside V2I technology to address these issues in the future.

Other technical issues include the security of the system, and the collected data and the readiness of RSU and OBU devices. V2I technology would still face threats of

cyberattacks. The communication between automobiles and V2I system is exposed to external intervention which opens a gap to the connection for hackers.

In general, planners need to be aware that the total dependence on technology to do major roles in transportation isn't always efficient and requires human interventions. Ensuring the system proper planned introduction and participation by all stakeholders in the process would increase the chance of reaching the communities' goals.

Chapter 6: Recommendations

Along all transportation technologies, V2I technology creates a combination of safety, mobility, and environment benefits. The expectations from USDOT, local transportation departments, and technologies institutions are in the process to be proven by the current pilots projects in the United States that started in 2015 in Manhattan, NY, Tampa, FL, and Wyoming. These pilots will provide key points in the process of deploying V2I technology and its challenges. The cases of Manhattan, NY, Tampa, FL, and Wyoming have been going through similar processes of deploying V2I. Most problems that have showed up in the field were technical. These problems are still in the process of being resolved. In addition to the pilots, the University college of Dublin and the Innovative Transportation Research Institute in Houston, Texas have proved, by their suggested algorithms, that V2I technology is capable of delivering the mobility and the environmental benefits. In general, V2I technology is promising to change many aspects of cities if applied. Reviewed planning journals stated that V2I technology will more likely make changes in different scales in zone ordinance, streets design, economy, and policies and regulations regarding density and land use permits. The following suggested recommendations are from the selected case studies and planning journals:

- All pilots that have been conducted by USDOT and local transportation departments have a certain number of participants that will most likely increase. It is important to include the public in the first stages of a deployment and educate the public about the technology and what can it do. In addition, give them the opportunity to prepare for the event. For example, creating public events and meets describing what is the technology, how it is going to be implemented, their

role in the experiment, and things that they need to be aware of during the experiment.

    - Serval ways to recruit participants are local websites, digital outreach materials, and automatic calls and messages, which is encouraged to continue for the full duration of the pilot.

- As the study done by the Transportations Institution in Taxes shows, it is important to study when the receivers are going to receive the notification to prepare for the action. For example, local governments need to consider the distance to the curve or the work zone and speed to decide on the time of the notification.
- The selection of roadside unit locations is an important aspect of any V2I project and has a huge impact on the results. Roadside units are basically constrained by power, line-of-sight abilities, network, and infrastructure. Also, aspects such as goals, cost, shortage of suppliers need to be considered as well. The pilot of Tampa, FL has assigned different V2I applications in different locations based on the need. For example, a number of Transit Signal Priority has been used in the most affected areas where public buses usually get behind the schedule. The nearby areas don’t have the application because they weren’t delaying public buses.
- The deployment of V2I technology is still in the first stages. Therefore, maintain the existing road signs to back up the technical errors of V2I system and roadside units hardware it essential. The safety and mobility application in Wyoming pilot still face technical problems. These problems stopped safety messages to drivers

and sometimes gave drivers wrong messages. Maintaining the conventional traffic signs on the road helps avoiding V2I technical issues.

- Tampa pilot has created infrastructures to install End of Ramp Deceleration Warning and Wrong Way Entry RSU. For the problem of delay in Lee Roy Selmon Expressway's Reversible Express Lanes, these applications were installed in specific places to have a better vision of upcoming automobiles and calculate their number to analyze. It is important to create new infrastructure for V2I equipment to improve its efficiency.
    - Sometimes, an infrastructure can face higher use than normal, additional infrastructure would assist with the heavy usage.
- The problem-solving process can be faster when local governments are aware and knowledgeable about the transportation technologies companies and vendors to maximize the benefits and reduce the cost. Problems such as the unreliable GPS location in Manhattan can be focused on by technology institutions and companies to be solved. In addition, involving and supporting the market would lay down benefits on the V2I equipment in terms of cost and quality. The increase in market penetration would create opportunities for a better V2I system.
- To have a better and more accurate results, it is important to not exclude any type of vehicle or any user of other travel modes in the study area. Even though it is a challenge to have all participants install the necessary equipment, it is important to include all users in V2I to operate properly.
    - The V2I system should be aware of all users moving in an area to get a better observation. Therefore, the calculation and the analysis would

create better results in terms of speed harmony, traffic signal timing, and the safety of pedestrians.

- Be active with vendors to provide equipment, replacements, and maintenance in a short time. Every pilot project USDOT is doing, with the effort of other local transportation departments, has been facing unfixed technical problems regarding V2I hardware. Hardware problems were common while installing and testing. Late communication with vendors resulted in testing delay and wasting time and effort on unequipped vehicle on the test field. It is highly recommended to create a collaborative environment of different suppliers to adjust with unexpected situations. An early search of vendors and agreements would help speed up the process of building and implementing the software and hardware of V2I.
- To have a better understanding of the results, it is important to have an up-to-date data collection pre the deployment of V2I to compare with collected data after deploying V2I technology. Both studies of the University college of Dublin and the Innovative Transportation Research Institute in Houston, Texas have used before-and-after analysis to better understand the results. Comparing two data will elaborate how effective V2I is in terms of solving a particular problem or reducing a particular impact.
- As V2I technology has to chance to bring opportunities to change zone ordinance, it is important to develop legislations to address potential changes on land use, transportation network, and future technologies such as autonomous vehicles.

- As the changes on land use, transportation network, and the built environment are expected, multiple policies and regulation could be integrated to maximize the benefits and help achieve communities' goals.
    - In terms of land use regulations, unused parking spaces and garages can be replaced with missing amenities for the communities. In addition, policies regarding densities and land use changes can be adjusted to fit the needs and maximize the benefits.
    - Planners can offer more safety walkability options throughout redesigning the standards of walking paths and intersections crosswalk. In addition, policies regarding planting trees instead of unnecessary parking spaces can be considered to increase the safety of pedestrians.

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