pennsylvania
DEPARTMENT OF TRANSPORTATION

Connected and Autonomous Vehicles 2040 Vision

FINAL REPORT

July 10, 2014

By Chris Hendrickson, Allen Biehler, Yeganeh Mashayekh
Carnegie Mellon University

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

CONTRACT # CMUIGA2012
WORK ORDER # CMU 1

Technical Report Documentation Page

1. Report No. FHWA-PA-2014-004-CMU WO 1	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Connected and Autonomous Vehicles 2040 Vision	**5. Report Date** July 10, 2014 **6. Performing Organization Code**
7. Author(s) **Yeganeh Mashayekh, Allen Biehler and Chris Hendrickson**	**8. Performing Organization Report No.** FHWA-PA-2014-004-CMU WO 1
9. Performing Organization Name and Address Carnegie Mellon University 5000 Forbes Avenue Pittsburgh, PA 15213	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** **CMUIGA2012 - CMU WO 1**
12. Sponsoring Agency Name and Address The Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064	**13. Type of Report and Period Covered** Final Report: July 11, 2013 to July 10, 2014 **14. Sponsoring Agency Code**

15. Supplementary Notes

N/A

16. Abstract

The Pennsylvania Department of Transportation (PennDOT) commissioned a one-year project, Connected and Autonomous Vehicles 2040 Vision, with researchers at Carnegie Mellon University (CMU) to assess the implications of connected and autonomous vehicles on the management and operation of the state's surface transportation system. This report explores the impacts of connected and autonomous vehicles on design and investment decisions, communication devices investment, real-time data usage, existing infrastructure, workforce training needs, driver licensing and freight flow as they relate to PennDOT. For each of these areas, a set of recommendations has been provided. As connected and autonomous technologies are advancing, it is recommended that PennDOT take these actions in a timely manner. A timeline for the recommended actions has been provided to help PennDOT plan accordingly. The timelines are based on current available information and the time frames are likely to change over time.

17. Key Words Vehicle Automation, Automated Highway, Connected Vehicles, Autonomous Vehicles	**18. Distribution Statement** No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 163 (70 pages excluding appendix)	**22. Price** **N/A**

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

Table of Contents

List of Figures

List of Tables

Executive Summary

The Pennsylvania Department of Transportation (PennDOT) commissioned a one-year project, Connected and Autonomous Vehicles 2040 Vision, with researchers at Carnegie Mellon University (CMU) to assess the implications of connected and autonomous vehicles on the management and operation of the state's surface transportation system. This report explores the impacts of connected and autonomous vehicles on design and investment decisions, communication devices investment, real-time data usage, existing infrastructure, workforce training needs, driver licensing and freight flow as they relate to PennDOT.

Findings of this report are based on an assumed condition that connected and autonomous technology will be incorporated into all motor vehicles by 2040. While the actual date for full incorporation will depend on the pace and scale of connected and autonomous technology adoption, the assumed 2040 date in this report provides context for PennDOT decision makers facing a future involving these vehicles.

Design and Infrastructure Investment

Design and investment decisions related to ITS message signs, radio advisories, lane capacity, clear zones, width of lanes and medians, and traffic signals are disaggregated into groups of connected, autonomous and connected automated environments. There are numerous uncertainties that make design and investment decisions related to lane capacity and highway right-of-way cross-section challenging including:

- Lack of research and demonstration data,
- Travel demand may change significantly,
- Market penetration of new technology,
- Transit demand,
- Shape and weight of vehicles,
- Induced demand due to less onerous driving, and
- Modal shifts of freight and passengers.

Nonetheless, it is recommended that PennDOT reevaluate any planned or potential capacity enhancement project prior to making final investment decisions on those projects. For instance adding roadway capacity through widening may not be necessary by the year 2040 as a result of connected and fully automated driving. In relation to ITS message signs, radio advisories, and traffic signals the following recommendations and immediate action items are proposed:

- Evaluating all upcoming ITS related investments and capacity/LOS enhancement projects to be compatible with a connected and automated vehicle fleet.
- Identifying key locations for connectivity.
- Funding and deployment of Dedicated Short Range Communication (DSRC) and roadside units

- Deciding on when to send traveler information to the cloud
- Working with the private sector to deploy vehicle to other devices (V2X) applications

As technologies advance PennDOT will need to follow market driven forces while being cautious with new investment decisions that could interfere with vehicle to infrastructure (V2I) deployment and technologies. Guidance on V2I deployment will be provided by US DOT by the year 2015.

Communication Device Investment

PennDOT's communication device investments will mostly relate to V2I applications. These applications include but are not limited to stop sign violation, red light violation, queue warning and speed harmonization. Mobility applications will likely use cellular technology, which will need minimal investment from PennDOT. Collaboration and partnership with the private sector and companies that convert data into information, then transmit them to users, is a crucial step for PennDOT to promote and deploy connected and autonomous technologies.

Safety applications will rely more heavily on DSRC technology. Therefore V2I safety applications will need communication device investments. Near term initial steps PennDOT may take to enhance safety and mobility through V2I DSRC enabled technologies are:

- Identifying locations for roadside units that would generate substantial safety and/or mobility benefits such as high crash intersections, narrow roads, tunnels and sharp curves.
- Identifying traffic signal systems and other ITS locations (e.g. toll facilities, ramps) that would need equipment (i.e. controller) upgrades.
- Collaborating/partnering with private companies to enhance data sharing capabilities.

Real Time Data

Real time data on parking availability, congestion and weather conditions can be transmitted between vehicles, roadside units and traffic management centers. Real time data must first be converted into meaningful information to help users (i.e. transportation managers, drivers, transit operators and driverless vehicles) make decisions on transit routing, traffic management and regional traveler information. In order to provide real time data through various mobility applications the following investments will likely be needed:

- Signal equipment and traffic management center upgrades,
- Roadside units (DSRC),
- Roadside interface with local systems (DSRC),
- Backhaul communication,
- Mapping systems,

- Data management , and
- Security network compatibility.

While core policy issues such as governance, privacy, and liability are being dealt with at a national level, it is recommended that PennDOT examine approaches to expedite deployment of connected and autonomous vehicles in Pennsylvania. To aid deployment, PennDOT could identify available datasets for useful distribution as well as identifying priority applications that are less costly and less labor intensive to deploy. Small scale deployments focused on PennDOT's immediate or near-term needs would assure a high level of performance in addition to providing real-life scenarios that could be beneficial for large scale deployments.

Workforce Training

Workforce training needs are typically addressed by third party programs and certifications such as professional institutions (e.g. Institute of Transportation Engineers), community colleges, trade schools and universities (e.g. Indiana University of Pennsylvania), and government agencies (e.g. U.S. DOT). Therefore, PennDOT is not expected to have direct impact on the anticipated changes to any of the third party programs. The only exception is training offered by PennDOT for driver's license examiners, which needs to be updated as vehicle automation evolves. It is recommended that PennDOT encourage its transportation practitioners to participate in appropriate training programs, seminars and workshops to advance their knowledge on the field of vehicle automation. Workforce preparation through training will have significant impacts on the smooth and efficient transition to connected and automated environment. In addition, PennDOT's collaboration with local entities and institutions that offer training on vehicle automation will be important to enhance workforce training.

Driver Licensing

Changes to driver's license issues and training to accommodate automation for the design year of 2040 will be incremental. Therefore driver's license training should be updated according to each level of automation between now and 2040. It is anticipated that fully self driving vehicles (level 4 automation) would need zero to minimal involvement from drivers. Simulators will be effective tools to use for training purposes as they can be adjusted to various levels of automation. Basic familiarity with electronic assist features as well as required interactions between drivers and vehicles should be included in both knowledge and skill testing criteria. Assuming Level 4 automation will need no contribution from drivers in the year 2040, allowances can be made for use by at least some drivers who are currently restricted due to medical impairments or age.

Licensing for commercial drivers should generally parallel license changes for the general population. However, some special skills may be considered, such as commercial drivers leading and managing platoons of vehicles on general purpose roadways or specialized truck lanes.

Freight Flow

With regard to specific PennDOT changes for freight transportation, this report makes several recommendations:

1. During the Automated Permit and Route Analysis System (APRAS) update for over-height and overweight vehicles, PennDOT should consider the numerous opportunities connected and autonomous vehicle capabilities will present. The update is also an opportunity for PennDOT to work with the trucking industry and State Police to design features tailored to these stakeholders. Both enforcement and freight movement will be significantly enhanced as a result of an improved APRAS. Specifically, PennDOT should take the opportunity of the APRAS system update to include local regulators, to make real time re-routing possible and to ensure routes are followed as required.
2. PennDOT should ensure that information on overweight/oversize equipment movements be made available to connected vehicles in the vicinity of such movements as connected vehicles begin to appear.
3. PennDOT should encourage the availability of electronic driver logs in commercial vehicles for providing data on commercial vehicle movements and for apportioning federal diesel fuel tax revenues.
4. Specialized freight infrastructure such as over-height warnings and weigh stations can be phased out by PennDOT as new technology for connectivity and weigh-in-motion is introduced.
5. Most policy decisions related to freight and automation are in the hands of federal regulators and private operators and will not be impacted by PennDOT. However, PennDOT can play a significant role in moving the industry towards automation by providing test beds and insuring that information on incidents and overweight/oversize vehicle movements is available to connected vehicles.

Implementation Timeframe

The following figure provides a timeline for the actions recommended in this report to help PennDOT plan accordingly. The timelines are based on current available information and the time frames are likely to change over time. The timelines in the figure should be updated frequently as connected and autonomous technologies advance.

2014 - 2020

2014-2016

- Thorough evaluation of all existing and planned capacity/LOS enhancement and ITS related investments.
- Collaboration with private sector to convert data into information for sending to cloud.
- Prioritization of safety and mobility applications.
- Identification and prioritization of key locations for DSRC and roadside equipment deployment.
- Funding allocation for DSRC and roadside units.

2015: FHWA Guidance to V2I Deployment

2016-2020

- Upgrading signal controllers, equipment and firmware where necessary.
- Early small-scale deployment of V2I applications at key locations.

2021 - 2030

- Collaboration with local and state educational institutions to enhance workforce training.
- Update of testing criteria for level 3 automation.
- Design of driver licensing training for emergency situations, system malfunctions, regulations and human interaction levels.
- Work with the trucking industry and State Police to design features tailored to these stakeholders.
- Deployment expansions – large scale deployment of equipment and applications.

2031 - 2040

- Provisions for a new license class for those wishing to drive their manual cars.
- Dedicating some highway lanes to autonomous vehicle use.
- Reconfiguration and repurposing of the lanes.
- Phasing out the freight infrastructure (e.g. over-height warnings, weigh stations) as new technologies are introduced.

Recommended Timeframe for PennDOT's Actions with regards to Connected and Autonomous Vehicles

Project Overview

The Pennsylvania Department of Transportation (PennDOT) commissioned a one-year project with researchers at Carnegie Mellon University (CMU) to assess the implications of connected and autonomous vehicles on the management and operation of the state's surface transportation system.

Connected vehicle research within the U.S. Department of Transportation (US DOT) is a multimodal program that involves implementing wireless communication between vehicles, infrastructure, and personal communication devices to improve safety, mobility, and environmental sustainability. Simultaneously, the U.S. DOT has begun researching the implications of autonomous technology, including fully automated vehicles.

This research study is based on the assumption that connected and autonomous vehicle technology will be incorporated into all motor vehicles, including automobiles, freight trucks, and transit buses. Using a design year of 2040, this research evaluates implications on the highway infrastructure within the Pittsburgh region in southwestern Pennsylvania. In addition, the study assumed that the Mon-Fayette Expressway and the Southern Beltway have been fully constructed, with the exception of SR 0051 to Pittsburgh.

Implementation of connected and autonomous vehicle technology will produce a shift in the decision making process regarding existing and planned transportation infrastructure. Additionally, the automation of road vehicles is accelerating, catalyzed by substantial private investment, successful demonstrations and significant public discussion. The Pennsylvania Department of Transportation wishes to understand how these new technologies will change their approach to designing, managing and operating existing and planned transportation infrastructure. This research report includes eight tasks:

- Task 1: Connected and Autonomous Vehicles Experts workshop (Appendix)
- Task 2: Impacts to Design and Investment Decisions
- Task 3: Real-Time Data Usage
- Task 4: Impacts to Existing Infrastructure
- Task 5: Impacts to Workforce Training Needs
- Task 6: Impacts to Driver Licensing
- Task 7: Impacts to Communication Devices Investments
- Task 8: Impacts to Freight Flow

Tasks 9 and 10 of the project represent submission of the draft final report and the project final report.

Introduction

Connected and autonomous vehicle technologies have the potential to significantly change surface transportation as we know it today. Externalities associated with driving including accidents, traffic congestion, air pollution, greenhouse gas emissions and energy consumption may significantly diminish as connected and autonomous vehicle technologies are introduced. The design of metropolitan regions could potentially change with automated technologies, especially self-driving vehicles. Potential design changes could among many other factors affect land use planning, demand management, incentive and restriction strategies (i.e. time of day, vehicle size), parking enforcement, freight station management and load sharing strategies. Transportation agencies play a significant role in adoption and adaptation of these technologies. As connected and autonomous vehicles enter the marketplace, public sector stakeholders need to be able to efficiently manage these technologies to assure the highest level of benefits resulting from the implementation and deployment of the technologies.

This report assesses impacts of connected and autonomous vehicles on various issues including design, investment decisions, real-time data usage, existing infrastructure, communication devices investments, workforce training needs, driver licensing and freight as they relate to PennDOT. It is important to note that issues related to connected and autonomous technologies affecting surface transportation cover an extremely broad range of topics. To stay within the scope of this project however, the report mainly focuses on issues and impacts that relate to PennDOT decision making and operations. To address impacts, consistent with the scope, where applicable three different scenarios were assumed:

1) Fully connected light duty vehicle and infrastructure environment (vehicle to vehicle V2V and vehicle to infrastructure V2I communication capabilities)
2) Fully autonomous light duty vehicle environment (in the absence of connectivity)
3) Connected automated light duty vehicle environment (more plausible given the design year of 2040)

Background

Connected Vehicles versus Autonomous Vehicles

Connected vehicles use wireless technology to connect vehicles' information and locations to one another (V2V), to infrastructure (V2I) or to other modes such as internet clouds, pedestrians and bicyclists (V2X). The wireless technology typically used for connected vehicles is dedicated short range communication (DSRC) or cellular, although other types such as Satellite or Fiber might be possible too. In the case of vehicle to infrastructure (V2I), vehicle information and location (e.g. latitude, longitude, brake status, length, width) are communicated with cell towers or DSRC roadside units. Other types of information such as traffic information, signal phase and timing, speed limit and parking information are communicated from traffic management centers (TMC) to roadside units and the onboard units (OBU) inside the vehicles.

Cellular technology is currently available to be used for V2V and V2I technologies. On February 3, 2014, the U.S. National Highway Traffic Safety Administration (NHTSA) announced a decision to move forward with incorporation of required V2V technologies on light duty vehicles, which will likely result in the use of DSRC for connected vehicles (NHTSA 2014). The primary purpose of this decision is to enable collision warnings to drivers prior to a crash. An implementation timeframe is uncertain as it will first require a public comment and rulemaking process.

Autonomous vehicles do not necessarily need to communicate with other vehicles or infrastructure; hence DSRC or cellular technology is not required for such vehicles. Autonomous vehicles are typically equipped with standalone sensors and cameras that allow for some or all aspects of safety features of the vehicle to function without direct driver input or interference. NHTSA defines five levels of vehicle automation described as follows (NHTSA 2013):

Level 0: No Automation assumes the driver is in complete and sole control of the vehicle and all of its functions (e.g. brake, throttle, steering) at all times. The driver is responsible for monitoring the roadway and for safe operation of all vehicle controls. Only warning systems such as those for speed limits and blind spots are included. Most connected vehicle safety applications fall under this category.

Level 1: Function Specific Automation includes systems such as adaptive cruise control or collision detection braking. One or more control functions may be automated, although they operate independently from one another. The driver needs to be in full control and is responsible for safe operation of the vehicle. Automated steering or braking controls may assist the driver. The driver can choose to cede limited authority over specific functions as in adaptive cruise control.

Level 2 Combined Function Automation involves automation of at least two primary control functions (e.g.: adaptive cruise control in combination with lane-keeping). The driver is still responsible for roadway monitoring and safe operation and is expected to take control on short notice. Vehicle platooning, where groups of vehicles travel together at close distances to increase efficiency, is possible. Because the degree of savings possible via platooning depends on the portion of vehicles on the roadway capable of platooning, we examine both low and high penetration scenarios.

Level 3 Limited Self-Driving Automation allows the driver to cede full control of the vehicle under certain traffic or environmental conditions.

Level 4 Full Self-Driving Automation allows the driver to cede full control of the vehicle under all conditions and may include vehicles that can drive themselves without occupants.

Since currently some varying definitions of some of the vehicle automation terminologies exist, given that the scope of this project specifies connected and autonomous vehicles, it is important to clarify and differentiate between "autonomous vehicles" and "vehicle automation". NHTSA levels defined above are specific to "vehicle automation", in which suggests that some processes are controlled automatically and not manually; whereas "autonomous" generally is synonymous with "self-driving" and refers to a vehicle that acts independently sometimes or all the time (NHTSA Level 3 and Level 4). In this report, "autonomous" always refers to "driverless vehicles" and "automation" is a broader umbrella category. In other words, autonomous vehicles are a subset of automated vehicles. This is also consistent with Webster's dictionary definitions (Merriam-Webster 2014):

au·ton·o·mous (*adjective*): Acting independently or having the freedom to do so.

au·to·ma·tion (*noun*): The automatic operation or control of equipment, a process, or a system.

The scope of this project specifies "autonomous vehicles" with the design year of 2040. Furthermore, the scope suggests that this research study is based on the assumption that connected and autonomous vehicle technologies will be incorporated into all motor vehicles, including automobiles, freight trucks, and transit buses. Although we acknowledge that the process towards "autonomous vehicles" is a gradual one, for this project our main focus will be based on the above requested assumption, which entails NHTSA automation Level 3 and Level 4. Issues such as transition and mixed-fleets will not be assessed as part of this project. Issues relevant to timing and when PennDOT should begin to make different decisions with respect to the connected and automated technologies will be discussed as part of each task topic where relevant.

There is a wide range of predictions on the deployment timeframe and penetration through vehicle sales of connected and autonomous vehicles. Tesla Motors has announced plans to produce autonomous vehicles in three years, and Nissan plans to introduce an autonomous vehicle by 2020 (Carrol 2013, Stenquist 2013), but US DOT and its NHTSA are more conservative in their deployment timeframe predictions. Level 1 and 2 automation features are becoming more common in new vehicles, with more than a dozen auto manufacturers offering various safety warning systems such as lane keeping warning and speed limit warning. Adaptive cruise control is already available from more than a dozen vehicle manufacturers including, but not limited to, Cadillac, Acura, Toyota, BMW and Mercedes. Other company and research institutions are aggressively working on fully automated prototypes. Google Inc. just publicized its new autonomous prototype hoping to prepare public for the new technology (Tech News World 2014). Predictions are showing that vehicles with provisions for driver control will hit market in 2025 followed by fully autonomous vehicles in 2030 (IHS 2014). Furthermore, IHS forecasts show total sales of autonomous vehicles will increase from 230,000 in 2025, to 11.8 million in 2035. After 2050 nearly all vehicles in use will be autonomous according to IHS (IHS 2014).

While private industry is more aggressive with their announced timeframe, government in general is taking a more conservative approach towards deployment and implementation of connected and autonomous technologies. Nonetheless, if the automotive industry moves as aggressively as they have over the last few years, the automated features installed on vehicles may be fully designed as standalone features without dependence on any changes to the existing infrastructure, standards or design criteria. Autonomous vehicles are being tested today to assure they would work flawlessly with the current design standards and criteria and within the existing infrastructure environment.

Potential Impacts of Autonomous Vehicles – Levels 3 and 4

With the introduction of levels 3 and 4 automation, drivers will be able to cede control of the vehicle, either under some conditions (Level 3) or under all conditions (Level 4). While a number of automobile manufacturing companies and research institutions are examining these advanced levels of automation and testing their driverless vehicles, per NHTSA's guidelines, levels 3 and 4 automation are not yet allowed on the U.S. public roads for reasons other than testing. Therefore there is no real world data on the advanced levels of automation that can be used for impact analysis. Perhaps more importantly, driverless vehicles constitute a paradigm shift so significant that it is likely to affect many aspects of transportation in ways for which no relevant data exist. Autonomous self-driving vehicles have the potential to:

- Significantly reduce accidents that result from human error (including intoxicated drivers) along with the concomitant congestion and fuel consumption. Roadway incidents have been estimated as the cause of 30 to 50% of peak period congestion in urban areas (Wang 2011, FHWA 2004, Schrank 2012).
- Enable widespread platooning, potential congestion reductions due to increased density on the roadways, and reduced fuel consumption resulting from reductions in drag.
- Enable safe travel at higher speeds, but at the cost of increased drag and energy consumption.

- Affect the types of vehicles purchased, encouraging purchase of compact cars, lightweight cars, or novel 1- or 2-seater vehicle designs as safety improves and there is less safety benefit from large, heavier vehicles.
- Encourage people to live farther from their workplace, since commute time can be used more effectively, hence increasing vehicle miles traveled (VMT).
- Enable automated parking, encouraging drivers to use inexpensive parking locations away from dense destinations, increasing VMT, and affecting design and location of parking infrastructure. The reduced parking needs at destinations could increase the density of the metropolitan urban core, potentially increasing the demand for transit and reducing VMT for city residents.
- Automated travel to refueling areas associated with alternatively fueled vehicles, could optimize infrastructure needs, reducing the total cost and encouraging alternatively fueled vehicle adoption.
- Increased fuel economy through vehicle weight reductions, which would also reduce the battery and storage tank requirements and costs of electric, natural gas, and hydrogen-powered vehicles.
- Enable new demand from those who cannot drive in current conditions (e.g.: elderly, disabled, children), with corresponding increased energy consumption.
- Influence the relative competitiveness of other modes of transportation, e.g.: affecting airline travel and transit demand.
- Encourage car-sharing and driverless taxis with potentially reduced individual vehicle ownership.
- Reduce PennDOT’s revenue from a number of sources. Under a sharing system licensing and associated revenue can be reduced, affecting PennDOT. In addition revenue from traffic and parking tickets can be reduced.

The transportation industry is approaching a transformational inflection point with the introduction and penetration of autonomous vehicles as well as other energy efficiency changes such as increased adoption of hybrid and electric vehicles. While automated features added to vehicles will have a significant impact on safety, secondary benefits including, but not limited to, reduced congestion, fuel consumption and emissions may also result from these features. The impact of vehicles may be wide ranging, influencing urban design and sprawl, transportation for children and the elderly, and location of residences and businesses. At the same time, the reliability and security of these automation features is an intense focus of the automotive industry.

Summary of State Legislation Activities

In recent years, a number of states, including Nevada, California, Florida, Michigan and District of Columbia, have passed laws on autonomous vehicles. In addition, there are states, including Georgia, New York, New Jersey, and Minnesota among many others that are working on such legislation. The objective of most states' laws is to make it easier for manufacturing companies and researchers to explore and test the autonomous technologies. As a result, the departments of motor vehicles (DMVs) of those states that have passed laws have been working on procedures suitable for autonomous vehicle testing on public roads. These laws do not address issues regarding drivers of the autonomous vehicles, mainly due to the fact that autonomous vehicles are not yet commercially available. Instead, their focus is on the safety of the vehicles themselves while being tested on public roads. Table 1 briefly describes some of the characteristics of the enacted laws to-date:

Table 1: Characteristics of Enacted State Laws on Autonomous Vehicles*

State	Intent of Legislation	Enacted	Operator	Liability
Nevada	Testing, Individual Ownership	June 2011, revised July 1, 2013.	The regulation stipulates an endorsement on driver's license to operate	Manufacturer not liable for damages if vehicle is converted by third party.
Florida	Testing, Development, Operation	April 2012	Vehicles may be operated by persons with a valid driver's license	Manufacturer not liable for damages if vehicle is converted by a third party.
California	Testing, Operation	September 2012	Employees, contractors, or other persons designated by the manufacturer of the autonomous technology	No mention of Liability.
District of Columbia	Testing, Operation	January 2013	--	Manufacturer not liable for damages if vehicle is converted by a third party.
Michigan	Testing, Operation	March 2014	Carmakers, auto suppliers and developers	Manufacturer not liable for damages if vehicle is converted by a third party.

*A link to the complete legislature bills for each State may be found in the bibliography.

Traditionally, the federal government regulates vehicles while states regulate inspections, operators and drivers. This pattern may be changing as drivers will likely cede control of the vehicles by the year 2040 when most vehicles will be connected and autonomous. Instead of regulating drivers, autonomous vehicles will need to be tested and regulated. Hence, it is the vehicle that will have a license to operate, not the driver in most cases. An exception may occur for driving enthusiasts who wish to continue manual driving. States will have to determine under what conditions and licensing such manual driving would be permitted.

As more states pass laws regulating autonomous vehicles, it will be important to have laws that are consistent among the states. The RAND Corporation report published in January 2014, “Autonomous Vehicles Technology: a Guide for Policymakers,” summarizes stakeholders’ concerns on conflicting state laws. The report emphasizes that automobile manufacturing companies need a framework that works in all 50 states (Anderson 2014).

In the next few sections we assess the impacts of connected and autonomous vehicles on a specific list of tasks specified on the work scope of this project.

Chapter 1: Connected and Autonomous Vehicles Experts Workshop

Task 1 of the project required the researchers to coordinate, conduct and facilitate a workshop concerning the agency implications of connected and autonomous vehicles. This workshop was held in Enola, Pennsylvania on Thursday, October 3, 2013. The workshop was consisted of a series of presentations by experts from the private and public sectors and four breakout sessions:

Session 1: Impacts to Existing Infrastructure, Design and Investment Decisions

Session 2: Communication Device Investments and Real Time Data Usage

Session 3: Impacts to Freight Flow

Session 4: Impacts to Driver Licensing and Workforce Training Needs

All workshop documents including presentations and breakout session notes are included in Appendix.

Chapter 2: Impacts to Design and Investment Decisions

This task evaluates the impacts of connected and autonomous technologies on design criteria and investment decisions. Issues including effective capacity of lanes, traffic signal designs, in road communication devices, ITS message signs and their life expectancy, and clear zone investments will be assessed. This task provides recommendations regarding when and how PennDOT should begin to make different investment decisions.

Assuming the design year of 2040 and that all motor vehicles are connected and/or autonomous, design criteria changes relevant to capacity of lanes, traffic signal design, ITS message signs and their life expectancy, and clear zone investments are discussed below:

ITS message signs and radio advisories: Assuming the existence of connectivity by the year 2040, radio advisories as well as ITS message signs and the way they are designed today will be obsolete in a fully connected environment. Information that currently is available through ITS message signs will be disseminated directly to the vehicles using V2I or V2X technologies and on-board units (OBUs). Cellular technology available today can provide capabilities of sending ITS messages to individuals through smartphone applications. As capabilities of new cellular technologies are expanding, information provided through ITS message signs will become readily available inside vehicles through original equipment manufacturers (OEMs) and on-board units in as early as several years. General Motors (GM) has already announced that some of their 2015 cars will be equipped with GM's OnStar technology, which is a built-in 4G LTE that the driver can use to turn the vehicle into a hotspot receiving traffic information through various applications (General Motors, 2014). Existing vehicles could also be fitted with communications devices providing the same level of driver information as built in connected systems.

In the absence of connectivity, autonomous vehicles will be able to detect messages from the ITS message signs through their cameras and convert the messages into meaningful actions using their complicated algorithms. In this unlikely case of no connectivity, ITS message signs and radio advisories should still be available.

The most likely scenario for the year 2040 is where we have a connected automated environment. In such an environment using either cellular or DSRC technology, the actual ITS message signs and radio advisories will be obsolete since the information transferred through the signs could be transmitted directly from a traffic management center to a cell tower or cloud then to the vehicle itself.

With regards to timeframe, PennDOT's decision should be based on when the agency is ready to send traveler information including roadway and weather condition, travel advisories, and construction advisories, currently disseminated through radio advisories and ITS message signs, to other sources (i.e. internet cloud) so that it could be transmitted to vehicle owners through various applications. Working with private sector companies and data companies would be crucial in this process to help PennDOT convert data into information and then sending it to various applications for the use of public.

Radio advisories and ITS message signs in a

- ***fully connected environment (with or without automation): Obsolete (More likely scenario)***
- ***fully automated environment (without connectivity): Still needed (Less likely scenario)***

Capacity of Lanes: Using the design year of 2040, it is anticipated that connected and autonomous vehicles result in expanding the effective capacity of lanes. This can be due to a number of factors such as:

- Fewer accidents, therefore less congestion and bottlenecks.
- Smooth, uniform and increased throughput and flow around bottleneck areas such as tunnels, on-ramps, and construction zones.
- More efficient traffic management due to automated traveler information systems that result in diverting vehicles to travel on less congested roadways.
- Fewer vehicle miles traveled (VMT) due to availability of automated parking information systems that result in less driving in dense areas in search of finding parking.
- Potential gap reduction in between vehicles traveling in platoons resulting in increased lane capacity.

While lane capacity increase due to any of the above factors is likely, other factors and uncertainties may adversely affect the potential increase of capacity and flow. For instance lane capacity increase due to reduction of gaps may be limited by the number of vehicles allowed in each platoon and the minimum distance required between the vehicles in each platoon. Gap design criteria being tested for platoons (average 2 seconds) is in many cases more than what conventional vehicles allow in between themselves especially at lower speeds. Although most driving manuals suggest that drivers allow a minimum gap of 3 to 4 seconds between their car and the vehicle in front of them, drivers typically do not follow this guidance especially at lower speeds and during peak periods. If 3 to 4 second following distance is observed, then any gap designed between vehicles in a platoon less than 3 seconds would result in increased capacity.

Companies testing platoons are typically designating a truck as the leader of the platoon. This might limit the availability of platoons and drivers might be forced to travel individually if there is no platoon available to join at the time and the place they would need one. Level of penetration – mixed fleet vs. 100% penetration or having dedicated lanes for platoons – and time of day – peak period versus all day long – will also play a role into the flow factor.

Other factors that could adversely affect the extra lane capacity are:

- Induced demand due to travel time savings associated with less congestion and more efficient driving.
- Induced demand due to fuel savings associated with less congestion and more efficient driving.
- Newly generated demand resulting from driving capability of special groups (i.e. children, elderly and people with disabilities) to drive.
- Increased VMT as drivers may have the option of sending their vehicles off to park themselves in economy parking lots.
- Increased VMT due to urban sprawl encouraged by driving efficiency and new opportunities for productivity while traveling.

How much the capacity of each lane will increase and how much new demand is induced due to the above mentioned factors associated with connected and autonomous vehicles and applications are both extremely uncertain. Lack of data on most items mentioned above, results in ineffective quantification of the balance between the two sets of factors, those that potentially increase the capacity and those that potentially decrease the capacity. For instance, rate of VMT increase resulting from vehicle owners sending their cars to economy parking lots or rate of VMT increase due to urban sprawl are uncertain. The following table shows each of the factors affecting lane capacity and flow, type of impact on capacity (increase or decrease), whether the factor is applicable to arterials and/or freeways, most relevant type of data needed to estimate the impact and the availability of such data. Under "Availability of Data", 1 indicates that most data needed is available, 2 indicates that some level of preliminary research data is available although not enough to be able to estimate the impacts thoroughly, and 3 indicates that zero to minimal information is available.

Table 2: Factors Impacting Capacity and Flow

Factor Impacting capacity of lanes	Increase (+) Decrease (-)	Freeway(F)/ Arterial(A)	Data Needed	Availibility of Data
Less congestion due to reduction of accidents	+	F/A	Accident & Congestion Data	1
Smooth flow around tunnels, ramps, construction zones	+	F/A	Capacity, Geometry & Throughput Data	1
Automated traveler information systems	+/-	F/A	Impact Data on Roadway and System levels	3
Less VMT due to automated parking information systems	+	A	Parking Related VMT Data	1
Gap reduction due to platooning or adaptive cruise control	+	F	Platooning and ACC data	2
Design speed increase due to safety enhancement	+	F	Speed Data	2
Limitations on number of vehicles in a platoon	+/-	F	Platooning Data	2
Limitations on design specifications related to gaps	+/-	F	Platooning Data	2
Availibility of platoons	+/-	F	Platooning Data	2
Induced demand (due to travel time or fuel savings)	-	F/A	Elasticity Data	2
Newly generated demand (from elderly, disabled, children)	-	F/A	Travel and Social Behavioural Data	2
Increased VMT due to unnecessary activities	-	F/A	Social and Behavioral Data	3
Increased VMT due to sprawl	-	F/A	Social and Behavioral Data	3

From the above table, impacts of connected and autonomous vehicles on capacity of lanes from those factors indicated with “Availability of Data 1” (i.e. less congestion, smooth flow and throughput around bottleneck areas, less VMT due to parking information systems) can be estimated as follows:

Less congestion: accident related congestion accounts for about 30 to 50 percent of peak period congestion in urban areas and about 55 percent of freeway congestion (Wang 2011, FHWA 2004, Schrank 2012). Assuming that all vehicles will operate in a connected automated environment by the year 2040, and accidents due to human errors (about 80 percent of total accidents) are eliminated, we can assume that about 40 percent of congestion will be eliminated during the peak hours. If we assume that the decrease of 40 percent congestion is distributed uniformly along the roadway network, lane capacity is increased by about 40 percent during peak hours. That means a Level of Service (LOS) F roadway segment could potentially change to a LOS D and a roadway with a density between 35 to 45 cars per mile per lane (LOS E) could shift to LOS C.

Smooth and increased flow around bottleneck areas: much of congestion typically occurs around bottleneck areas such as tunnels, construction zones or ramps, where flow decreases while capacity stays the same. Roadway capacity is generally thought of as maximum vehicle flow on a lane per unit time. Automated vehicles in platoons should be able to avoid low flow and low speed regimes, especially since traffic would behave more uniformly, resulting in less congestion and improved LOS along roadways around the bottleneck areas.

Parking information systems: research indicates that about 8 to 74 percent of central business district area traffic is a direct result of cruising for parking (Shoup 2006). Assuming an average of 40 percent reduction of congestion is possible due to availability of automated parking information systems, roadway segments with LOS D or worse could be improved to LOS D or better.

The three factors briefly explored above illustrate that automated vehicle technologies have the capability to increase flow on roadway segments given the existing capacity. For investment decisions that are based on levels of congestion, the increase in average flows would lead to less investment in capacity increases.

Other factors mentioned on Table 1 are less certain. For instance social and behavioral analysis and data is needed to estimate impacts of autonomous vehicles on urban sprawl. More accurate understanding of platooning and design specifications related to platooning is necessary in order to estimate the impacts of platoons on lane capacity and flow.

Newly generated demand resulting from driving capabilities of special groups such as elderly persons or those with disabilities is yet another contributing factor to the lane capacity analysis. Presumably individuals under the driving age or with disabilities preventing their driving would take advantage of autonomous vehicles to increase their travel. The following figure shows the average annual miles traveled versus age in the state of Pennsylvania. Average yearly travel decreases in the elderly population. The average annual miles traveled by elderly persons is about 3,800 versus the population average of 6,900 miles and the non-senior average of 9,300 miles.

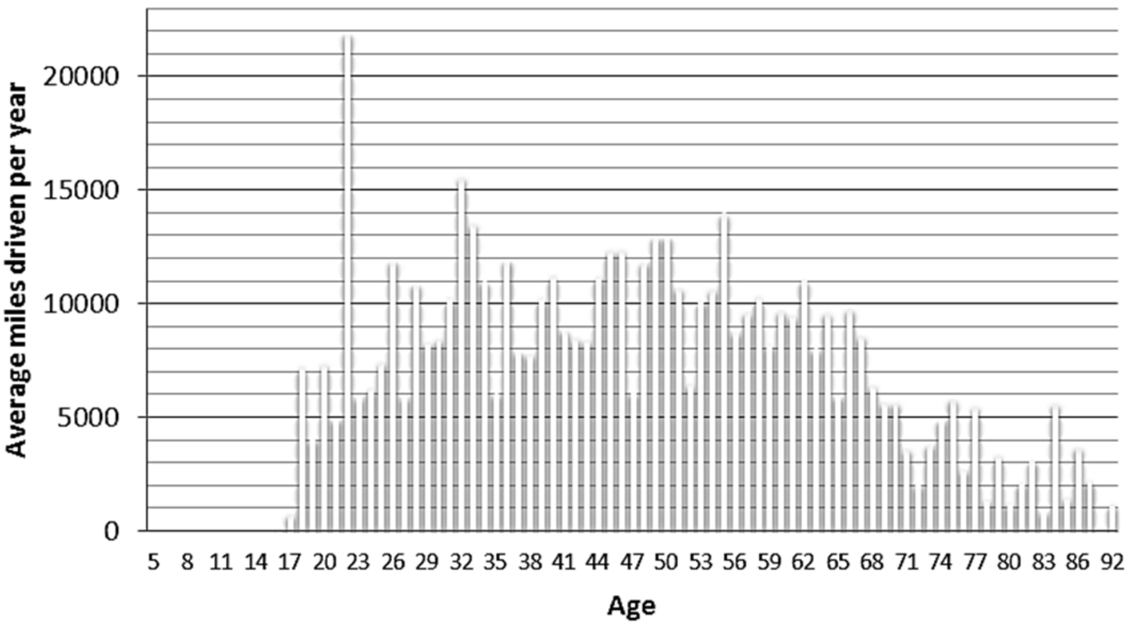


Figure 1: Average Annual Miles Traveled Vs. Age (Source: The 2009 National Household Travel Survey)

Based on the data in Figure 1, if elderly individuals used autonomous vehicles at the same level as the general population, their "driving" would increase of about 3,100 miles per year per person, almost doubling the existing amount of travel by elderly persons. With about 2 million elderly in the state of Pennsylvania (PAG 2013), according to the Pennsylvania Attorney General website, this would account for an additional 6.2 billion additional miles driven annually. With connected and automated vehicles, elderly travel would likely increase, but probably not to the non-senior average of 9,300 due to health restraints and lack of commuting. A similar pattern can be expected for individuals under the age of sixteen.

Another special group that currently has limited mobility is individuals under 65 with medical conditions or disabilities. If their travel was at the same level as the general population, it would increase by about 4,400 miles annually per person or 45 percent. With about 670 thousand non-senior individuals with driving prohibited medical conditions or disabilities, this would account for an additional 2.9 billion additional annual vehicle miles of travel in Pennsylvania. Some of this increased travel would be offset as a result of using Pennsylvania's extensive paratransit system, which helps serve this population.

In general, factors such as induced demand, rate of input and output of a platoon, minimum distance required between the vehicles and design speed of vehicles will all impact density and flow. The capacity of the roadways depends upon the stability of density regimes. Automated vehicles avoid high-density roads to reduce the risk of accidents. Even the lower levels of automation suggest and adopt driver-assist applications that lead the driver to avoid congested roadways and take detours. As long as connected and autonomous features such as platooning are designed in a way to allow for maximum flow traveling along a segment of a roadway while diverting the excess throughput onto other roads and arterials, the technologies will result in benefits such as travel time savings, fuel savings and emission savings. This is assuming that other roadways in the network can accommodate the extra throughput and the system does not fail due to overflow and congestion. Even though PennDOT's investment decisions for capacity increases are typically based on levels of congestion, such decisions should be carefully studied as in many cases capacity increases might not be needed. Uncertainties of various factors affecting capacity and flow could significantly and adversely impact the overall optimism on congestion improvement due to the adoption of connected and autonomous vehicles.

Longitudinal versus Cross-Sectional Capacity

It is important to note the difference between the overall roadway capacity versus lane capacity. Features such as "lane keeping" will have significant impacts on roadway capacity not so much from the longitudinal standpoint but from the cross-sectional perspective. Connected and autonomous features can keep vehicles safely in their own lanes. As a result, current width standards for lanes, shoulders, clear zones, and medians are probably in excess of what is necessary for safe operation. Therefore, a four-lane freeway may be converted into a five-lane freeway with minimal investment from PennDOT (i.e. cost of lane markers repainting). Adding this extra capacity to freeways could provide dedicated lanes for platooning without necessarily jeopardizing existing capacity. Before making large investments on existing highway corridors, it is recommended that the opportunities and costs of lane reconfiguration and repurposing become one of the standard options considered for all potential projects.

Capacity of lanes from

- ***the longitudinal perspective: uncertain impacts***
- ***the lateral perspective: investment decisions on pavement markings and repainting***

Clear zone investments: Clear zone areas including shoulders will continue to be used for emergency vehicles, pull-off areas for vehicle breakdowns and maintenance operations. Although risks associated with crashes will be reduced, accidents, extreme events and maintenance problems with vehicles will occur. Therefore clear zone areas will be needed and should remain in place.

Clear zones will need to remain in place.

Width of lanes, medians, and clear zones: Connected and autonomous vehicles will be able to safely operate within narrower lanes. Therefore, widths of lanes, medians and clear zones can be narrowed providing smaller roadway footprints for new facilities and increased design options within existing rights-of-way. The challenge will be timing. As mentioned earlier, if a large investment is required on an existing corridor, reconfiguration and repurposing should be one of the investment options considered.

- ***Width of lanes, medians, shoulders and clear zones can be decreased.***
- ***Cost of construction time and congestion associated with repainting and reallocating of lanes must be taken into account for investment decisions.***

Traffic Signal Design: By the year 2040, when the scenario assumes all vehicles are driving in a connected environment, whether we need traffic signals as we know them today is an arguable matter. Virtual signals not visible to drivers are being studied by a number of researchers across the U.S., including at Carnegie Mellon University. In a fully connected or connected automated environment, vehicles will be able to safely go through an intersection by communicating with one another. However, the authors of this report believe that traffic signals similar to those we have today will still be in place by the year 2040. Signals will be needed to facilitate safe operation for bicyclists and pedestrians at intersections. In addition, the existing traffic signals could act as backup systems in case of connectivity failure. In an autonomous environment (in the absence of connectivity) traffic signals will also be needed to allow vehicles to fully communicate with signals using cameras and sensors.

In terms of V2I communication, there are a number of safety applications that could reduce crashes at intersections. Safety applications include red light violation warning, stop sign violation, and gap assist at signalized and un-signalized intersections. These applications would mostly need DSRC equipment to transmit signal phasing and timing (SPaT) data to the OBUs inside vehicles. An interface between the DSRC radio and the signal controller would also be required. Most updated controllers in the U.S. (i.e. 2070s controllers, NEMA controllers) are capable of functioning within the connected environment. Older controllers (e.g. 170 controllers) would have to be upgraded to permit DSRC operation. It is anticipated that by the year 2040 eighty percent of signalized intersections around the nation will be equipped with DSRC equipment.

To manage traffic at signalized intersections, it is important to evaluate the opportunities that V2I applications provide versus continued deployment of traditional ITS measures versus purchasing commercial traffic information. All three options have benefits and costs associated with them. However, it is expected that opportunities presented through V2I capabilities will reduce the overall cost of traffic management compared with the traditional ITS capabilities. Implementing traffic signal V2I applications will need the following investment considerations:

- Considering the integration and interactions with the existing ITS applications. This includes:
    - upgrades and changes to the existing traffic management centers (TMCs)
    - upgrading controllers
    - upgrading firmware of controllers
    - upgrading back office software including any traveler management system software
- Identifying and prioritizing key deployment locations (e.g. intersections with high crashes)
- Funding and deployment for the new DSRC and roadside units

Given the potential benefits of safety enhancement through connectivity (V2I), and the interference of V2I applications with the existing systems, it is recommended that PennDOT consider V2I installations before expanding current ITS systems. ITS systems may soon be in conflict with the new technologies needed for V2I applications.

Traffic signals

- ***in connected environments (with or without automation): identification and prioritization of DSRC locations***
- ***in autonomous environments (without connectivity): no immediate investment decision***

Summary

By 2040, it is tempting to say travel demand will increase because that has been the general trend over the last 30 years until about 2007. On the other hand, after leveling off, VMT in Pennsylvania has dropped in each of the last five years so it is not clear whether travel demand will or will not increase in the State. Driver preferences, teleworking, modal shifts, and induced demand will all affect VMT. Transit demand may increase or decrease due to varying motivations for autonomous and/or modal shifts. Vehicles will be lighter and smaller. While there is a real need for understanding potential futures to inform the timing, location and magnitude of investment decisions, the associated uncertainties and lack of data require making decisions that are robust under a range of conditions. In this section we disaggregated investment decisions into groups of connected, autonomous and connected automated environments to make recommendations on investment decisions related to the year 2040 and mostly with the assumption of 100 percent penetration. As it was explained, most decisions impacting PennDOT will be related to connectivity and specifically V2I technologies, as they would need more of PennDOT's participation, funding and investments. Examples of such technologies are those related to traffic signals (e.g. red light violation applications) and lateral capacity expansion (e.g. lane remarking, reconfiguration).

Guidance on V2I deployment will be provided by US DOT by the year 2015. As technologies progress PennDOT will need to follow the market driven forces while being cautious on new investment decisions that could potentially interfere with V2I deployment and technologies.

Chapter 3: Real-Time Data Usage

This task: 1) evaluates how real time data can be transmitted to vehicles regarding parking availability, congestion, weather, and converted into decisions on transit routing, traffic management and regional traveler information stations, 2) Provides recommendations regarding how policy decisions should change on investment strategies by mode based upon the above mentioned factors and 3) includes how connected and autonomous vehicles can contribute to the efficiency of maintenance and to systems planning by providing management with enormous amounts of data about the condition and utilization of the system.

1) Transmission of real-time data to vehicles:

Effective traffic management for various modes of transportation has long been a major priority of transportation authorities including state DOTs, metropolitan planning organizations (MPOs), local authorities and transit agencies. Typical Issues impacting the efficient management of traffic include but are not limited to:

- Traffic congestion
- Parking availability
- Weather conditions
- Emergency incidents
- Special events

For roughly two decades, intelligent transportation systems (ITS) applications have been instrumental in providing transportation and traffic management multi-modal services and enabling users of various transportation modes to move safely and efficiently. According to the US DOT, "ITS encompass a broad range of wireless and wireline communications-based information and electronics technologies." ITS measures and applications deployed by many agencies throughout the nation over the last couple of decades include variable message signs, closed circuit television (CCTV) cameras, navigation systems, traffic signal control systems, traveler information systems, traffic management centers, parking guidance and information systems, bus rapid transit, electronic payment systems, transit signal priority, highway advisory radios, and emergency vehicle preemption to name a few. To efficiently manage traffic operations, conventional ITS applications typically use the following information:

- Traffic data including real time data (e.g. speed limits, traffic signal state, etc.)
- Surrounding bicycle, pedestrian and vehicle locations
- Merging and platooning management among vehicles

With the introduction of connected technologies, ITS has taken a different level of communicating information between vehicles (V2V), vehicles to infrastructure (V2I), and vehicles to other modes (V2X). In all three cases real time data is transmitted to and from vehicles using wireless technologies including cellular or DSRC. With either of the wireless technologies, on-board units (OBUs) would be installed on vehicles (trucks, buses, and automobiles) typically by original equipment manufacturers (OEMs) or automotive manufacturing companies to receive and transmit data and information.

Real time data on parking availability, congestion and weather conditions can be transmitted to/from vehicles from/to infrastructure units and traffic management centers (TMCs) using roadside units installed by transportation agencies (state DOTs, transit agencies, etc.). Real time data must first be converted into meaningful information to help the appropriate user (i.e. transportation manager, driver, transit operator or the driverless vehicle itself) making decisions on transit routing, traffic management and regional traveler information.

Unlike connected vehicles, autonomous vehicles do not necessarily receive this data unless they are functioning in a connected environment or the driver/operator is using a tablet or a smart phone with applications that provide such information. Instead autonomous vehicles use cameras and sensors to detect objects and read messages; then using algorithms decide on the best possible safety or mobility action.

Mobility applications discussed in this section include those relevant to transit routing, traffic management and traveler information systems. In a connected environment, real time data on weather, parking, congestion and incidents need to feed into mobility applications. According to US DOT Research and Innovative Technologies Administration (RITA), these mobility applications include, but are not limited to,

- Advanced Traveler Information Systems (ATIS)
- WX-Info (weather information)
- Motorist advisories and warnings
- Integrated Network Flow Optimization (INFLO)
    - Cooperative Adaptive Cruise Control
    - Queue Warning (Q-Warn)
    - Dynamic Speed Harmonization
    - Next Generation Ramp Metering System (RAMP)
- Multi-Modal Intelligent Transportation Systems (M-ISIG)
    - Intelligent Traffic Signal System (I-SIG)
    - Transit Signal Priority (TSP)
    - Pedestrian Mobility (PED-SIG)
    - Emergency Vehicle Preemption
- Integrated Dynamic Transit Operation (IDTO)
    - Connection Protection (T-CONNECT)
    - Dynamic Transit Operation (T-DISP)
    - Dynamic Ridesharing
- Next Generation Integrated Corridor Management (ICM)

    - Enhanced Maintenance Decision Support System
        - Winter road treatment and snow plowing
        - Non-winter maintenance
- Information for Maintenance Management Systems
- Response Emergency and Staging and Communications, Uniform Management and Evacuation (R.E.S.C.U.E.M.E)
- Information and Routing Support for Emergency Vehicles

Mobility applications listed above each have varying requirements to transmit real time data and convert them into information and useful applications. For instance while some would need roadside units or backhaul communications, others do not. PennDOT's decision on deploying any of the mobility applications would depend on the physical requirements of each application, feasibility of deployment of each application and ultimately cost of deployment for each application. Most of the mobility applications mentioned above can be deployed with either cellular or DSRC technologies. In case of cellular, no roadside unit, interface to local systems and backhaul communications would be necessary. Using DSRC technology, all of these applications need to have on-board units installed on vehicles (automobiles, trucks or buses). Most need roadside interface with local systems and some need backhaul communication. In addition, most mobility applications mentioned above, need some level of mapping system (e.g. network level, lane level) and some need ongoing management of data. On the vehicle side, OBUs will likely be installed by OEMs and automobile manufacturing companies. For trucks, motor carriers need to make a decision on implementation of these units on their vehicles and the same holds true for transit agencies. Currently many applications are working using cellular technology and drivers' smartphones. PennDOT potential investments would be categorized into groups of:

1- Upgrading signal equipment and traffic management centers if necessary

2- Roadside unit (DSRC)

3- Roadside interface with local systems (DSRC)

4- Backhaul communication

5- Mapping systems

6- Data management

7- Security network compatibility

Specific data and communication requirements to deploy each of the mobility applications mentioned above are listed in the American Association of State Highway and Transportation Officials (AASHTO)'s National Connected Vehicle Field Infrastructure Footprint Analysis document.

(http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm)

2) *Policy Issues with respect to Real Time Data Usage:*

With regard to real time data usage, there exist many policy challenges, most of which are being dealt with at a national level. According to US DOT RITA (http://www.iteris.com/cvria), these issues are:

- *Privacy* issues related to the level of anonymity provided to drivers.
- *Governance* includes issues such as roles of participants and who may access the data.
- *Spectrum* includes compromised safety by other applications adjacent to the selected spectrum.
- *Ownership* issues related to data sharing.
- *Interoperability* issues between roadside units and on-board units.
- *Timeline* includes issues such as when DSRC will be available.
- *Security* issues between outside sources including roadside units and on-board units.
- *Liability* includes issues such as liability for faulty data.
- *Social Equity* includes issues such as how well the connectivity protects non-motorize users.

While these core policy issues are being dealt with at a national level, it is recommended that PennDOT examine approaches that can expedite deployment of connected and autonomous vehicles. To accomplish such action, identifying available datasets as well as identifying applications that are less costly and less labor intensive to deploy would be useful to set as priorities. Small scale deployments focused on PennDOT's immediate or near-term needs would assure a higher level of performance. For instance, if weather related maintenance is a top priority, investing in enhanced maintenance support decision systems would be recommended as one of the first steps.

In addition to the mobility applications mentioned in this task, data applications could be useful especially in support of maintenance and operation decisions. Examples of such applications are: probe enabled traffic monitoring and probe based pavement maintenance. These data applications rely on vehicles to collect and transmit data through either cellular or DSRC technologies. Investing in data applications is also a useful step in early stages of connected vehicles deployment. Using cellular technology, backhaul communication is required for such applications.

3) *Contribution to the Efficiency of Maintenance and System Planning and Data Management:*

Maintenance and system planning for data management is a critical part of effective traffic operation and management. Effective management of the enormous amounts of real time data received and transmitted daily is an important yet challenging part of connectivity. Mobility applications mentioned in the first part of this section can play a significant role in the efficiency of maintenance and systems planning. Weather, congestion, parking and incident related data need to not only be captured but also managed properly and converted into useful information for users to achieve maximum benefit possible. To achieve the highest level of benefits and to prepare for the deployment of connected and autonomous technologies, it is recommended that PennDOT consider the following actions:

- Identifying and prioritizing mobility applications that are most useful for transportation operation and management. Cost analysis will be required for prioritization.
- Identifying types of data, communication devices, and mapping levels needed for selected mobility applications.
- Assessing currently obtained data, its usefulness and applicability. Identifying gaps in data collection and procurement.
- Capturing and procuring real time data based on the above selections. In most cases real time data for mobility applications can be captured through cellular technology.
- Establishing partnerships with private sector companies. The advantage of such partnerships for PennDOT is twofold: 1) provide data and encourage innovation and 2) receive processed data and useful information for maintenance, management and planning purposes.

Chapter 4: Impacts to Existing Infrastructure

This task evaluates what the Parkway East (I-376) should look like between the Squirrel Hill and Fort Pitt Tunnels if the Mon-Fayette Expressway outer legs are built in the future and connected and autonomous vehicles platoon traffic. The task includes evaluation of the design speed and any required characteristics changes to create a consistent rate of travel (tunnel effect on speeds). As part of this task several neighborhood areas of differing characteristics are evaluated and case studies have been developed to examine the technology effects on pedestrian traffic, transit, signal network and resultant land use decisions.

Impacts of Connected and Autonomous Vehicles on the Parkway East

The Parkway East is a portion of Interstate 376, also known as Penn-Lincoln East, which runs from I-279 in downtown Pittsburgh to I-76 (Pennsylvania Turnpike) in Monroeville, Pennsylvania. Between the Squirrel Hill and Fort Pitt tunnels, the major part of the Parkway runs along the Monongahela River.

The Mon-Fayette Expressway is planned to link the Parkway East to Morgantown, West Virginia. Upon completion, it is expected that the Mon-Fayette Expressway will relieve traffic on SR 51 while providing a bypass to the Squirrel Hill tunnel. The following figure shows the Expressway and its proximity to the Parkway East. The work order for this project assumes that the Mon-Fayette Expressway (the Mon-Fayette) and the Southern Beltway have been fully constructed, with the exception of SR 51 to Pittsburgh. Therefore, construction of a section of the Mon-Fayette from point A to point B on Figure 2 (Sections 53 A-G) is what is considered built for this analysis. Conversely, Sections 53 H, J, K, L, M, and N are assumed not to be built.

Figure 2: Project Area (I-376 and Mon-Fayette Expressway) (Source: FHWA, ContextSensitiveSolutions.Org)

Comparing the existing 24-hour volumes on the Parkway East with the year 2040 projections, given that the Southern Beltway and the Mon-Fayette will be constructed, demand will increase by about 6 percent. If the Southern Beltway and the Mon-Fayette were not constructed, then the 24-hour volumes along the Parkway East would increase by about 10 percent. Figure 3 shows the existing volumes and 2040 projections along the Parkway East in between Fort Pitt and Squirrel Hill Tunnels.

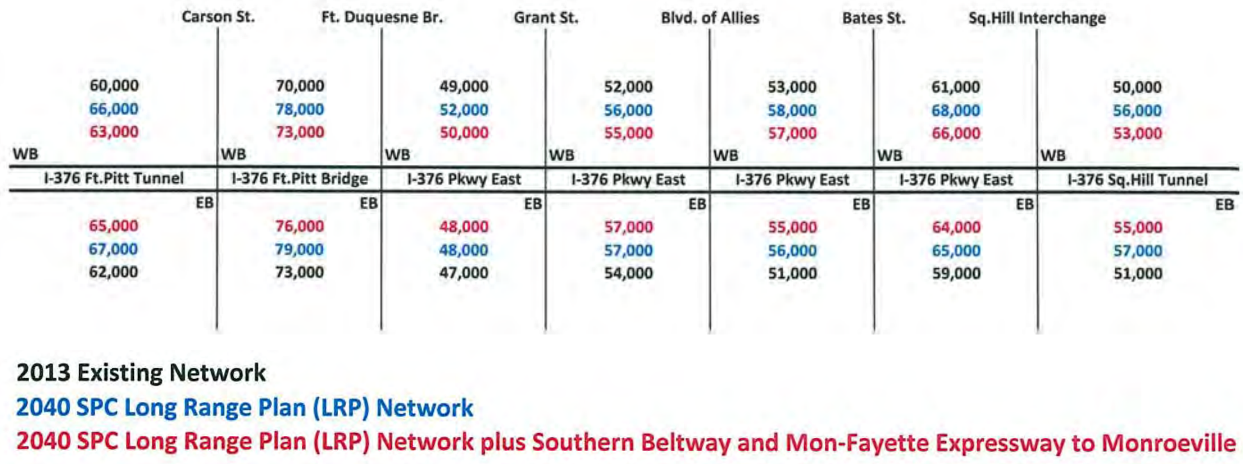


Figure 3: 24-hour traffic volume comparison along the Parkway East between Fort Pitt Tunnel and Squirrel Hill Tunnel (Source: SPC Transportation Models - 1/15/2014)

The Fort Pitt Tunnel and Squirrel Hill Tunnel each have two lanes in each direction. Traveling westbound (WB), the Parkway East is constrained by going from 4 lanes on the Fort Pitt Bridge to 2 lanes in the Fort Pitt Tunnel. Traveling eastbound (EB), the number of potential bottleneck areas increases: the four-lane Fort Pitt Bridge merges into 2 lanes and the three-lane Parkway East merges into 2 lanes as vehicles enter the Squirrel Hill Tunnel. With the volume increase of 6 percent by the year 2040 the tunnel effect will be more significant than what commuters experience today.

Assuming that connected and autonomous vehicles platoon traffic by the year 2040, a number of characteristics along the Parkway East may change to accommodate the additional throughput and provide for a smooth travel in and out of the tunnels.

Roadway Capacity: As discussed in Task 2 of this report, lateral capacity of roadways could be increased allowing for additional lanes along the segment of the Parkway East between the Fort Pitt Tunnel and Squirrel Hill Tunnel. As safety increases due to the elimination of accidents caused by human errors and travelers adopt smaller (but still safe) vehicles, standard 12 feet lanes may not be necessary, particularly for lanes restricted to small vehicles. In addition width of emergency lanes, shoulders, medians and clear zones could be decreased. The reduction in lane width might allow for an additional lane in the tunnel. The width of Squirrel Hill Tunnel is currently 29’4” including two 12’ lanes and barriers. By reducing each lane to 10’ (to accommodate for trucks), reducing width of the barriers, and having a 9’ lane for small vehicles,, the two-lane tunnel may potentially be converted into a 3-lane tunnel. It is important to note that for safety reasons this is only an option if all motor vehicles are driving in platoons and within a fully connected automated environment. This example only provides a hypothetical case scenario to provide a perspective on changes that PennDOT could experience. Lateral roadway capacity could also be increased on the 2-lane portion of the Parkway East immediately after the Fort Pitt Bridge as well as the Fort Pitt Tunnel (28’) to accommodate a smoother throughput.

Flow: With the increased 2040 volume projections, traffic congestion around bottleneck areas on the Parkway East between Squirrel Hill Tunnel and Fort Pitt Tunnel will be anticipated. This is due to the fact that typically either flow (rate of travel - speed) decreases while capacity stays the same or the number of lanes (capacity) decreases while demand stays the same. Regardless of the number of lanes along the Parkway East and in and out of the tunnels, connected and autonomous vehicles should be able to avoid low flow and low speed regimes. This would help the traffic operate more uniformly, resulting in less congestion and improved LOS along the Parkway East and specifically around the bottleneck areas.

Gap reduction between the vehicles in a platoon is a primary factor in increasing the number of vehicles travel along the Parkway East. In addition to enhanced safety resulting from connected and autonomous technologies, vehicles can travel at a much faster speed compared to the current operating speed of 55 mile per hour. Dynamic speed harmonization between the segment of the Parkway East before or after the tunnels and inside the tunnels will reduce congestion along the Parkway.

In both the Fort Pitt and Squirrel Hill Tunnels, where the allowable speed is 55 mph, assuming drivers are following the recommended guideline of a 3-second gap between vehicles, the gap distance would be about 70 meters. Connected and autonomous vehicles currently being tested are designed for gaps around 6 meters. With the current operating speed of 55 mph, this would reduce the gap time to 0.2 seconds. In a completely connected automated environment, where there is no human interaction involved, this will also result in increased flow throughout the tunnels, hence less congestion.

Merging flow might also be enhanced by connected and autonomous vehicles as smooth gaps could be produced by vehicles on the mainline route. With merges before each approach to the Squirrel Hill Tunnels, this potentially smoother merging could further contribute to increased average flow.

Signage: As discussed earlier, the presence of connected vehicles would eliminate the need for directional signs and variable message signs along the Parkway East.

Neighborhood Evaluations

As part of Task 4 three neighborhood areas of differing characteristics are evaluated to examine the effects of connected and autonomous technologies on pedestrian traffic, transit, signal network and resultant land use decisions. The three areas selected for evaluation are: Cranberry Township, the East Liberty neighborhood in Pittsburgh and the Waterfront Area in Homestead Borough. Each of these neighborhoods has vastly different characteristics that could either impact or be impacted by the connected and autonomous technologies as will be explained. This section first gives a brief overall view of each of the selected neighborhoods followed by various factors affected by the connected and autonomous technologies. Some of the factors discussed here are applicable to all three neighborhoods while others are specific to each area.

Cranberry Township: Cranberry Township, Pennsylvania is located twenty miles north of Pittsburgh at the crossroad of two interstate highways, the Pennsylvania Turnpike (I-76) and I-79, in neighboring Butler County. Its proximity to the major interstates as well as the City of Pittsburgh has encouraged many businesses and corporations to move their headquarters and offices into the Township resulting in rapid growth and economic and social changes over the last decade. The combination of a number of factors including Cranberry’s:

- newly implemented signal timing plans,
- newly implemented hardware and software traffic signal systems throughout the Township,
- state of the art traffic operation center (TOC),
- geographic location in relation to Pittsburgh, and
- rapid economic and population growth,

makes Cranberry Township a good case study to illustrate the impacts of connected and autonomous technologies on various travel management topics. Additionally, in September of 2013, CMU’s autonomous Cadillac SRX drove itself from Cranberry Township to Pittsburgh International Airport covering 11 intersections along Route 19. The total distance traveled was 33 miles and included autonomous travel on Route 19, I-79 South and I-376 West.

Cranberry Township currently operates and maintains a total of 44 traffic signals, 37 within or partially within the Township limits, while the rest are in Adams and Marshall Townships, as well as one in Seven Fields Borough in Butler County, Pennsylvania. Two major corridors in Cranberry Township are Route 19 and Route 228. Route 19 is significant to the traffic network systems as it runs parallel to the Pennsylvania Turnpike (I-76) at the junction with I-79. Route 228 and Route 19 provide access to both these interstates.

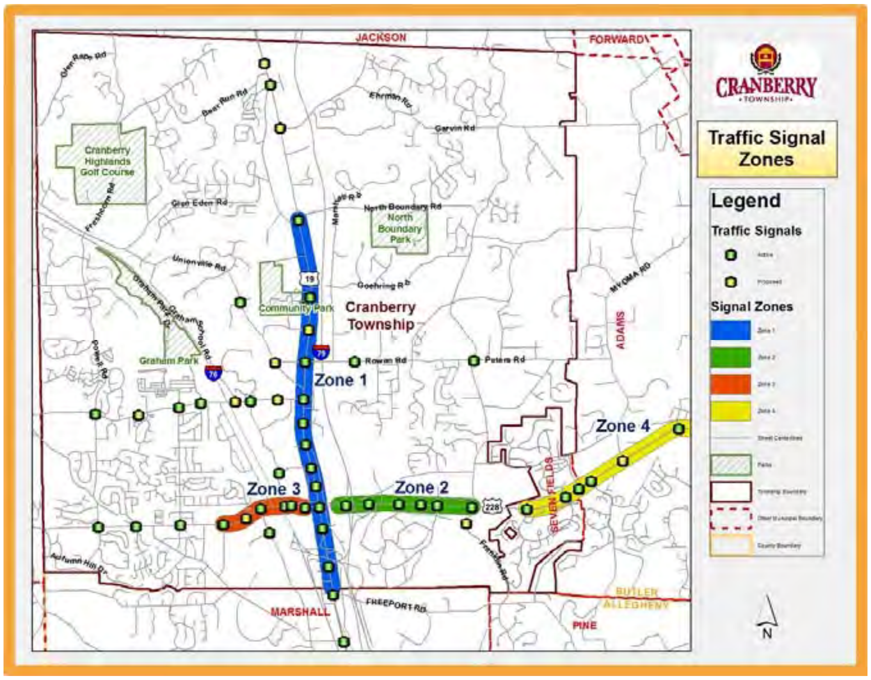


Figure 4: Traffic Signals Operated and/or Maintained by Cranberry Township (Source: http://www.cranberrytownship.org/traffic

East Liberty-Penn Circle Area: Penn Circle in the East Liberty neighborhood of Pittsburgh, Pennsylvania is another area selected for evaluation of connected and autonomous technologies. The portion of Penn Circle selected for this study supports two-way traffic and includes 9 traffic signals, 8 of which are interconnected through fiber optics. The following figure shows the study area:

Figure 5: Map of the Penn Circle study area (Source: Smith, Stephen F., et al. (2013))

East Liberty has experienced significant redevelopment over the past decade, resulting in numerous travel pattern changes. A new Target Department Store in the area has added substantial demand to the roadway network. The network consists of three major roads: Highland Avenue, Penn Circle and Penn Avenue. The triangular roadway network is subject to high levels of flow throughout the day in varying directions. An adaptive traffic signal control technology (SURTRAC), developed by the Robotics Institute at CMU, adjusts and coordinates signal timings dynamically to respond to the real time volume and demand fluctuations. SURTRAC was deployed on all 9 intersections in 2012 (Smith 2013). Initial results of the SURTRAC installation measured by CMU's Robotics Institute showed favorable results.

Waterfront Area in Homestead: Located in Homestead, Pennsylvania, the Waterfront (formerly Homestead Steel Works) consists of 256 acres of retail, dining and entertainment facilities. The site is considered a brownfield redevelopment (WPBC 2013). Since its opening in 2002, the Waterfront has significantly helped the distressed economy of Homestead. Its location however is not easily accessible to communities within walking distance to the site. Active railroad tracks separate the development from surrounding communities. Although land use impacts of the Waterfront were significant for Homestead, the site's transformation was not based on the surrounding communities of Homestead and West Homestead; instead the decision to transform the site was based on the presence of the more affluent neighborhoods of Squirrel Hill and Shadyside. This neighborhood was selected as part of the evaluation to mainly assess the impacts of connected and autonomous vehicles on land use decisions as mentioned in the work order.

Connected and Autonomous Technologies' Impacts on Neighborhoods

Lane Capacity: As discussed earlier in this report, connected and autonomous technologies will likely impact the flow and capacity of roadways. In Cranberry Township and Penn Circle neighborhood, potential increase of flow and capacity associated with connected and autonomous vehicles could be beneficial in response to growth and demand as well as reducing traffic congestion. In cases where increased lane capacity and flow are not sufficient to address demand, additional lanes can be reconfigured by reducing the current width of lanes, shoulders and medians.

Parking Lanes: By the year 2040, parking lanes in the East Liberty area could become obsolete. Widespread availability of parking information systems, which would allow autonomous vehicles to drive themselves into parking garages, as well as ridesharing and increased use of shared taxis, could provide opportunities for reconfiguring number of lanes along all three major roadways of Penn Circle.

Pedestrians and Bicyclists: Increased safety resulting from the deployment of connected and autonomous technologies will not only reduce the rate of vehicular incidents, it will also provide a safer environment for pedestrians and bicyclists. Extra potential capacity resulting from lane reconfigurations mentioned earlier could be used in all three neighborhoods for sidewalks and bike lanes. In addition to increasing opportunities for walking and biking, connected and autonomous technologies could improve connectivity and mobility to change these neighborhoods into communities with networks of interconnected streets, sidewalks and trails. Furthermore, connected and autonomous technologies will enhance the safety of pedestrians and bicyclists by detecting them, using sensors and cameras installed on vehicles. Safety enhancement for pedestrians and bicyclists will be crucial in areas like the Waterfront, since there exists a lack of interconnectivity between sidewalks and streets in Homestead and West Homestead.

Traffic Signals: Traffic signals are an important part of connected and autonomous vehicles in urban areas. Depending upon their type and mode, traffic signals can impact the deployment of connected and autonomous vehicles. Outdated traffic signal controllers and firmware need to be upgraded prior to deployment of connected and autonomous technologies. In addition all ITS technologies already deployed need to be evaluated to assess potential conflicts with the new technologies. Traffic signals are perhaps one of the most costly and challenging elements of connected and autonomous technology deployments. Therefore early assessment of the controllers, firmware and any potential ITS project is recommended. The three areas selected for this task demonstrate great examples and challenges involved with the upgrades of traffic signals.

As far as ITS technologies and traffic management, Cranberry Township is running its major corridors at an optimal level. With the state of the art TOC, recent upgrade of most controllers and the proactive maintenance of their signals, Cranberry Township seems to provide an excellent platform for the deployment of connected and autonomous technologies. The Township provides a great example of making investments today that are aligned with the technologies of tomorrow. Upgrading signal controllers to accommodate connectivity is a major investment for those cities and jurisdictions that are still running their signal systems with older controllers and firmware. Roadside units need to be installed at intersections in order to provide connectivity. The connection between Cranberry Township's TOC and its signals is functional. Cranberry Township's ITS equipment is up to date and sufficient for the installation of roadside units.

SURTRAC adaptive signal system has been implemented on all 9 intersections along Penn Circle in the East Liberty area. Controllers and firmware have been upgraded to accommodate the new adaptive system. Prior to deployment of connected and autonomous technologies, evaluation of any potential interference or conflict between the new technologies and the equipment installed and upgraded as part of the SURTRAC project needs to be conducted.

While we do not have accurate information on the type of signal controllers around the Waterfront area, given that all access roads to the Waterfront were developed recently, it is anticipated that signal controllers and firmware are new and functional and they can accommodate the connected and autonomous technologies. Much like the Penn Circle area, signals around the Waterfront should be evaluated prior to the deployment of connected and autonomous technologies to avoid any potential conflicts between the existing systems and the new technologies.

Signs: Occasionally in all three selected areas, dynamic message signs are placed to alert drivers of closures, construction, work zone areas, travel times, traffic information or speed information. Connected environment will eliminate the use of dynamic message signs as messages can be transferred directly to the vehicles and drivers.

Transit: Impacts of the connected and autonomous technologies on transit are extremely uncertain at this stage, regardless of the type of neighborhood. Due to potential widespread availability of ridesharing and taxi-sharing opportunities, it is anticipated that transit demand decreases by the year 2040. Much of this prediction however depends on the cost of opportunities such as ridesharing. Assuming user cost is a prohibiting factor, in the case that transit fees are less than ridesharing fees, transit demand could stay the same in distressed neighborhoods such as the Waterfront in Homestead and it could decrease in affluent neighborhoods like Cranberry Township.

Land Use: Connected and autonomous vehicles will have significant impacts on land use. Issues such as urban sprawl become crucial in assessing land use impacts of these technologies. Specific to our work order, the Waterfront was selected to discuss land use impacts of connected and autonomous vehicles. In addition to interconnectivity between streets, bike lanes and sidewalks discussed earlier, behavioral changes are important in the context of land use impacts.

Assuming all vehicles are connected and autonomous by the year 2040, and time spent commuting can be used more efficiently, there will always be a risk for facilities such as the Waterfront to lose their customers and business to other facilities with advantages appealing to customers (i.e. size, diversity, etc.). Currently, many customers of the Waterfront are residents of Squirrel Hill and Shadyside neighborhoods. Assuming cost of travel time is minimal, since time will be used efficiently while riding, a percentage of the current customers might decide to go to the Ross Park Mall or the Mall at Robinson for shopping or dining. These choices could impact the economy of Homestead and bring it back to the distressed phase it was before the Waterfront. Behavioral and land use incentives should be provided to reduce potential costs associated with connected and autonomous vehicles.

Chapter 5: Impacts to Workforce Training Needs

This task evaluates the impacts of connected and autonomous vehicles technologies on workforce training needs.

Effective workforce management is crucial to the successful operation of any system. Workforce management typically includes various tasks and activities required to maintain an efficient and productive operation. Workforce training is one such activity that is fundamental to the effective and sustainable operation of any system. The evolution of connected and autonomous vehicle technologies will have implications for the management of the transportation sector's workforce, including its training.

The automobile and transportation industry has evolved to have a stable training program, suitable for our current transportation system. Most of the training has been in place for a long period of time experiencing gradual changes over the years to reflect new technologies, such as on-board diagnostic and hybrid systems. With the introduction and deployment of connected and autonomous vehicles technologies, workforce training will need to change significantly. The new technologies may impact a wide range of training offered by various groups and institutions. Training is typically offered by:

- Professional Institutions (e.g. ITE, SAE),
- Community colleges, trade schools and universities (e.g. IUP), and
- Government agencies (e.g. U.S. DOT).

As part of this task, we introduce and examine various types of training offered by professional organizations, government agencies and educational institutions and why they will need to change as the nation's surface transportation is moving toward automation.

As per the scope of work, we have worked with the Indiana University of Pennsylvania (IUP) to examine how, and or if, its curriculums need to change to accommodate connected and autonomous technologies. We also provide recommendations on how PennDOT can continue to adequately meet its workforce training needs and educate its workforce as automotive technologies advance.

Professional Organizations:

Institute of Transportation Engineers: Today's transportation engineers and planners can become certified as Professional Traffic Operations Engineers (PTOE) and/or Professional Transportation Planners (PTP), once eligible, by taking the PTOE or PTP exams offered by the Transportation Professional Certification Board, Inc. (TPCB), an Institute of Transportation Engineers affiliate (TPCB 2014). Assuming all vehicles are connected and autonomous by the year 2040, concepts on the exams associated with traffic operations analysis as well as concepts related to the operational effects of geometric design, public transit demand planning, and public policy are likely to experience changes.

The PTOE certification is available to those who have four years of traffic operation engineering experience. The exam covers subjects such as traffic operations analysis, traffic safety, traffic control devices, and the operational effects of geometric design. The traffic operation analysis portion of the exam consists of roadway and intersection operations, traffic flow concepts, and travel demand management**.** The concepts associated with traffic operation analysis as well as concepts related to the operational effects of geometric design are likely to experience change by the year 2040 when fully automated vehicles make up most of America's light-duty vehicle fleet.

The PTP certification is available to those who have earned at least a bachelor's degree and have anywhere from three to five years of experience in transportation planning. This exam covers topics such as land use and transportation relationships, public policy, and transportation system planning for short- and long-range goals. Automated vehicles are likely to affect future transportation planning decisions, such as parking supply and public transit demand and as a result the test should reflect these changes in transportation planning. Transportation planners will need to plan differently and consider more factors for long-term planning as more automated vehicles come onto the market. Accordingly the PTP exam should be updated to include topics relevant to impact of the new technologies on land use, demand management, public transit, etc.

Society of Automotive Engineers: The Society of Automotive Engineers (SAE) offers both curriculum certificates and certifications for professionals to further advance their careers by demonstrating they possess a certain level of competence related to the physical components or physics of a car, truck or automotive legal issues. Curriculum certificates are earned by attending and successfully completing a collection of classroom or online seminars offered by the SAE (SAE 2014). Professionals who pass these courses receive a "Certificate of Achievement." SAE offers curriculum certifications in the areas of diesel technology, vehicle dynamics, transmission and drivetrain, product engineering tools and methods, professional and legal issues, and spark ignition engines.

These certificates would still be useful in the progression to vehicle automation, but there should be a curriculum certification offered to those who can demonstrate sufficient knowledge in the areas of human factors and ergonomics. SAE already offers a selection of courses in the area of human factors and ergonomics, which will become of much higher importance as computerized systems become more complex and are engaged in more decision making processes during driving. Going forward, the SAE should offer a curriculum certificate in this area and expand its program to include education on the physical components of an automated car and truck, as well as standards and legal aspects of connected and autonomous vehicles.

Community Colleges, Trade Schools and Universities:

RTI and CCAC: The two trade schools or community colleges in the Pittsburgh region, which offer training related to automobiles or trucks, are the Community College of Allegheny County (CCAC) and Rosedale Technical Institute (RTI). Both institutions offer associate degrees and certifications/diplomas in automotive technology, which are designed to prepare students to be automotive technicians and to be able to repair and service today's automobiles, and take the tests necessary to earn Pennsylvania Safety and Emission Inspection Licensing and Automotive Service Excellence (ASE) certifications (CCAC 2013). Both diploma/certification programs last for two years and only require hands-on course work to be completed. The associate degree programs at both institutions require hands-on work to be completed along with additional math courses.

Vehicle automation will most likely result in additional and/or modified courses added to the certificate and associate degree program curriculums at both institutions. This is due to the fact that the number of electronics has been increasing in the vehicles. In 1970, electronics made up 5 percent of the total cost of a vehicle and by 2005 this number has risen to 15 percent (Charette 2009). Today's conventional automobile includes more than 40 electronic controllers, five miles of wiring, and more than 10 million lines of software code, which make up about 40 percent of the content of today's vehicle (Federal Reserve Bank of Chicago 2011). By the year 2040, the amount of electronics in vehicles will increase as higher level automated vehicles are able to sense their environment and navigate on their own using LiDAR, radar, and GPS detection devices; and communicate with other vehicles through short-range wireless data exchanges. Along with these features, a complex information system will be standard equipment in fully automated vehicles. These systems will contain detailed cloud-based road maps and additional tools for communicating road and weather conditions.

As automobiles become more sophisticated, automotive technicians will have to keep up with the advancements in automotive technology to be able to correctly diagnose and quickly repair any vehicle issues presented to them. Therefore, more emphasis in the curriculum for automotive technicians at the CCAC and RTI should be placed on electronics, information technology and electronic communication systems along with computer science. Implementing courses devoted to the aforementioned topics would better prepare students to be competitive and well-rounded technicians who would be knowledgeable about the complex computer and communication systems as well as the mechanical components of an automated vehicle.

In-house training must continue to take place at car dealerships so automotive technicians will be familiar with the types of cars they are likely to encounter on a daily basis. In-house training would vary by car maker and change over time due to the fact that cars would be made up of different components, which would cause the manufacturer's standard operation procedures for repair to be modified. Customers and dealers alike may also have to receive training at the dealership level. A growing number of dealers offer short in-car tutorials to train users so they become acquainted with ever-changing features of vehicles.

Indiana University of Pennsylvania (IUP): Located in Indiana, Pennsylvania, the Highway Safety Center at IUP provides driver education and improvement programs and first responder and emergency response team training. Safety and driver education courses offered at IUP provide certification in driver education with the completion of the following four courses:

1- Foundations of Safety and Emergency Health Care: introduces students to the foundation of safety, involving accident prevention and injury control.

2- Introduction to the Driving Task: provides an in-depth, thorough treatment of operating a motor vehicle competently in all major variations and under most conditions encountered within the traffic environment.

3- Driving Education Program Management: prepares prospective driver education teachers to plan, teach and evaluate the driver education classroom instructional mode.

4- Application of Driver Education Instructional Modes: prepares prospective driver education teachers to plan, teach and evaluate the driver education instructional modes such as simulation, multiple car driving range, and on-street training.

More information on the Highway Safety Center may be found at http://www.iup.edu/highway/about. As part of its curriculum, IUP offers lectures on perceptual driving, which is designed to enhance the knowledge needed to effectively improve perceptual driving skills by being able to quickly identify situations that could be problematic and how to properly respond. Assuming all vehicles are connected and autonomous by the year 2040, there will need to be an additional set of core classes integrated into the curriculum to ensure students learn how to handle potentially dangerous situations one might encounter when driving or responding to an emergency involving an automated vehicle. Vehicle control system failures are inevitable and as a result it is recommended that this course continue to teach drivers how to identify problematic situations. These concepts would have to evolve with advancements in automated vehicle technology. By the year 2040, classes should be implemented to teach students how to handle emergency situations or vehicle malfunctions when a user must override the vehicle control process and manually drive to a safe destination. If drivers are educated on how to properly react to vehicle control system failures, then potentially fatal accidents could be avoided. Connected and autonomous vehicles will have additional electrical and mechanical equipment to enable automation features. Training is required for first responders to ensure the safety of drivers and responders during an accident or other emergency with automated vehicles. This could include, but is certainly not limited to, risk of electric shock, or unanticipated vehicular movement.

With the growing implementation of platooning, courses need to cover topics such as safely entering and exiting a platoon as well as a safe following distance. Platooning has the potential to greatly increase traffic flow and fuel economy, if users in the platoon follow proper procedures. Another topic of interest related to the 2040 design year of automation would be on how to react to oncoming emergency vehicles. As humans begin to rely heavily on vehicles that drive themselves, it remains imperative that drivers are able to react quickly to oncoming emergency vehicles so the emergency vehicle may get to its destination in a timely manner.

One of the main challenges on driver's education and training for trainers is the lack of resources at the university or college level. Training for trainers requires hands-on experience with vehicles equipped with electronic assist features. Providing the training and educational institutions with resources in terms of funding, simulation packages or an actual vehicle will help the institutions to better train and prepare their trainees for driving education.

Collaboration with local and state educational institutions (e.g. IUP), including provision of funding to support training offered at these institutions, will be important to enhancing workforce training as higher levels of vehicle automation evolve.

IUP's curriculum on training of drivers, including high-school based driver's education will be discussed in more detail as part of the next task.

Government Agencies:

U.S. Department of Transportation (U.S. DOT): The United States Department of Transportation offers free Intelligent Transportation System (ITS) training, which can take place through tailored specific events, standard training modules, peer-to-peer (P2P) programs, knowledge resource databases, and webinars (U.S. DOT 2014). Training modules include an introduction to ITS, topics on systems engineering and traffic operations, and emerging applications and technologies in the field of transportation. P2P programs can be utilized as a tool for experts to be able to share knowledge, resources, and various experiences to public agencies and the transportation industry. This training option provides an opportunity for experts to learn from each other and openly share any knowledge they have available related to ITS, making resources more widely available and easily accessible to those who otherwise would not of been able to access this information. The U.S. DOT also offers knowledge resource databases, which include a collection of journal articles and technical documents related to ITS. The last training option offered by the U.S. DOT is webinars, which are 90-minute web conferences on discussions about ITS life-cycle issues, highway, transit, multimodal applications, etc.

With the growing interest in connected and autonomous vehicles, U.S. DOT has been also offering webinars on new technologies. It is anticipated that U.S. DOT will be updating its standard training modules, P2P programs, knowledge resource databases, and webinars as surface transportation issues evolve toward automation.

PennDOT Training: PennDOT provides in-house training for all new employees who will be working as examiners at driver's license test centers. In addition, PennDOT will soon implement a new web-based training program that Driver License Examiners will be required to take in order to administer the non-commercial skills test. The new web-based training includes information on new vehicle technologies, such as back-up cameras, sensors and self/auto park features. In a future with automated vehicles, it will be important for PennDOT to continually evaluate its in-house training program and to include coursework and material relevant to connected and autonomous vehicles. Since this type of training is directly related to driver's licensing, we discuss this topic further as part of Task 6.

With the exception of PennDOT's training for driver's license examiners, all programs and certifications explained above are supported by the federal government or third party professional groups. State DOTs, including PennDOT, are not expected to have direct impact on the anticipated changes to any of the programs discussed above. However, to respond to workforce training needs within the field of connected and autonomous vehicles, it is recommended that PennDOT encourage its transportation personnel and practitioners to participate in these training programs and webinars, which are geared toward educating state and local highway agencies on how to evaluate and effectively implement various technologies.

To adequately train its workforce, PennDOT should encourage its transportation engineers, planners, and practitioners to participate in webinars, seminars and training offered by the U.S. DOT and other entities to assure familiarity with connected and autonomous vehicles.

Chapter 6: Impacts to Driver Licensing

This task evaluates the impacts of connected and autonomous technologies on driver licensing. The following specific topics were explored as part of this task:

- How skills testing criteria should change to properly determine driver skills in a vehicle with various electronic assists, such as self-parking, lane position detectors, left-turn assistance, emergency braking and intersection assistance.
- What allowances can be made if self-driving cars minimize the impact of medical impairments on the ability to use connected and autonomous vehicles.
- How training of drivers, including high school based driver's education and mature driver's courses, and the training for driver license examiners on administrating skills test for people with autonomous vehicles should change.

Skills Testing Criteria: In the Commonwealth of Pennsylvania, the current testing procedure for obtaining a non-commercial driver's license includes a knowledge test and a road (skills) test. The knowledge test measures the applicant's knowledge of Pennsylvania's driver laws, traffic signs, and safe driving practices. The knowledge test is a computerized, self-administered test, and can be taken in 10 languages.

The road test includes:

- Inspection of the vehicle used for testing;
- Vehicle controls: operating horn, lights, windshield wipers, parking brake, flashers, defroster, etc;
- Parallel parking: parking a vehicle midway between two uprights in a space that is 24 feet long and 8 feet wide; and
- Actual road test: driving while obeying signs, stop signs, and traffic lights.

In addition to understanding and obeying traffic control devices and rules of operation, driver condition is also an important factor in successfully obtaining a driver's license. Conditions such as inattention, alcohol use, drug use, medical conditions and disabilities can adversely affect testing skills.

With the advancement of automation, the current skills testing criteria will likely need to change. Level of change on all skill set criteria, including knowledge test, road test and medical conditions correlates with the level of automation. For detailed explanation of automation levels introduced by NHTSA, please refer to the *Background* section.(NHTSA 2013).

For level 4 automation, assuming vehicles do not rely on any human interaction, skills testing will gradually become obsolete. An exception may be if vehicle manufacturers rely upon human intervention to stop a vehicle in case of a malfunction. The alternative would be to have fail-safe systems to stop a malfunctioning vehicle automatically.

In 2040, when all vehicles are connected and automated, there may be drivers who would still wish to drive their cars manually or use their older vehicles. State DOTs may consider a new class of licensing for manual driving.

For the 2040 design year, a new license class may be introduced for those wishing to drive their manual cars or drive their automated cars manually.

For levels 0-3, since a driver needs to be present and in control of the vehicle, skills testing should be required. PennDOT should continue testing drivers for all early levels of automation (0-3). Criteria for skills testing, however, will likely change for each level of automation.

Driving and skills tests should be required for all levels of automation with an exception of level 4 (fully autonomous vehicles), where there will be no interaction between drivers and vehicles.

Testing criteria for all levels of automation (0-3) should be updated to assure driver's basic familiarity with electronic assist features as well as required interactions between drivers and vehicles.

With the advancement of automation, various electronic assists, including self-parking, lane position detectors, left-turn assistance, emergency braking and intersection assistance, are either already available on some vehicles or will soon become available. The electronic assist features are designed to enhance the safety of vehicles and its passengers. Some of these features can be activated or deactivated by the driver (e.g. self-parking assist), while others are not exposed to human interactions (lane position detectors). In the Commonwealth of Pennsylvania, vehicles equipped with advanced parking guidance systems can be used for testing; however, the self-parking feature must be turned off and is not permitted to be activated during the road (skills) test.

While it is possible to limit the use of electronic assist features during road tests today, as automation levels advance the task of deactivating some of the features during road tests will become daunting. Deactivation of some of the electronic assist features may need a thorough understanding of the electronic equipment and sensors installed on vehicles, which may not necessarily be a skill for drivers to tackle. Therefore, it appears that the current method of testing drivers by disabling the electronic assist functions such as self-park will become less practical as automation advances.

PennDOT's Deputy Secretary for Driver and Vehicle Services noted that a current driver testing decision rule related to electronic assist features is whether or not the feature can be deactivated. If not, then the skills test would include their use. This is a logical decision rule that should serve PennDOT through the expected transition from today's vehicle technology to full automation.

Basic familiarity with the electronic functions of automated vehicles should be required for all drivers using automated vehicles levels 0-3. This will help the drivers to take over the control of the vehicles in emergency situations or on an as-needed basis. In addition, education on how and when a driver should interfere with automated features will be necessary as automation level increases. Understanding of the electronic features of vehicles as well as the level of interaction between drivers and vehicles should all be tested as part of the knowledge test to assure a basic familiarity of drivers with vehicles' equipment and features.

A challenge with testing drivers' knowledge on automated and electronic assist features is that different vehicles may have features that operate differently. Therefore, standardization becomes crucial in this process. Much like seat belts and air bags that function and operate the same way from one vehicle to another, automated and electronic assist features should be designed in such a way that drivers would be able to use them or interact with them on an as-needed basis, regardless of the make and model of the vehicle. While this is not a problem for PennDOT to directly deal with, it will impact the design criteria of knowledge and road tests.

The following factors will impact skills testing criteria as we approach the year 2040 and a fully connected and automated environment:

- Higher levels of automation (levels 2 and 3) will likely require a more comprehensive knowledge test. Basic familiarity with electronic assist packages and equipment, regulatory and liability issues, as well as guidance on interactions between human and vehicle (when and how to interact) should all be included as part of the knowledge test.

- Standardization of electronic assist features will be crucial in the process so that drivers know how to work with these features in all types of vehicles. In the absence of such standardization, automobile manufacturers need to set procedures for driver's education on the make and model of the vehicles they offer for sale or lease. Although this is not a state DOT challenge, it will impact the skills testing criteria.

- For road (skills) tests, automated vehicles should be allowed for testing purposes and be used with the features they come with. While some functions are easy to deactivate, others may not be.

Changes to skills testing criteria will be a gradual process. PennDOT should update both knowledge and road test requirements as automation advances with each level.

Medical Impairment: The current state law in Pennsylvania requires healthcare personnel to report those drivers whose skills may be impacted by a medical condition to PennDOT. A Medical Advisory Board at PennDOT is responsible for setting physical and mental criteria for driver licensing. Reporting criteria includes physical and mental conditions, such as seizure disorder, unstable diabetes, cognitive impairments and cardiovascular conditions among many others.

With level 4 automation, where there will be no driver-vehicle interaction, it will be probable that allowances can be made for medically impaired individuals to use autonomous vehicles. With earlier levels of automation (0-3), it is recommended that PennDOT not change its current requirements and procedures, since levels 0-3 automation require full or partial control of vehicles by drivers. Medical teams should continue to be involved providing guidance to DMVs as to what level of driving a person could undertake.

Medically impaired individuals:

Automation levels 0-3: no change to current procedures

Automation level 4: allowances should be made

Driver's Education and Examiner's Training: Training for drivers (including high school based driver's education and mature driving courses), training for educators, as well as training for examiners will need to change as we approach higher levels of automation. Training for each of these groups is offered by different organizations.

- Training for drivers: Most drivers receive their driving education in high school. Those who do not take a driver's education class in high school have an option of receiving their education from private instructors.

- Training for driver's educators: The certification and regulation of driver education teachers is administered by the Pennsylvania Department of Education based on the Pennsylvania Public School Code of 1949. Instructors who wish to teach driver education are required to complete four university level courses in driver and safety education. A list of these four courses offered by IUP in the state of Pennsylvania was presented as part of Task 5. Teachers at a private driving school are not required to take the driver and safety education courses. In fact, teachers at a private driving school are not required to take any course as long as they satisfy the following requirements:

    - Be a citizen of the U.S. of at least 21 years of age and of good moral character.
    - Present a certificate from a medical doctor stating that the teacher does not have any mental or physical ailments that would prevent him or her from being a driving instructor.
    - Possess a valid Pennsylvania Driver's License.

  - Submit documentation of having driven at least 15,000 miles in all weather conditions in both urban and rural areas.
  - Maintain a driving record of no more than one reportable accident resulting in suspension or revocation of a driver's license within a three-year period.
  - Pass a written examination administered by the Department of Education.
  - Pass a driving test administered by PennDOT.

- Training for driver license examiners: All new employees wishing to work as a driver license examiner are required to take training offered by PennDOT. As mentioned earlier, the new, web-based training program regarding the administration of the non-commercial skills test will soon be available to train PennDOT driver license examiners.

All three types of training will likely need to change as vehicle automation advances. Here is a list of changes anticipated for training as connected and autonomous vehicles become widespread. The list may serve as a guide for adding topics and modules to the current curriculums as we get closer to the year 2040 and connectivity and automation become prevalent.

- Class modules and hands-on training on the new connected and autonomous technologies, including the electronic assist features installed on vehicles.
- Training and lectures on emergency situations or system malfunctions, where a human would need to override the vehicle control process.
- Training and coursework on human interaction levels. Coursework should include:
  - Risks and benefits of human interaction with higher levels of automation.
  - Regulations on enabling and disabling safety features.
  - Human distraction due to information overload, especially at lower levels of automation.
- Course topics on rules and regulations related to platooning of vehicles.
- In a rapidly changing era of automation, where technologies are changing at an extremely fast pace and training resources are limited, investing on trainings through simulators will be an efficient way to train teachers and examiners. Simulators can be adjusted to various automation levels to make sure educators and examiners are up to date with respect to the mainstream technologies at any given point of time.

Changes to training and driver license issues will be incremental.

The focus of training should be on automation levels 2 and 3, as level 4 is further out and would need far less involvement from drivers.

Simulators will be effective tools to use for training purposes as they can be adjusted to different levels of automation.

As for regulations to permit operation of autonomous vehicles, PennDOT will need to adopt regulations that establish the requirements for the manufacturing companies that plan on testing their vehicles in the Commonwealth of Pennsylvania. These requirements can be categorized into three groups of:

- Requirements for manufacturing companies (e.g. testing of vehicles under controlled environment);
- Requirements for drivers (e.g. completion of training offered by manufacturing companies); and
- Requirements for application and vehicle (e.g. evidence of insurance, bond or self-insurance).

Beyond testing, PennDOT will also need to establish requirements for approval of any application submitted for driver licensing to ensure the safe operation of autonomous vehicles on public roads. To assist with a smooth transition and preparation of legislations, statewide committees need to be formed, which may include stakeholders from PennDOT, Commonwealth of Pennsylvania Insurance Department, and the Pennsylvania Turnpike Commission, among others. Other decisions that need to be made could be types of vehicles excluded from testing, type of license plates (if different than the regular plate), and grounds for suspension of driver licenses. As with any legislation, informing and educating the public and conducting public hearings will be a crucial part of the legislation process.

Chapter 7: Impacts to Communication Devices Investment

This task evaluates communication devices investment and what, if any, roadside communication devices are needed to communicate with connected and autonomous vehicles. In addition this task will recommend time frames for such investments.

As briefly mentioned in the background section of the report, there are two main categories of wireless technologies associated with connected vehicles: 1) cellular, and 2) DSRC.

Cellular based technology generates geo-located data and transmits those data through devices such as smart phones or cellular equipment built into the vehicle by the original equipment manufacturers (OEM). Types of data generated include latitude, longitude, speed, acceleration, brake status, external temperature, vehicle length, and vehicle mass among many others.

V2V safety applications include forward collision warning, emergency electronic brake light, lane departure warning, do not pass warning and left turn assist. Assuming that by the year 2040 all vehicles or drivers/operators will be equipped with some form of cellular equipment either built into their vehicles or carried with them, data will be transmitted between the cellular devices to assure safety. Investments and design changes made by government authorities in this case are minimal, since most equipment are already either installed on the vehicle or is purchased by the driver of a light duty vehicle through applications installed on their smart phones, tablets or OBUs.

In terms of V2V and safety applications for transit vehicles, transit agencies need to decide which types of V2V enabling equipment need to be installed on buses or need to be provided to bus operators.

With V2I technology, messages transmitted from infrastructure include, but are not limited to, signal phasing and timing, speed limit, available parking spaces, weather information, transit and freight information. The following table shows V2I applications that would need physical roadside unit investment and installation for DSRC, categorized into two groups: safety and mobility applications.

Table 3: V2I applications needing DSRC roadside unit installation

Safety Applications	Stop Sign Violation
	Red Light Violation Warning
	Oversize Vehicle Warning
	Curve Speed Warning
	Reduced Speed Warning
Mobility Applications	Advanced Traveler Information System
	Weather Information
	Motorist Warning and Information
	Dynamic Route Guidance
	Queue Warning
	Speed Harmonization
	Emergency Communication

DSRC technology uses Wi-Fi radio, which transmits messages ten times per second within a 300 meter range. Types of information transmitted through DSRC are fairly similar to cellular technology (e.g. speed, location, etc.). DSRC technology is currently being tested at about six test beds around the nation. It is however important to note that V2V technology using DSRC does not require any infrastructure. Therefore, when speaking of DSRC it is only for the applications that pertain to V2I that infrastructure investments may be needed.

NHTSA's decision on regulating DSRC, announced on February 3, 2014, indicates that US DOT will begin taking steps to require V2V communication technology for light duty vehicles. This decision only pertains to V2V applications and does not include V2I technology. The installation of roadside units for DSRC is a choice for each state and local agency. In 2015, US DOT will provide guidance for those agencies that wish to deploy V2I applications. If PennDOT wishes to use DSRC for V2I applications, the infrastructure investment it makes will have to conform to NHTSA's security network requirements. Associated costs will need to be considered before installing DSRC roadside units. Given the existing uncertainty with the regulation of DSRC technology at the time of drafting this report, PennDOT can decide if and how any investment decision needs to be made based on this draft report.

The following list includes our general recommendations for PennDOT regarding V2V and V2I investment decisions:

- Zero to minimal investment decision is necessary for PennDOT regarding cellular or DSRC technologies related to V2V applications for light duty vehicles. It is our prediction that most vehicles manufactured within the next five years will be equipped with either high speed cellular 4G LTE technology or will be equipped with DSRC on-board equipment to allow communication between vehicles.

- In terms of V2V applications for heavy duty vehicles, transit and freight agencies within Pennsylvania will need to decide if it is beneficial to provide cellular devices to their operators of the vehicles or use built-in equipment to communicate with one another. Such investment costs are minimal to the involved agencies. A number of smart phone applications such as DriveWyze are currently available in the market.
- With respect to V2I safety and mobility applications that would need DSRC equipment, PennDOT needs to decide which categories of information and which application from Table 2 are most beneficial and prioritize investment decisions accordingly. Categories of applications include mobility and safety.
- V2I applications using cellular technology are currently available through various smart gadget applications such as Drivewyze, Nextbus, variety of weather information apps and a variety of GPS apps for routing information and accident information such as Waze. These V2I applications are already available in the market. DriveWyze is an application that can be downloaded on smart gadgets in order for the operators to bypass weight stations, and consequentially save time and fuel. Transit apps such as Nextbus provide real time passenger information for buses and riders. These apps are provided at a minimal cost to the operators and drivers of light and heavy duty vehicles as well as pedestrians and bicyclists. No major investment decision is needed from PennDOT in this area as most of the data is being provided by large data companies. The only potential investment area for PennDOT is to provide information on traffic signals. Since this type of information needs to be within a security network we recommend that PennDOT await US DOT’s guidelines on DSRC to pursue communicating infrastructure information that demands a high level of security. We predict that when DSRC technology is regulated, a variety of OEMs will provide roadside units for V2I applications that follow US DOT’s security network regulations. As a result, the system and applications will be far less vulnerable and the risk of application failure due to hacking will be reduced significantly.

  Steps that PennDOT can take in near term, while 1) NHTSA is moving forward with the regulation procedures, 2) US DOT is providing guidelines and 3) until the OEMs are ready to distribute their equipment to the market, are:

  - Identify locations for roadside units that would generate substantial safety and/or mobility benefits such as high crash intersections, narrow roads, tunnels and sharp curves.
  - Identify traffic signal systems and other ITS locations (e.g. toll facilities, ramps) that would need equipment (i.e. controller) upgrades.

Given the embedded security concerns in the field of automation, and the rapid pace of research in both worlds of connected vehicles – from the government side – and autonomous vehicles – from the private industry – the connected automated scenario seems to be more likely for the design year of 2040. It is our judgment based on current available information that by the year 2040 driverless vehicles in most urban areas will be operating in a fully connected environment. As such, investment decision recommendations applicable to connected and autonomous vehicles follow the same general path of connected vehicles mentioned earlier.

Given the expected developments in V2V and V2I communications and applications, PennDOT should be seeking private and public partnerships to help manage communications and communication investments. Applications such as E-ZPass have illustrated the scale economies and benefits of such partnerships in this area.

Chapter 8: Impacts to Freight Flow

This task evaluates the impact of connected and autonomous vehicles on freight flow. The task provides evaluation and recommendations on how, if at all, the implementation of these technologies will affect freight flow.

Commercial vehicles and trucks are crucial for the country's economy and shipping industry. Traffic congestion in most urban areas impacts goods movement negatively due to delays. Therefore connectivity and automation technologies could be effective in enhancing freight movement and flow.

Much like the other types of impacts discussed in earlier tasks, changes to freight flow, if any, will be incremental. Connected and autonomous vehicles' impacts on freight flow may be investigated from three distinct perspectives:

- Technological perspective
- Regulatory perspective
- Economic perspective

One or a combination of these factors will drive the environment of connected and autonomous vehicles and trucks. However, none of these perspectives will directly impact PennDOT's decisions and operation as they are driven by other agencies, institutions or entities. For instance, technological aspects of freight flow needs to be enhanced and investigated by automobile/truck manufacturing companies. Decreased fatigue and hour of service, which could be a significant economic driver is a regulatory decision that needs to be addressed by the Federal Motor Carrier Safety Administration (FMCSA). Many of the steps needed to be taken for the full deployment of freight automation will fall under legislative policy changes and will not be impacted by State DOTs including PennDOT. Demonstration and pilot tests is another step that will significantly help moving the industry towards automation. This is an area that PennDOT can impact by providing a test bed, especially in conjunction with corridors of freight transport or individual city logistics management.

One area within PennDOT's control is permitting procedures for oversize and overweight trucks. PennDOT currently manages a computerized Automated Permit and Route Analysis System (APRAS) which it makes available to freight haulers to automatically obtain routing permits for hauling oversize and overweight truck loads. Haulers identify their intended trip origin and destination along with the loads height and weight and APRAS automatically provides safe routing and an associated permit valid for five days. The hauler then has to decide if the selected route is optimum for the intended trip. If not, then typically an iterative process ensues to select a final routing. Approximately 500,000 permits are issued yearly through APRAS. Low height and weight restricted bridges are the primary focus of APRAS. There have been 121 *reported* overhead bridges hit since 2005 according to Glenn Rowe, Chief of PennDOT's Transportation

Operations Division. The actual number is likely to be a good bit higher due to unreported strikes. PennDOT updates weight restrictions, as needed, immediately following inspections on its 25,000 bridges.

There are vulnerabilities and difficulties with the current overweight/over-height truck management system. One is that haulers voluntarily list the height and weight of their load on the APRAS application. Another is that a bridge could receive a new weight restriction within the five-day period after the APRAS permit is issued and unless the hauler checked back, there wouldn't be any notification. Roadway overlay projects can also affect bridge clearance and lag in having that information input into PennDOT's Bridge Management System and APRAS. Incidents such as flooding will affect permitted routes. Finally, APRAS routings can be complex and drivers can miss some turns. For example, an over-height truck travelling on I-80 might be routed off an interchange ramp and immediately back on to avoid an overpass height restriction. A driver could miss this instruction unless he/she is very attentive.

The APRAS system covers PennDOT's 40,000 miles of state-owned roads, but not the 80,000 additional miles of roads owned by counties and municipalities. Haulers have to contact each jurisdiction for their portions of routes. This is both cumbersome and difficult in the case of small municipalities with part-time staff.

Potential issues that need to be considered to address the wide proliferation of automation of commercial vehicle for freight by 2040 are discussed below, along with specific actions that PennDOT can address in the near term.

Operation Changes:

- Management and permitting for oversize/overweight loads should take advantage of new capabilities for vehicle communication. Oversize/overweight loads will eventually require less local warning with V2X communication. Moreover, other traffic may be able to re-route to avoid oversize/overweight loads. In addition, routing of oversize/overweight loads can be changed in real time in response to incidents or new load limits.
- Dispatch and logistics of commercial vehicles themselves will be in the hands of private companies and fleet operators. Connectivity and real time information systems for routing and dispatch are expected to bring additional efficiencies in the logistics of roadway freight movement (Crainic 2009).
- Hours of service are set nationally (USFMSA 2014) and are unlikely to be changed until considerable experience with autonomous vehicles has occurred. No action from PennDOT is required in this regard.
- Enforcement issues: Vehicle identification and weigh-in-motion scales at toll booths could eliminate the need for dedicated weigh stations, resulting in cost savings for station construction and operation. Drivers of over-height vehicles could be notified

digitally, reducing the need for warning signals. For drivers who ignore height restriction notifications, camera detection could provide an automated enforcement tool.

- Construction zones: Truck crashes in construction zones should be reduced, especially for vehicle collisions with attenuators, resulting in contractor cost savings that will eventually be shared with PennDOT.
- Congestion, Construction Zone and Incident Information: As with all vehicles (and discussed in Task 2 report), PennDOT should move to make information on congestion, construction zone and incident information available to third party information providers.
- Incident management should be streamlined with the use of new technology. For example, accident reconstruction should take advantage of new video technology to minimize lane closures. This is not a PennDOT change as police officers perform this task.
- Dedicated truck and bus lanes may result in a number of benefits including increased capacity for trucks. Potential increased capacity would demand updates to design manuals. Detailed analysis and implications of capacity increase for light and heavy duty vehicles were discussed as part of Task 2 of the project.
- As noted in Task 2, light duty vehicle lanes might be smaller in width than standard 12 foot lanes, provided the possibility of additional lanes in some areas dedicated to small, autonomous vehicles. No action is required by PennDOT in this regard in the near term, but lane management changes may be worthwhile considering by 2040.

PennDOT should insure that information on overweight/oversize and farm equipment movements be made available to connected vehicles in the vicinity of such movements as connected vehicles begin to appear.

Specialized freight infrastructure such as over-height warnings and weigh stations can be phased out by PennDOT as new technology for weigh-in-motion and connectivity are introduced.

Technology Changes:

- This year, PennDOT will be hiring a contractor to update APRAS. While it is expected to take over a year to implement, the update will provide significant opportunities to accommodate both current and emerging connected and autonomous vehicle technologies. The combination of real-time transportation data and trucks with GIS capability will provide nearly fail-safe routing and on-route directions for drivers.
- The updated APRAS system will accommodate municipalities who wish to enter their respective road networks and associated weight and height restrictions. Interestingly,

emerging vehicle sensing devices present an opportunity to capture real-time height and width data and perhaps even axle-loading data critical to safe routing.

- Information about truck drivers and freight companies is also becoming available in digital forms that can aid enforcement. Driver operating logs are being converted to electronic logs. Further, FMCSA is producing electronic records of both driver performance and companies with repetitive vehicle violations. V2I and V2X data systems will be important methods to both monitor truck movements as well as provide real-time information.
- A major issue for truck drivers and haulers is dealing with incidents. Examples of incidents are accidents that block routes, weather that restricts travel or simply major congestion that produces delay. Faced with these impediments, APRAS permitted drivers today have to remain on their designated routes in order to be in compliance with their permits. In the future, the combination of connected vehicle technology and real-time transportation information will provide for real-time re-routing for oversize/overweight loads. Similarly, routings will be able to be instantly revised if a bridge has to be weight limited due to a new structural inspection.
- Electronic driver logs should permit less costly and faster retrieval of information on truck movements in the Commonwealth of Pennsylvania.
- Implementation of platoons with mixed or single classes of vehicles is very likely to occur, especially on interstate roadways. As noted earlier, these platoons may increase the expected flow on such roadways.
- Connectivity vs. automation timeframe will vary, with connectivity expected to become prevalent earlier. Adoption of new information and communications technologies in the freight transportation industry also varies significantly (Perego, 2011)

During the APRAS system update, PennDOT should consider the numerous opportunities connected and autonomous vehicle capabilities will present. It is also an opportunity for PennDOT to work with the trucking industry and State Police to design features tailored to each group. Both enforcement and freight movement will be significantly enhanced as a result.

PennDOT should encourage the availability of electronic driver logs in commercial vehicles for providing data on commercial vehicle movements and for apportioning federal diesel fuel tax revenues.

Policy Changes:

The introduction of connectivity and autonomous freight vehicles raises numerous policy issues, including dealing with varying levels of automation, truck following regulations, acceptance of new technology, additional training to deal with technology, and licensing requirements. As mentioned earlier many of these issues will be addressed by either federal government (i.e. FMCSA) or truck manufacturing companies. Operational issues will generally be addressed by private trucking companies except as noted above. However, PennDOT can serve a major role in providing a test bed for new policies and technologies.

Most decisions related to freight and automation will not be impacted by PennDOT.

PennDOT can play a significant role in moving the industry towards automation by providing test beds and insuring that information on incidents and overweight/oversize vehicle movements is available to connected vehicles.

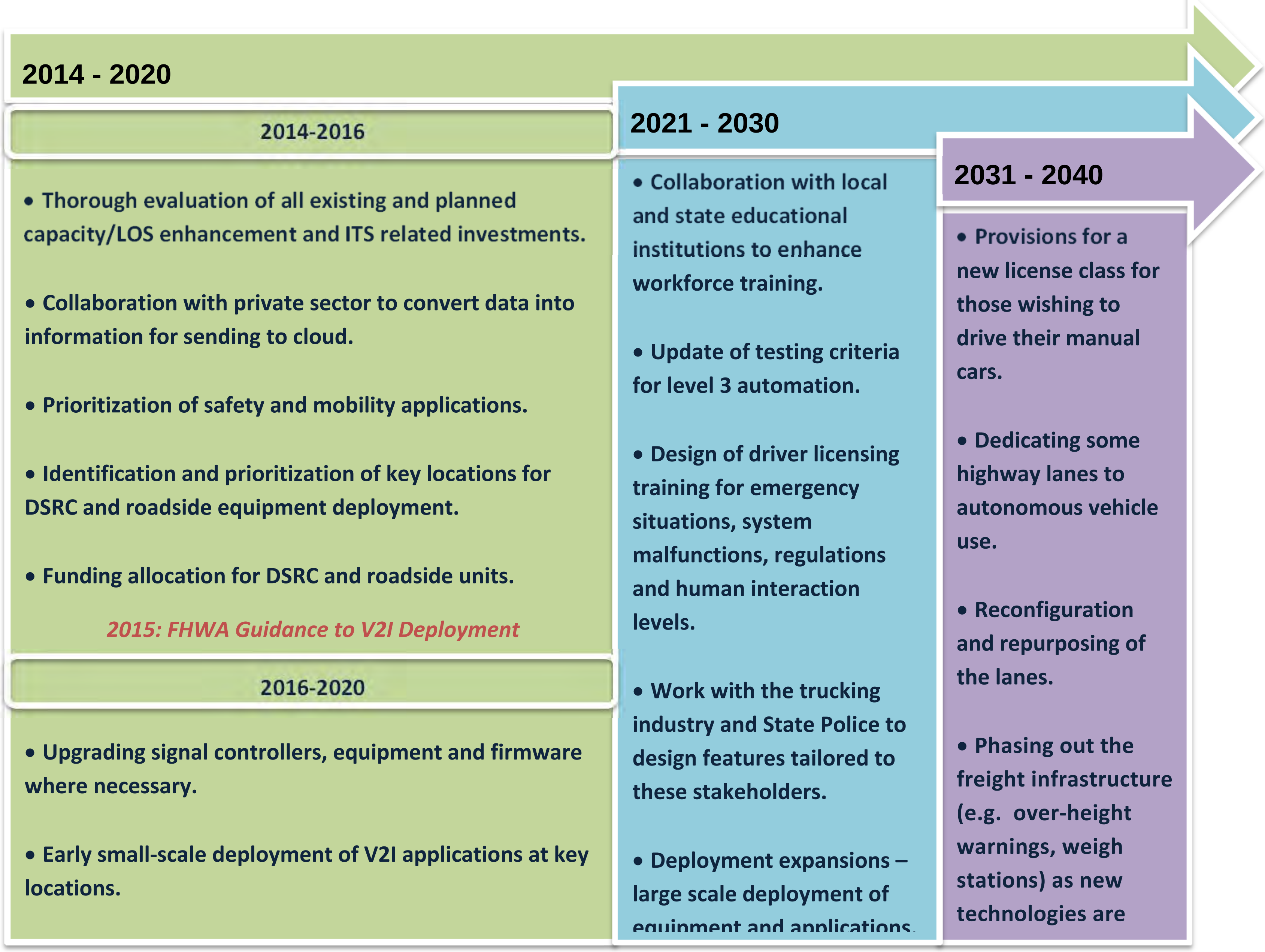
Challenges

Freight automation poses challenges that are different than light duty vehicle automation. These challenges may adversely impact the implementation of connected and autonomous technologies on freight and its flow. Here is a list of some of these challenges:

- While interstate operation of automated freight movement may be possible, implementing the technology onto the local roads will be extremely challenging.
- Drivers' role in freight movement is more than just driving (i.e. picking up and dropping packages and trailers). Therefore a driver will be needed even with automation. However, one driver may be able to manage a set of autonomous vehicles in movements between warehouses.
- Licensing requirements will encompass additional technical requirements for operating a truck.
- Cost is a major issue for both new equipment and for maintenance.

Timeline

For each of the tasks discussed in previous chapters a set of recommendations and actions applicable to PennDOT's operation were presented. As connected and autonomous technologies are advancing, it is recommended that PennDOT take these actions in a timely manner. Figure 6 provides a timeline for the actions recommended in this report to help PennDOT plan accordingly. The timelines are based on current available information and the time frames are likely to change over time. The timelines in the figure should be updated frequently as connected and autonomous technologies advance.



2014 - 2020

2014-2016

- Thorough evaluation of all existing and planned capacity/LOS enhancement and ITS related investments.
- Collaboration with private sector to convert data into information for sending to cloud.
- Prioritization of safety and mobility applications.
- Identification and prioritization of key locations for DSRC and roadside equipment deployment.
- Funding allocation for DSRC and roadside units.

2015: FHWA Guidance to V2I Deployment

2016-2020

- Upgrading signal controllers, equipment and firmware where necessary.
- Early small-scale deployment of V2I applications at key locations.

2021 - 2030

- Collaboration with local and state educational institutions to enhance workforce training.
- Update of testing criteria for level 3 automation.
- Design of driver licensing training for emergency situations, system malfunctions, regulations and human interaction levels.
- Work with the trucking industry and State Police to design features tailored to these stakeholders.
- Deployment expansions – large scale deployment of equipment and applications.

2031 - 2040

- Provisions for a new license class for those wishing to drive their manual cars.
- Dedicating some highway lanes to autonomous vehicle use.
- Reconfiguration and repurposing of the lanes.
- Phasing out the freight infrastructure (e.g. over-height warnings, weigh stations) as new technologies are

Figure 6: Recommended Timeframe for PennDOT's Actions with regards to Connected and Autonomous Vehicles

Acknowledgment

The authors wish to acknowledge the valuable information provided by Dr. Louis J. Pesci, Indiana University of Pennsylvania Highway Safety Center and Kurt J. Myers, PennDOT Deputy Secretary for PennDOT's Driver and Vehicle Services, in preparing the reports for Tasks 5 and 6. The authors wish to acknowledge the valuable information provided by Charles L. Hammel III, President, Pitt Ohio Express and Glenn C. Rowe, Chief of PennDOT's Transportation Operations Division, in preparing the report for Task 8.

Bibliography (including both references in the report and useful background documents)

American Association of State Highway and Transportation Officials, (2013), 'National Connected Vehicle Field Infrastructure Footprint Analysis', Application Analysis', Version 3, July 31, 2013. http://ssom.transportation.org/Documents/Applications_Analysis%20v3%20july%202013.pdf accessed January 19. 2014.

American Association of State Highway and Transportation Officials, (2013), 'National Connected Vehicle Field Infrastructure Footprint Analysis, Deployment Scenarios', www.its.dot.gov/index.htm. Accessed January 19, 2014.

Amend, James M. (2014), 'GM Links with AT&T to Bring 4G LTE Connectivity in 2014', WardsAuto, http://wardsauto.com/vehicles-amp-technology/gm-links-att-bring-4g-lte-connectivity-2014 , accessed January 24, 2014.

Anderson, J., Kalra, N., Stanley, K., Sorensen, P., Samaras, C., Oluwatola, O. (2014). 'Autonomous Vehicle Technology: A Guide for Policymakers', Santa Monica, CA: RAND Corporation, RR-443-RC, 2014.

Barr, L. C. (2000) 'Testing for the significance of induced highway travel demand in metropolitan areas', Transportation Research Record: Journal of the Transportation Research Board, vol. 1706, pp. 1-8.

Bayly, M., Fildes, B., Regan, M., & Young, K. (2006). 'Review of crash effectiveness of Intelligent Transport Systems'. Emergency, 3, 14.

California Bill SB 1298, (2012), 'autonomous vehicles: safety and performance requirements.' http://www.leginfo.ca.gov/pub/11-12/bill/sen/sb_1251-1300/sb_1298_bill_20120926_status.html, accessed February 17, 2014.

Carrol, Rory (2013), 'Tesla Enters Race to Build Self-Driving Car', Reuters, accessed September 17, 2013. http://www.reuters.com/article/2013/09/18/us-tesla-selfdriving-idUSBRE98H01720130918

CCAC Community College of Allegheny County (2013), "Community of Allegheny County Catalog 2013-2014', http:/ /www.ccac.edu/files/PDF_Document/5d47b13151 fc477a9dec96be7a0ae2d0.pdf, pp.171-173, accessed February, 10 2014

Charette, R. (2009), 'This Car Runs on Code', February 1, 2009, http://spectrum.ieee.org/green-tech/advanced-cars/this-car-runs-on-code, accessed February 20, 2014.

Crainic, Teodor Gabriel, Michel Gendreau, and Jean-Yves Potvin. "Intelligent freight-transportation systems: Assessment and the contribution of operations research." *Transportation Research Part C: Emerging Technologies* 17.6 (2009): 541-557.

Davila, A. (2010). 'SARTRE: SAfe Road TRains for the Environment'. IDIADA Automotive Technology meeting, London, UK. September 2010. http://www.princeton.edu/~alaink/Orf467F10/PRT@LHR10_Conf/Arturo_Davila_prez_SafeTrains.pdf, accessed October 15, 2013.

Dustin, W. (2013). 'Riding shotgun in a nearly autonomous vehicle: An amazingly gentle cruise.' http://www.crainsdetroit.com/article/20131008/BLOG012/131009866/riding-shotgun-in-a-nearly-autonomous-vehicle-an-amazingly-gentle, accessed February 20, 2014.

District of Columbia Bill B19-0931, (2013), 'Autonomous Vehicle Act of 2012'. http://dcclims1.dccouncil.us/lims/legislation.aspx?LegNo=B19-0931, accessed February 17, 2014.

Fagnant, Daniel J. and Kockelman, Kara M. (2013), 'Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations', The Eno Center for Transportation, Washington, D.C.

Federal Highway Administration, Office of Operations, (2004), 'Traffic Incident Management', accessed January 14, 2014. http://www.ops.fhwa.dot.gov/aboutus/one_pagers/tim.htm

Florida CS/HB 1207, (2012), 'Vehicles with Autonomous Technology', http://www.flsenate.gov/Session/Bill/2012/1207, accessed February 17, 2014.

Fountain, H. (2012), 'Yes, Driverless Cars Know the Way to San Jose', New York Times, October 26, 2012, accessed October 15, 2013.

General Motors (2014), 'Stay Connected Wherever You Go', https://www.onstar.com/web/portal/4GLTE?seo=goo_|_GM+OnStar_|_RTN-OnStar+4G+LTE-Broad_|_In-Car+4G+LTE_|_onstar%204g%20lte&g=1 , accessed January 22, 2014.

IHS (2014), 'Self-Driving Cars Moving into the Industry's Driver's Seat', http://press.ihs.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat, accessed May 28, 2014.
Indiana University of Pennsylvania (IUP), (2014), http://www.iup.edu/highway/, accessed February 17, 2014.

Insurance Institute for Highway Safety (2013), 'Measuring Crash Avoidance Systems Effectiveness with Insurance Data'. SAE Government Industry meeting proceedings, January 2013. http://www.iihs.org/iihs/topics/t/crash-avoidance-technologies/presentations/bytag, accessed October 15, 2013.

Insurance Institute for Highway Safety (2013), ‘Mercedes-Benz collision avoidance features: initial results’. Volume 29, No. 7, April 2012. http://www.iihs.org/iihs/sr, accessed October 15, 2013.

IntelliDriveSM Traffic Signal Control Algorithms (2011), prepared for the Cooperative Transportation Systems Pooled Fund Study by the University of Virginia, April 2011.

Lutin, J., Kornhauser, A., Lerner-Lam, E. (2013), ‘The Revolutionary Development of Self-Driving Vehicles and Implications for the Transportation Engineering Profession’, ITE Journal, July, pp 21-26, http://digitaleditions.sheridan.com/display_article.php?id=1446463&id_issue=165937, accessed May 29, 2014.

Klier, T. and Rubenstein, J. (2011). ‘Making cars smarter: The growing role of electronics in automobiles’. 291a. The Federal Reserve Bank of Chicago.

Litman, T. (2014), ‘Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.’ Victoria Transport Policy Institute. http://www.vtpi.org/avip.pdf accessed February 19, 2014.

Looney, S. and Gulledge Jr, T. (1985). ‘Use of the correlation coefficient with normal probability plots’. The American Statistician, 39 (1), pp. 75-79.

Merriam-Webster (2014), http://www.merriam-webster.com/, accessed June 9, 2014.

Mashayekh, Y.; Hendrickson, C.; Matthews, H. S.; ‘The Role of Brownfield Developments in Reducing Household Vehicle Travel.’ ASCE J. of Urban Planning and Development. 2012; 138(3), 206-214.

Mashayekh, Y.; Hendrickson, C.; ‘Benefits of Proactive Monitoring of Traffic Signal Timing Performance Measures – Case Study of a Rapidly Developing Network.’ Green Streets, Highways, and Development; Advancing the Practice. 2013; 202-211. American Society of Civil Engineers.

Michigan Bill 0169, (2014), ‘Michigan Vehicle Code’, http://www.legislature.mi.gov/(S(lbbfpl55omolkhqw0ulbktiz))/mileg.aspx?page=getobject&objectname=2013-SB-0169&query=on, accessed February 17, 2014.

Narla, S. (2013). The Evolution of Connected Vehicle Technology: From Smart Drivers to Smart Cars to… Self-Driving Cars. ITE Journal, pp. 22-26. www.ite.org/membersonly/itejournal/pdf/2013/JB13GA22.pdf , accessed May 30, 2014.

National Highway Traffic Safety Administration (2013) ‘Preliminary Statement of Policy Concerning Autonomous Vehicles,’ http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development, accessed September 11, 2013.

National Highway Traffic Safety Administration (2012) 'Traffic Safety Facts, Distracted Driving 2010,' http://www-nrd.nhtsa.dot.gov/Pubs/811650.pdf, accessed February 19, 2014.

Nevada Bill SB 313, (2013), http://leg.state.nv.us/Session/77th2013/Reports/history.cfm?ID=759, accessed February 17, 2014.

National Highway Traffic Safety Administration (2014) 'U.S. Department of Transportation Announces Decision to Move Forward with Vehicle-to-Vehicle Communication Technology for Light Vehicles,' http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles, accessed February 8, 2014.

National Cooperative Highway Research Program (2013), 'Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies', Transportation Research Board, Washington, D.C.

Paine, M., Paine, D., Griffiths, M., & Germanos, G. (2007). 'In-vehicle intelligent speed advisory systems'. Proceedings of 20th ESV, http://tinyurl. com/367gpf.

Pennsylvania Attorney General, Elder Abuse Unit. (2013), 'Protecting Elder Pennsylvanians', accessed January 22, 2014. http://www.attorneygeneral.gov/seniors.aspx?id=296

Perego, Alessandro, Sara Perotti, and Riccardo Mangiaracina. "ICT for logistics and freight transportation: a literature review and research agenda."*International Journal of Physical Distribution & Logistics Management* 41.5 (2011): 457-483.

RTI, Rosedale Technical Institute (2013), 'Rosedale Technical Institute 2013-2014 Catalog', accessed February 10, 2014, pgs. 7,9.

Schrank, D., Eisele, B., & Lomax, T. (2012), 'TTI's 2012 Urban Mobility Report', Texas A&M Transportation Institute. The Texas A&M University System.

Shladover, S.(2012). 'PATH Progress on Truck Platoons and Bus Steering Guidance', Transportation Research Board. July 2012. http://onlinepubs.trb.org/onlinepubs/conferences/2012/Automation/presentations/Shladover3.pdf, accessed October 15, 2013.

Shoup, D. C. (2006). 'Cruising for parking'. Transport Policy, 13(6), 479-486.

Smith, Stephen F., et al. (2013)) ‘Smart Urban Signal Networks: Initial Application of the SURTRAC Adaptive Traffic Signal Control System.’ Twenty-Third International Conference on Automated Planning and Scheduling. 2013.)

Snider, A. (2013), ‘Bill Shuster: Driverless cars are ‘the future of transportation’, Politico, September 9, 2013, accessed November 20, 2013. http://www.politico.com/story/2013/09/driverless-cars-transportation-future-96438.html

Society of Automotive Engineers (SAE), (2014), ‘Professional Development Courses’, http://training.sae.org/automotive, accessed February 19, 2014.

Stenquist, Paul, (2013), ‘Nissan Announces Plans to Release Driverless Car by 2020,’ New York Times, accessed September 1, 2013, pg. AU10.

Transportation Professionals Certification Board Inc., http://www.tpcb.org, accessed February 19, 2014.

Tech News World (2014), ‘Google Puts Cute Little Rides on the Road’, http://www.technewsworld.com/story/80525.html#, accessed May 29, 2014.

US Department of Transportation, Federal Highway Administration, 2009 National Household Travel Survey. http://nhts.ornl.gov, accessed January 20, 2014.

US Department of Transportation, Federal Highway Administration, Context Sensitive Solutions, ‘Mon-Fayette Expressway’, http://contextsensitivesolutions.org/content/case_studies/mon_fayette_expressway__pa/ accessed January 20, 2014.

US Department of Transportation, Federal Highway Administration, Office of Operations, Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Concept of Operations, v1.0, prepared by Battelle, May 29, 2012.

US Department of Transportation, U.S. DOT, (2014), ‘ITS Standard Training’. http://www.pcb.its.dot.gov/stds_training.aspx, accessed February 27, 2014.

US Department of Transportation, U.S. DOT, (2014), ‘Peer to Peer (P2P) Program’. http://rspcb.safety.fhwa.dot.gov/technical.aspx, accessed February 27, 2014.

US Department of Transportation, Research and Innovative Technologies Administration, Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO), Draft 3.0, prepared by Science Applications International Corporation, June 14, 2012.

US Department of Transportation, Research and Innovative Technologies Administration, Concept of Operations for Road Weather Connected Vehicle Applications, Draft Version 1.4.2, prepared by Booz Allen Hamilton, June 26, 2012.

US Department of Transportation, Research and Innovative Technologies Administration, 'Connected Vehicles Reference Implementation Architecture', prepared by Iteris, Inc. http://www.iteris.com/cvria. Accessed January 24, 2014

US Department of Transportation, Research and Innovative Technology Administration; Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications; Publication Number FHWA-HRT-11-040; November 2012.

US Department of Transportation, Research and Innovative Technologies Administration, Freight Advanced Traveler Information System, prepared by Cambridge Systematics, Final Report version 2.1, April 12, 2012.

US Department of Transportation, Research and Innovative Technologies Administration, Integrated Dynamic Transit Operations (IDTO) Concept of Operations, v3.0, prepared by Science Applications International Corporation, May 11, 2012.

US Department of Transportation, U.S. DOT, (2014), 'Talking Technology and Transportation Webinars'. http://www.pcb.its.dot.gov/t3_webinars.aspx, accessed February 27, 2014.

US Department of Transportation, Research and Innovative Technologies Administration, Vehicle Information Exchange Needs for Mobility Applications: Version 2.0, prepared by Noblis, FHWAJPO-
12-021, August 1, 2012. http://ntl.bts.gov/lib/46000/46000/46089/Final_PKG_FHWA-JPO-12-021_508_PDF.pdf

US Federal Motor Carriers Safety Administration (USFMCSA), (2014) 'Summary of Hours of Service Regulation,' http://www.fmcsa.dot.gov/rules-regulations/topics/hos/index.htm (accessed 3/29/2014.

Wadud, Z., MacKenzie, D., Leiby, P., (2013). 'Energy Savings and Rebound Effects of Highly Automated Vehicles.' TRB 2nd Annual Workshop on Road Vehicle Automation, July 2013. Stanford, CA.

Wang, Y., Yu, R., Lao, Y., Thomson, T., (2011), 'Quantifying Incident-Induced Travel Delays on Freeways Using Traffic Sensor Data: Phase II', Washington State Transportation Center. Seattle, WA. accessed January 14, 2014.
http://www.wsdot.wa.gov/research/reports/fullreports/758.1.pdf

Western Pennsylvania Brownfield Center, (2014), 'Case Studies',
http://www.cmu.edu/steinbrenner/brownfields/Case%20Studies/ accessed January 24, 2014.

Wikipedia, (2014), 'Workforce Management',
http://en.wikipedia.org/wiki/Workforce_management, accessed February 12, 2014.