Applications for the Environment: Real-Time Information Synthesis (AERIS)

Eco-Signal Operations: Operational Concept

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15. Supplementary Notes

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16. Abstract

This document serves as an Operational Concept for the Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Signal Operations Transformative Concept. It was developed along with two other Operational Concept documents that describe the AERIS Transformative Concepts – or operational scenarios describing connected vehicle applications that have the potential to reduce transportation's impact on the environment. The Transformative Concept includes five applications: (1)Eco-Traffic Signal Timing, (2) Eco-Traffic Signal Priority, (3) Eco-Approach and Departure at Signalized Intersections, (4) Connected Eco-Driving, and (5) Wireless Inductive Charging.

The Eco-Signal Operations Transformative Concept uses connected vehicle technologies to decrease fuel consumption and decrease greenhouse gas (GHG) and criteria air pollutant emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations as well as improving traffic flow at signalized intersections. A foundational component of this concept uses wireless data communications among enabled vehicles and roadside infrastructure. This includes broadcasting signal phase and timing (SPaT) data to vehicles. Upon receiving this information, Eco-Approach and Departure at Signalized Intersections applications located on-board vehicles can perform calculations to provide speed advice to the driver of the vehicle, allowing the driver to adapt the vehicle's speed to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner. The application may also consider a vehicle's acceleration as it departs from a signalized intersection and engine start-stop technology when the vehicle is stopped at a traffic signal. Engine start-stop capabilities allow the vehicle to automatically shut down and restart its engine when stopped thus reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. This is advantageous for the vehicle as it spends time waiting at traffic lights.

The Eco-Signal Operations Transformative Concept also considers infrastructure-based applications that may optimize the performance of the traffic signal. The Eco-Traffic Signal Timing application is similar to current traffic signal systems; however the application's objective would be to optimize traffic signals for the environment (i.e., optimize timing plans to reduce emissions or fuel consumption instead of delay) by leveraging connected vehicle data. The application would collect data from vehicles, such as vehicle location, speed, and emissions data using connected vehicle technologies to determine the optimal operation of the traffic signal system. The Eco-Signal Operations Transformative Concept also supports multi-modal operations, including transit and freight. The Eco-Traffic Signal Priority application supports these modes by allowing either transit or freight vehicles approaching a signalized intersection to request signal priority. By consider the transit or freight vehicle's location, speed, vehicle type (e.g., alternative fuel vehicles) and associated GHG and other emissions, it is possible for the traffic signal system to determine if priority should be granted. Other information, such as a transit vehicle's adherence to its schedule, the number of passengers on the bus, or the weight of the truck may also be considered in granting priority. The purpose of this application is to make better decisions about whether or not to grant signal priority with the goal of reducing overall emissions at the signalized intersection.

Finally, wireless inductive charging includes infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables inductive charging of electric vehicles including cars, trucks, and buses. Roadside charging infrastructure supports static charging capable of transferring electric power to a vehicle stopped at a traffic signal.

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Table of Contents

List of Tables

List of Figures

1 Introduction

This document serves as an Operational Concept for the Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Signal Operations Transformative Concept. It was developed along with two other Operational Concept documents that describe the AERIS Transformative Concepts – or operational scenarios describing connected vehicle applications that have the potential to reduce transportation's impact on the environment. The purpose of this document is to provide an operational description of "how" the Eco-Signal Operations Transformative Concept will operate. The Transformative Concept includes five applications:

- Eco-Traffic Signal Timing,
- Eco-Traffic Signal Priority,
- Eco-Approach and Departure at Signalized Intersections,
- Connected Eco-Driving, and
- Wireless Inductive Charging.

The Eco-Signal Operations Transformative Concept uses connected vehicle technologies to decrease fuel consumption and decrease greenhouse gas (GHG) and criteria air pollutant emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations as well as improving traffic flow at signalized intersections.

A foundational component of this concept uses wireless data communications among enabled vehicles and roadside infrastructure. This includes broadcasting signal phase and timing (SPaT) data to vehicles. Upon receiving this information, Eco-Approach and Departure at Signalized Intersections applications located on-board vehicles can perform calculations to provide speed advice to the driver of the vehicle, allowing the driver to adapt the vehicle's speed to pass the next signal on green or to decelerate to a stop in the most eco-friendly manner. The application may also consider a vehicle's acceleration as it departs from a signalized intersection and engine start-stop technology when the vehicle is stopped at a traffic signal. Engine start-stop capabilities allow the vehicle to automatically shut down and restart its engine when stopped thus reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. This is advantageous for the vehicle as it spends time waiting at traffic lights.

The Eco-Signal Operations Transformative Concept also considers infrastructure-based applications that may optimize the performance of the traffic signal. The Eco-Traffic Signal Timing application is similar to current traffic signal systems; however the application's objective would be to optimize traffic signals for the environment (i.e., optimize timing plans to reduce emissions or fuel consumption instead of delay) by leveraging connected vehicle data. The application would collect data from vehicles, such as vehicle location, speed, and emissions data using connected vehicle technologies to determine the optimal operation of the traffic signal system based on the data.

The Eco-Signal Operations Transformative Concept also supports multi-modal operations, including transit and freight. The Eco-Traffic Signal Priority application supports these modes by allowing either transit or freight vehicles approaching a signalized intersection to request signal priority. By consider the transit or freight vehicle's location, speed, vehicle type (e.g., alternative fuel vehicles) and associated GHG and other emissions, it is possible for the traffic signal system to determine if priority should be granted. Other information, such as a transit vehicle's adherence to its schedule, the number of passengers on the bus, or the weight of the truck may also be considered in granting priority. The purpose of this application is to make better decisions about whether or not to grant signal priority with the goal of reducing overall emissions at the signalized intersection.

This Transformative Concept supports eco-driving strategies. The Connected Eco-Driving application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions while driving on arterials. This advice includes recommended driving speeds, optimal acceleration, and optimal decelerations profiles based on prevailing traffic conditions, interactions with nearby vehicles, as well as information about the road grade. These applications would help a driver eco-drive by helping them anticipate traffic flow ahead, ensure they drive at an optimal cruising speed, minimize unnecessary accelerations and decelerations, and eliminate idling during short stops.

Finally, wireless inductive charging includes infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables inductive charging of electric vehicles including cars, trucks, and buses. Roadside charging infrastructure supports static charging capable of transferring electric power to a vehicle stopped at a traffic signal.

1.1 Goals

The Eco-Signal Operations Transformative Concept, and its associated applications, are expected to meet the following goals:

- **Goal #1: Reduce Environmental Impacts.** This Transformative Concept is expected to reduce emissions and energy consumption from surface transportation vehicles through improved operations of traffic signal systems that leverage connected vehicle technologies. Connected vehicle technologies allow traffic signal systems to collect a robust set of traffic and environmental data that can be used to improve the operation of the arterial transportation network.
- **Goal #2: Support "Green Transportation Decisions" by Travelers and Operating Entities.** This Transformative Concept is expected to increase eco-driving awareness and practice on arterials by leveraging connected vehicle technologies to provide real-time eco-driving information to the driver.
- **Goal #3: Enhance Mobility on the Transportation System.** This Transformative Concept is expected to improve the efficiency of the transportation system on arterials through improved operations of traffic signal systems. Additionally, the Transformative Concept is expected to improve transit and freight efficiency along strategic corridors through enhanced traffic signal priority applications.
- **Goal #4: Improve the Safety of the Transportation System.** This Transformative Concept is expected to reduce crashes, injuries, and fatalities occurring on arterials by leveraging connected vehicle technologies that provide drivers with SPaT messages and speed recommendations as vehicles approach signalized intersections. Connected vehicle technologies also allow in-vehicle systems to collect data from nearby vehicles (e.g., current speed, acceleration, activation of the brake) which can be used by in-vehicle systems to alert drivers of potential collisions at signalized intersections.

1.2 Connected Vehicle Research

Connected vehicle research is both a concept and a program of services that can transform travel as we know it. Connected vehicle research combines leading edge technologies – advanced wireless communications, on-board computer processing, advanced vehicle-sensors, Global Positioning System (GPS) navigation, smart infrastructure, and others – to provide the capability for vehicles to identify threats, hazards, and delays on the roadway and to communicate this information over wireless networks to provide drivers with alerts, warnings, and real time road network information. At its foundation is a communications network that supports vehicle-to-vehicle (V2V) two-way communications, vehicle-to-infrastructure (V2I) one- and two-way communications, and vehicle or infrastructure-to-device (X2D) one- and two-way communications to support cooperative system capability. In this context, the term “device” refers only to devices that are “carry-in” devices (i.e., devices that can be temporarily installed in vehicles and are not connected to in-vehicle information systems). These devices include ones (e.g., cell phones) that could also be carried by pedestrians or other users of the roadways (e.g., cyclists). Connected vehicles enable a surface transportation system in which vehicles are less likely to crash and roadway operators and travelers have the information they need about travel conditions to operate more effectively. Connected vehicle research will establish an information backbone for the surface transportation system that will support applications to enhance safety and mobility and, ultimately, enable an information-rich surface transportation system. Connected vehicle research also supports applications to enhance livable communities, environmental stewardship, and traveler convenience and choices.

The ability to identify, collect, process, exchange, and transmit real-time data provides drivers with an opportunity for greater situational awareness of the events, potential threats, and imminent hazards within the vehicle’s environment. When combined with technologies that intuitively and clearly present alerts, advice, and warnings, drivers can make better and safer decisions while driving. Additionally, when further combined with automated vehicle-safety applications, connected vehicle technology provides the vehicle with the ability to respond and react in a timely fashion when the driver either cannot or does not react quickly enough. Vehicle safety systems, because of the need for frequently broadcasted, real-time data, are expected to use dedicated short range communications (DSRC) technology for active safety applications. Many of the other envisioned applications could use other technologies, such as third generation (3G) or fourth generation (4G) cellular or other Wireless Fidelity (Wi-Fi) communications, as well as DSRC. The rapid pace of technological evolution provides tremendous opportunities for connected vehicles, and the program is positioned to capitalize upon these advances as they happen.

The U.S. Department of Transportation (USDOT) currently has a very active set of research programs that are focused on the development of crash avoidance systems based on both V2V and V2I (meaning both I2V and V2I) DSRC technology. In addition, the USDOT is actively researching ways to improve mobility and reduce environmental impacts of transportation, using wireless communications (not necessarily based on DSRC technology). The expectation is that, in the future, in-vehicle systems will run a combination of safety, mobility, and environmental applications that communicate using the most effective wireless technologies available.

1.3 The AERIS Program

The Intelligent Transportation Systems (ITS) Joint Program Office (JPO) is charged with planning and execution the ITS Program as authorized by Congress. This program encompasses a broad range of technologies applied to the surface transportation system. Under a collaborative and transparent governance structure established for ITS JPO projects, the ITS JPO coordinates with and executes the program jointly in cooperation with all of the surface transportation modal administrations within the USDOT to ensure full coordination of activities and leveraging of research efforts.

The USDOT is engaged in assessing applications that realize the full potential of connected vehicles, travelers, and infrastructure to enhance current operational practices and transform future surface transportation systems management. This effort is a collaborative initiative spanning the ITS JPO, Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), the Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA). These agencies of the federal government work closely with the American Association of State Highway and Transportation Officials (AASHTO), which represents state transportation agencies across the country, as well as the numerous private sector interests (car manufacturers, technology companies, etc.) to develop a nationwide system for ITS to be deployed in the future. The connected vehicle program is a major RITA program, focusing on the use of V2V and V2I transmission of information to promote safety, mobility, and the environment.

One foundational element of the connected vehicle research effort is the environmental research area. The vision and objectives of the AERIS Program include:

Vision: ***Cleaner Air through Smarter Transportation***

Objectives: Investigate whether it possible and feasible to:

- Identify connected vehicle applications that could provide environmental impact reduction benefits via reduced fuel use and efficiency impacts on emissions.
- Facilitate and incentivize “green choices” by transportation service consumers (i.e., system users, system operators, policy decision makers, etc.).
- Identify vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-grid (V2G) data (and other) exchanges via wireless technologies of various types.
- Model and analyze connected vehicle applications to estimate the potential environmental impact reduction benefits.
- Develop a prototype for one of the applications to test its efficacy and usefulness.

Employing a multi-modal approach, the AERIS research program will work in partnership with the connected vehicle research effort to better define how connected vehicle data and applications might contribute to mitigating some of the negative environmental impacts of surface transportation. The core scope of AERIS is the idea of “facilitating green transportation choices.” It is the intent of the program to:

1. Support research into the generation, capture, standardization, and use of real-time data present in the transportation system (i.e., connected travelers and infrastructure) to enable environmentally-beneficial choices by system users and system operators.

2. Leverage existing research and stakeholder activities to create a unique body of knowledge and experience that demonstrates the most effective uses of connected vehicles to reduce the negative impacts of transportation on the environment.
3. Form the foundation for addressing future, long-range efforts to conserve energy, address air quality issues, mitigate other environmental impacts of the transportation system, and support likely environmental goals in the new transportation authorization.

A successful AERIS Program will lead to the more rapid and cost-effective deployment of interoperable technologies and applications that reduce the negative impacts of transportation on the environment (i.e., emissions and fuel consumption). The AERIS Program will act to promote the highest levels of collaboration and cooperation in the research and development of transformative environmental applications for connected vehicles. The AERIS Program positions the federal government to take on an appropriate and influential role as a technology steward for a continually evolving integrated transportation system.

1.4 Document Overview

The purpose of this document is to communicate user needs and desired capabilities for and expectations of the Eco-Signal Operations Transformative Concept. This document also serves to build consensus among AERIS user groups and stakeholders concerning these needs and expectations. Stakeholders include the USDOT, state Departments of Transportation (DOTs), local DOTs, regional planning organizations (RPOs), the automotive industry, and potential ITS developers, integrators, and researchers. It is expected that users will read this document to determine whether their needs and desires have been correctly captured. Potential system developers and integrators will use this document as a basis for understanding the purpose and scope of the proposed Transformative Concept for future system development. Finally, the document should act as a guideline moving forward with research and development of any part of the AERIS Program.

As shown in the figure below, the Operational Concept provides a means for describing operational needs of a system without becoming bogged down in detailed technical issues that will be defined later in the process. Its purpose is to clearly convey a high-level view of the system to be developed that each stakeholder can understand. In doing so, the following questions are answered:

- **Who** – Who are the stakeholders/actors involved with the system?
- **What** – What are the elements and the high-level capabilities of the system?
- **Where** – What is the geographic and physical extent of the system?
- **When** – What is the sequence of activities that will be performed?
- **Why** – What is the problem or opportunity addressed by the system?

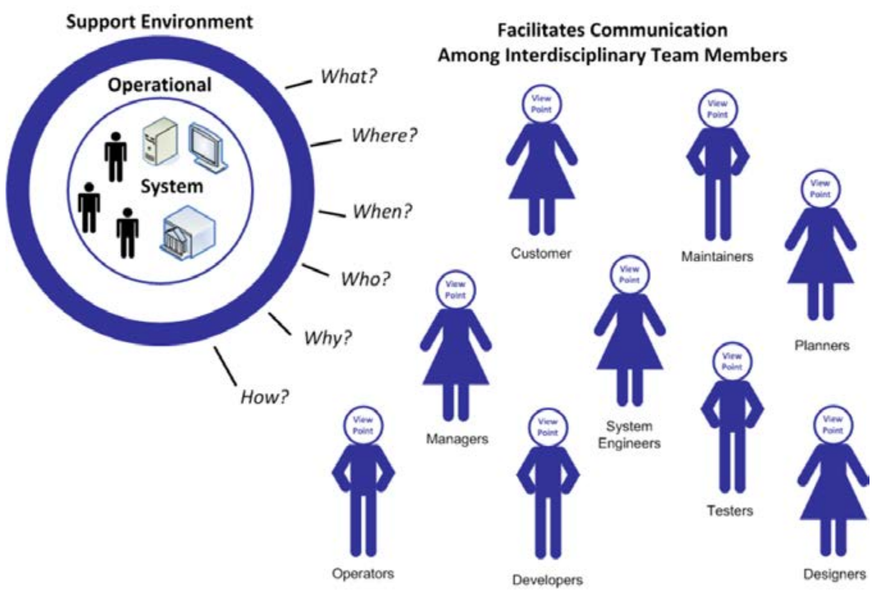

Figure 1-1: Conceptual Representation of the Operational Concept Document
(*Source: Noblis, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

At this time, the AERIS Program is not planning to build a system. Instead the AERIS Program intends to convey at a high-level how its Transformative Concepts may work, so others may design and implement systems in the future. The AERIS Operational Concept documents are intended to convey "transformational ideas" that will be modeled to show the potential environmental benefits that can be achieved through connected vehicle applications. As such, the AERIS Operational Concept documents are "generalized" and not specific to a geographic area, an operating entity (e.g., state or local DOT), existing systems that may be in place for a region, agency operating procedures, nor political environment.

This document is an interim document to a Concept of Operations that will be developed at a later date for specific prototypes and testing. Those Concept of Operations documents should use components of this document and present the materials in a format consistent with *IEEE Std 1362-1998 IEEE Guide for Information Technology—System Definition—Concept of Operations (ConOps) Document*.

This document includes the following sections:

- **Section 1** provides the scope, introduction to the AERIS Program, and an overview of the document.
- **Section 2** includes a discussion of transportation's impact on the environment and introduces the potential role that ITS and connected vehicles may have in reducing these environmental impacts.
- **Section 3** provides a description of existing traffic signal systems. This section is meant to familiarize the reader with the current state of the practice regarding traffic signal operations and their environmental benefits.
- **Section 4** describes the shortcomings of current systems, situations, or applications that motivate development of the Transformative Concept. This section provides a transition from

Section 3 of the Operational Concept, which describes the current situation, to Section 5, which describes the proposed Transformative Concept.

- **Section 5** provides a description of the Eco-Signal Operations Transformative Concept. Included is a storyboard describing, at a high-level, how the Transformative Concept will work. It then describes how the applications from the Transformative Concept were grouped into two systems: (1) an Eco-Traffic Signal System and (2) an In-Vehicle System. The section concludes with a discussion of how these systems interact with one another through a connected vehicle environment.
- **Section 6** describes the Eco-Traffic Signal System from a systems engineering perspective. This section begins with a description of the system, followed by a system context diagram, logic diagram, and subsystem diagram. A table of user needs is then provided. This section may be more appealing to systems engineers than other readers.
- **Section 7** describes the In-Vehicle System from a systems engineering perspective. This section begins with a description of the system and is followed by a system context diagram, logic diagram, and subsystem diagram. A table of user needs is then provided. This section may be more appealing to systems engineers than other readers.
- **Section 8** describes the interfaces and data exchanges between actors and systems associated with this Transformative Concept. This section may appeal to readers that want to visualize where systems (or actors) may reside and the data that may be exchanged between systems (or actors).
- **Section 9** provides scenarios which help the readers of the document understand how all the pieces of the Transformative Concept interact to provide environmental benefits. Scenarios are described in a manner that allows readers to walk through them and gain an understanding of how all the various parts of the Transformative Concept will function and interact. This section of the document should be useful to non-system engineers as well as system engineers.
- **Section 10** presents goals, objectives, and potential performance measures for the Eco-Signal Operations Transformative Concept. With successful implementation, this Transformative Concept is expected to meet these goals and objectives.
- **Appendix A** provides a list of acronyms used in the report.
- **Appendix B** provides definitions of the actors used in this document. The reader should refer to these definitions prior to, or while, reading this document to become familiar with the terminology used in this document.
- **Appendix C** includes a summary and working documentation of the data communications that will be required to support the Transformative Concept. This information may be useful to Systems Engineers planning to develop requirements for the AERIS Transformative Concepts and applications.
- **Appendix D** depicts the Eco-Signal Operations Transformative Concept's relationship to the National ITS Architecture. It provides a Subsystem Interconnect Diagram (also referred to as a Sausage Diagram) and a sample Market Package Diagram for the Transformative Concept. This appendix will appeal to readers familiar with the National ITS Architecture.

2 Transportation and the Environment: A Vision for the Future

2.1 Background

Transportation is the "fastest-growing source of U.S. GHG emissions, accounting for 47 percent of the net increase in total U.S. emissions since 1990, and is the largest end-use source of CO_2, which is the most prevalent GHG."[1] As shown in Figure 2-1, transportation activities accounted for 27 percent of all GHG emissions in the United States, with on-road vehicles contributing 84 percent to that total. This means that surface transportation is responsible for 22 percent of all GHG emissions in the United States.[1] Nearly "97 percent of transportation GHG emissions came through direct combustion of fossil fuels." Over forty-three percent (43%) of surface transportation emissions are the result of passenger vehicles, nineteen percent (19%) from light-duty trucks, and freight trucks account for another 22%. These statistics do not include life cycle emissions for the transportation sector, which includes the emissions of a product from extraction of raw materials through disposal, or "cradle to grave" emissions, which can also be significant. [2] Therefore, finding applications that can reduce emissions from surface transportation is an important strategy in addressing climate change.

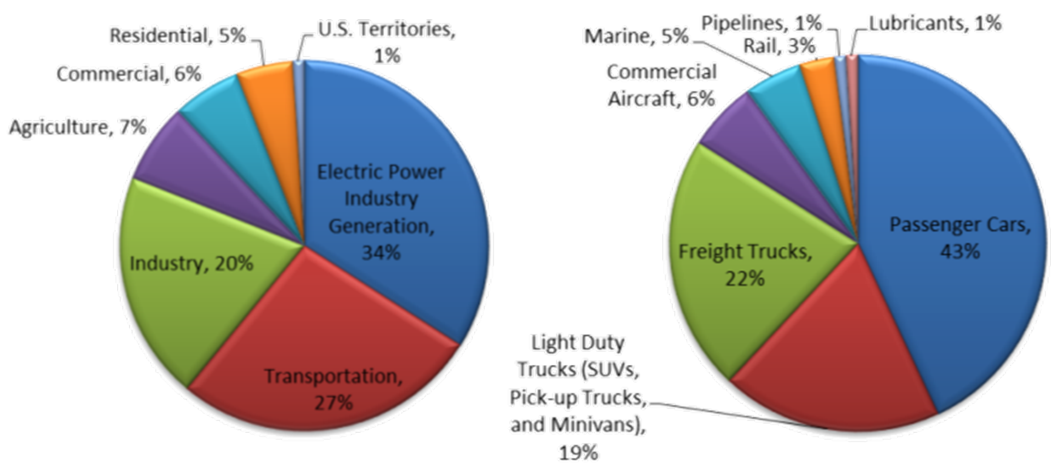

Figure 2-1: Transportation's Impact on the Environment *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012.)*

Figure 2-2 depicts GHG trends between 1990 and 2008. As shown in the figure, there has been a significant increase in the transportation-related emissions and if these trends continue, transportation is expected to surpass the electric power industry as the number one contributor to GHG emissions in the United States. In a recent Environmental Protection Agency (EPA) report, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010, several explanations for the increase in emissions from transportation sources are discussed. First, light-duty vehicle miles traveled (VMT) increased by 37 percent, in part because of "population growth, economic growth, urban sprawl, and low fuel prices" that occurred between 1990 and 2008. Second, while the total average fuel economy of vehicles increased during this time, the average fuel economy of vehicles sold during this time decreased. This trend occurred because of the growing popularity of light duty trucks, including sport utility vehicles, which accounted for more than half of the vehicle market in 2004. As VMT and sales of vehicles with poor fuel economy increased, petroleum consumption also increased, which led to an increase in emissions.[3] More recently the automotive industry has moved towards creating more fuel efficient vehicles as gas prices increase. Gas mileage is a pivotal selling point to car buyers these days. Concerns over fuel costs have spawned entirely new segments like hybrids and electric vehicles, and with a federal mandate of 54.5 miles per gallon (mpg) by 2025 quickly approaching, the auto industry will never be the same.

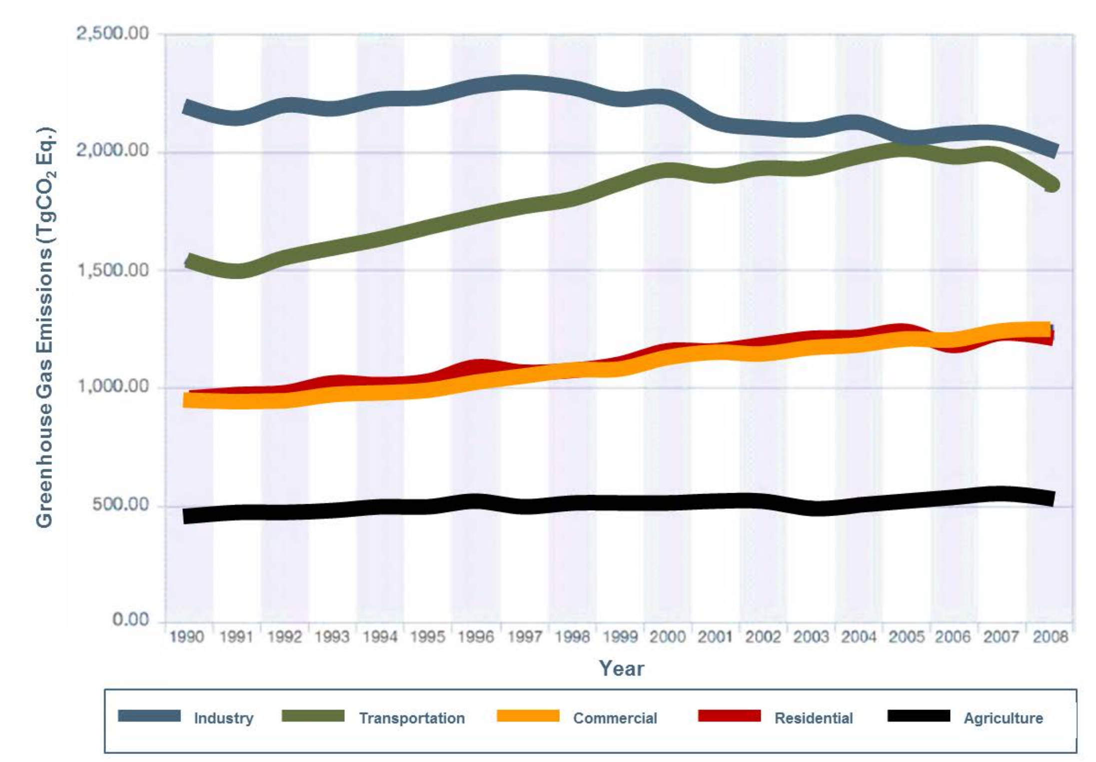

Figure 2-2: GHG Trends 1990 to 2008 *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012.)*

ITS includes a broad range of transportation improvements, such as traffic signal control, freeway management, transit management, incident management, and regional multi-modal traveler information services. ITS has generated considerable enthusiasm in the transportation community as a potential strategy for reducing congestion, improving safety, and reducing environmental impacts associated with motor vehicle travel. Some policy makers, however, are concerned that induced travel associated with ITS may partially offset the potential emission benefits of improved traffic operations. A recent report titled Moving Cooler, providing an analysis of transportation strategies for reducing GHG emissions, was commissioned by a diverse group of stakeholders representing transportation experts, industry, federal agencies, and environmental organizations. The report stated that Transportation GHG emissions are the result of the interaction of four factors: (1) vehicle fuel efficiency, (2) the carbon content of the fuel burned, (3) the number of miles that vehicles travel, and the (4) operational efficiency experienced during travel. Therefore, the range of transportation strategies that can be used to reduce GHGs fall into four basic approaches, as follows:

- **Vehicle Technology.** Improving the energy efficiency of the vehicle fleet by implementing more advanced technologies and improving the aerodynamics of the vehicle
- **Fuel Technology.** Reducing the carbon content of fuels through the use of alternative fuels (for instance, natural gas, biofuels, and hydrogen)
- **Travel Activity.** Reducing the number of miles traveled by transportation vehicles, or shifting those miles to more efficient modes of transportation
- **Vehicle and System Operations.** Improving the efficiency of the transportation network so that a larger share of vehicle operations occur in favorable conditions, with respect to speed and smoothness of traffic flow, resulting in more fuel efficient vehicle operations.

Findings from the report state that an integrated, multi-strategy approach – combining travel activity, local and regional pricing, operational, and efficiency strategies – can contribute to significant GHG reductions. Implementation of a complete portfolio of Moving Cooler strategies without economy-wide pricing could achieve annual GHG emissions ranging from less than 4 percent to as high as 24 percent less than projected baseline levels in 2050. Such reductions would, however, involve considerable – and in some cases major – changes to current transportation systems and operations, travel behavior, land use patterns, and public policy and regulations.

Strategies that contribute the most to GHG reductions are local and regional pricing and regulatory strategies that increase the costs of single occupancy vehicle travel, regulatory strategies that reduce and enforce speed limits, educational strategies to encourage eco-driving behavior that achieve better fuel efficiency, land use and smart growth strategies that reduce travel distances, and multimodal strategies that expand travel options. The analysis also showed that some combinations of strategies could create synergies that enhance the potential reductions of individual measures. In particular, land use changes combined with expanded transit services achieve stronger GHG reductions, than when only one option is implemented.

2.2 The AERIS Program's Role

The AERIS Program is focused on using connected vehicle strategies and technologies to achieve the maximum possible environmental benefit. Connected vehicle applications can assist in reducing petroleum consumption and resulting emissions through reduced VMT and increased vehicle efficiency. For purposes of the AERIS Program, applications are technological solutions (e.g., software, hardware, interfaces) designed to ingest, process, and disseminate data in order to address a specific strategy. Applications may be complemented with regulatory and educational tools. The remainder of the report describes connected vehicle applications, or applications that have the potential to use ITS, that can reduce emissions and benefit the environment. Some connected vehicle applications or strategies are incremental improvements to traditional approaches, and others are more transformational. Both types are enabled by V2V and V2I communications.

The AERIS Program is taking an innovative approach to transform how the transportation system operates by leveraging connected vehicle technologies. This innovative approach is described as a group of Transformative Concepts. AERIS Transformative Concepts are integrated operational concepts that use data collected by vehicles and/or infrastructure and transmitted via V2V and/or V2I communications in innovative ways to operate surface transportation networks to reduce the environmental impacts of transportation. Transformative Concepts are intended to change the way transportation systems operate, with an emphasis on combining applications to significantly reduce the environmental impact of surface transportation networks.

2.3 AERIS Transformative Concepts

The AERIS Transformative Concepts have a 30 year planning horizon, building on industry trends and technological advances including advances with smarter, fuel efficient vehicles. The vehicle of the future will be capable of collecting data from other vehicles and roadside infrastructure and presenting information to the driver allowing him/her to make informed mobility and environmental decisions. By providing this information to individual vehicles there is an opportunity to maximize personal mobility on a massive scale. At the same time, cities and transportation systems are slowly starting to change, with a new perspective on transportation's role on the environment. Smart cities are on the cusp of connecting the transportation network to other networks including the smart electric grid. The result is information at the fingertips of transportation operators that allows them to optimize the transportation system for mobility and the environment. The AERIS Program's research aims to see how creative we can be and to use as much functionality as possible from smarter vehicles and connected vehicle technologies to improve the environment.

The AERIS Program identified five Transformative Concepts or bundles of applications, depicted in Figure 2-3. The Transformative Concepts are: (1) Eco-Signal Operations, (2) Eco-Lanes, (3) Low Emissions Zones, (4) Eco-Traveler Information, and (5) Eco-Integrated Corridor Management. As depicted in the figure, each Transformative Concept encompasses a set of applications which individually achieve environmental benefits. Initial benefits of these applications are documented in the *Initial AERIS Benefit Cost Analysis Final Report* (not published). By strategically bundling these applications, the AERIS Program expects that Transformative Concepts can achieve additional environment benefits above those of the individual applications.

As shown in Figure 2-3, each Transformative Concept is comprised of applications (depicted as green hexagons), regulatory/policy tools (depicted as grey hexagons), educational tools (depicted as blue hexagons) and performance measures (depicted as yellow pentagons). Applications are technological solutions (e.g., software, hardware, interfaces) designed to ingest, process, and disseminate data in order to address a specific strategy. For example, the eco-traffic signal priority application may collect data from vehicles, sends these data to a local processor to determine if a vehicle should be granted priority at a signalized intersection, and then communicate this priority request to a traffic signal controller.

Applications are complemented with regulatory/policy and educational tools to further support the Transformative Concept. Regulatory/policy tools are authoritative rules that govern transportation, land development, and/or environmental behavior. For example, a Low Emissions Zone would require policy to be in place for the geographic area before a low emissions zone could be commissioned. This policy may establish the guidelines or rules that would be in place governing the low emissions system.

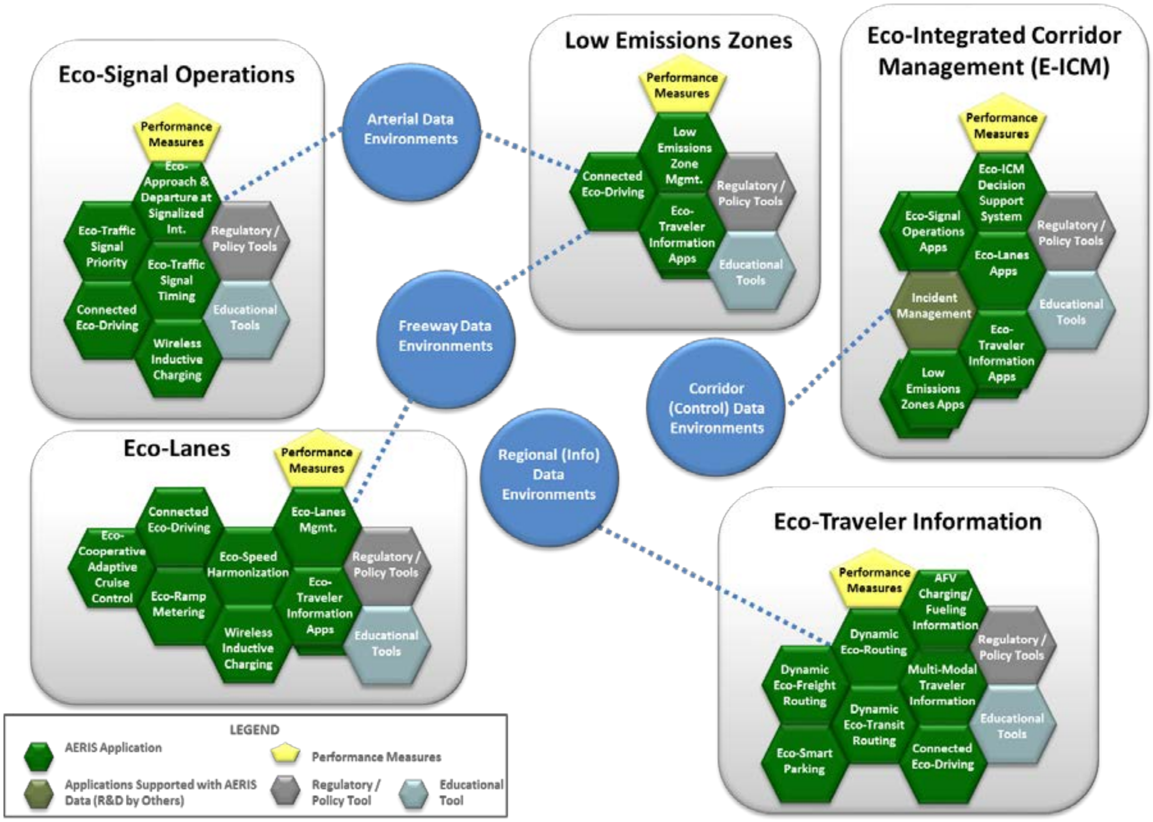

Figure 2-3: AERIS Transformative Concepts (*Source*: Noblis, 2013)

Since many of the AERIS Transformative Concepts and applications are new ideas with which the traveling public may not be familiar, there is a need for educational tools or campaigns used for educating transportation agencies and/or the general public on environmental benefits of the applications or Transformative Concepts. Finally, each Transformative Concept includes performance measures, which are used for collecting and reporting information regarding the performance of the Transformative Concept. These performance measures include goals and objectives for reducing emissions, improving traffic flow, and improving transportation or environmental performance.

Each Transformative Concept is connected to one or more Data Environments – or blue circles. Data Environments are well-organized collections of data, of specific type and quality that are captured and stored at regular intervals from one or more sources, and systematically shared in support of one or more applications. These Data Environments are defined by the USDOT's Data Capture and Management (DCM) Program. A description of each Data Environment is provided below:

- **Arterial Data Environment.** The Arterial Data Environment organizes multi-source data along a signalized arterial facility. Vehicles in this environment may include personal, transit, freight, non-motorized, emergency, and construction/maintenance vehicles. Data could be collected from all of these vehicles as well as mobile devices and roadside infrastructure. It is assumed that the Arterial Data Environment would be a signal arterial facility, bi-directional in nature. All data would be captured as vehicles approach and leave intersections along the arterial. Bus-only lanes, bike lanes, and pedestrian crosswalks may be present in the environment. Travel demand is expected to be highly variable based on time of day and day of week.
- **Freeway Data Environment.** The Freeway Data Environment organizes multi-source data along an uninterrupted flow (or freeway) facility. Vehicles in this environment may include personal, transit, freight, emergency, and construction/maintenance vehicles. Data could be collected from all of these vehicles as well as mobile devices and roadside infrastructure. It is assumed that the Freeway Data Environment would be a freeway facility, bi-directional in nature. All data would be captured along the freeway lanes and the interchanges including the ramps and arterial segments providing ramp access. Freeway lanes may have varying restrictions such as high-occupancy vehicle (HOV) or bus only lanes. Tolling may also be present in the freeway environment. Travel demand is expected to be highly variable based on time of day and day of week.
- **Corridor Data Environment.** The Corridor Data Environment organizes multi-source data in a multi-modal sub-regional corridor. Vehicles in this environment may include personal, transit, freight, non-motorized, emergency, and construction/maintenance vehicles. Data could be collected from all of these vehicles as well as mobile devices and roadside infrastructure. It is assumed that the Corridor Data Environment would primarily carry traffic in one direction (inbound or outbound) depending on the time of day and day of the week. Parallel arterial and freeway facilities as well as transit facilities would all be included in this environment. All data from all the types of facilities within the corridor would be collected into the Corridor Data Environment. This data environment would help support strategies such as Integrated Corridor Management (ICM).
- **Regional Data Environment.** The Regional Data Environment organizes multi-source data in a regional, state-wide, rural, multi-state, or national data environment. Vehicles in this environment may include personal, transit, freight, non-motorized, emergency, and construction/maintenance vehicles. Data could be collected from all of these vehicles as well as mobile devices and roadside infrastructure. It is assumed that the Regional Data Environment would span a network of subsidiary sub-networks including arterial, freeway, rural, parking, and transit facilities.

3 Description of Current Systems

Traffic signals are signaling devices positioned at roadway intersections, pedestrian crossings, and other locations to control competing flows of traffic. Traffic signals alternate the right-of-way accorded to road users (e.g., vehicles, pedestrians, and bicyclists) by displaying lights of a standard color (red, yellow/amber, and green). The typical sequence of color phases is provided below:

- The green light allows traffic to proceed in the direction denoted, it is safe to do so;
- The yellow/amber light denote prepare to stop short of the intersection, if it is safe to do so; and
- The red light prohibits any traffic from proceeding.

The brain of the traffic signal is the traffic signal controller. A traffic signal is controlled by a controller installed inside a cabinet. Traffic signal controllers use the concept of phases, which are directions of movement grouped together. For example, a simple intersection may have two phases: North/South and East/West. A four-way intersection with independent control for each direction and each left turn will have eight phases. Controllers also use rings or an independent array of timing sequences. For example, with a dual ring controller, opposing left turn arrows may turn red independently, depending on the amount of traffic. Thus a typical controller is an eight-phase, dual-ring control.

Traffic signals must be instructed when to change phase and are usually coordinated so that the phase changes occur in some relationship to other nearby signals. Traffic signal systems coordinate individual traffic signals to achieve network-wide traffic operations objectives. These systems consist of traffic signals located at an intersection, a traffic signal controller, a communications network to tie them together, and a central computer or network of computers to manage the system. In addition to control of traffic signals, current traffic signal systems provide wide-ranging surveillance capabilities, including various kinds of vehicle detection technologies including loop detectors, microwave detectors, and closed circuit television (CCTV) cameras. They also provide more powerful traffic control algorithms, including the potential for adaptive control and predictive surveillance.

To understand basic signal timing fundamentals, one must also understand the different modes of operation for the traffic signal controller. Many intersections have some sort of mechanism for detecting vehicles as they approach the intersection. The most common form of detection is induction loops. These loops of wire are buried in the roadway and detect vehicles by changes in their magnetic field caused by the metal in passing vehicles. Other common methods are video detection which uses pixilation, microwave detection, and infrared detection among others. An intersection equipped with detection is said to be actuated. An intersection without detection is said to be fixed.

Traffic signals may be operated one of three ways: fixed-timed, actuated, or adaptive.

- **Fixed-Timed Operation.** In fixed operation, a traffic signal controller has a set programmed time to service all movements every cycle. The controller will service all movements whether or not there is vehicle demand. When a detector at an actuated signal breaks, that movement will then have to operate as fixed until the detector is repaired. In this form of operation, the red, yellow, and green indications are timed at fixed intervals. Fixed-timed operation assumes that the traffic patterns can be predicted accurately based on time of day. This predictability can usually only be achieved by controlling the traffic entering the intersection with upstream signals, as in a system. In isolated locations, however, the traffic approaching the intersection arrives randomly, and is not usually predictable enough to make fixed-timed operation a good choice. Fixed-timed operation does not require traffic detectors at the intersection, and is therefore much cheaper to install and is the most common form of signal control in the United States.

- **Actuated Operation.** Intersections with this form of control consist of actuated traffic controllers and vehicle detectors placed in or on the roadways approaching the intersection. In actuated operation, the control algorithm is primarily concerned with when green intervals terminate. With actuated controllers, green intervals may terminate in one of four ways:
    - *Maximum Green Time is Reached*. Usually called maxing out or timing out, this occurs when a pre-determined maximum green time is reached. The interval is terminated and the next interval in the sequence is allowed to start.
    - *Traffic Flow Ceases on the Approach*. When a gap in traffic appears that is greater than a pre-determined threshold, the controller will terminate the green interval in favor of other movements that have demand. This form of termination is known as gapping out.
    - *A Signal System Forces the Termination*. When an actuated signal is part of a coordinated system, the system keeps the signal in step with the intended operation by forcing green intervals off at the intended times in the signal cycle. This is called applying a force-off.
    - *The Signal is Pre-empted*. As discussed below, when a priority vehicle approaches the intersection, non-priority green intervals may be terminated in favor of the priority movement.

  To save money on maintenance, some agencies opt to design an intersection as semi-actuated. Semi-actuated means the intersection has detection on the minor street approaches and major street left turns only. The major street is then programmed to operate a fixed time every cycle, but the controller will service the other movements only when there is demand. In signal coordination, most signals operate in a semi-actuated mode.

- **Adaptive Signal Operation.** This form of operation “coordinates control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions.”[4] These systems can include identification of individual vehicles and negotiated priority to minimize stops over the whole network, and therefore create smoother traffic flow.[5] There are several adaptive systems currently used throughout the world and several new adaptive products have recently been released. Examples of current adaptive signal control systems include Split Cycle Offset Optimization Technique (SCOOT) and the Sydney Coordinated Adaptive Traffic System (SCATS). Since 1990, FHWA has recognized the benefits to be achieved by the implementation of adaptive control over the traditional time-of-day (TOD) selection of fixed cycle length timing patterns, and has sponsored several programs aimed at developing adaptive signal systems, such as RT-TRACS in the 1990’s and ACS-Lite during the 2000’s. Other adaptive systems have also been deployed or trialed in the United States.

When traffic signals are located close enough together that traffic remains in recognizable platoons from one intersection to the next, traffic engineers will usually seek to coordinate their operation. Coordination refers to the timing of the signals so that a "platoon" of cars traveling on a street arrives at a succession of green lights and proceeds through multiple intersections without stopping. A well-coordinated signal system can enhance traffic flow, reduce delay, and minimize pollution. However, it is not always possible to retain progression throughout a network of signals. Signal coordination requires that the signal timings at multiple intersections be timed to meet network-wide objectives for traffic flow. This usually requires all signals to operate at the same or a compatible cycle length, with careful design of the time-space relationships between the intersections. The signals, therefore, need some means of staying in step with each other. At the most basic level, each intersection's traffic signal may contain an accurate clock, with all intersections coordinated according to their internal clocks. As long as the clocks at the intersections remain synchronized with each other, the signals stay in proper coordination.

By coordinating traffic lights along a corridor, it creates a "green wave" or a phenomenon in which a series of traffic lights are coordinated to allow continuous traffic flow over several intersections in one main direction. Any vehicle travelling along with the green wave – at an approximate speed decided upon by the traffic engineers – will see a progressive cascade of green lights, and not have to stop at intersections. This allows higher traffic loads, and reduces noise and energy use (because less acceleration and braking are needed). In practical use, only a group of cars, known as a "platoon", can use the green wave before the time band is interrupted to give way to other traffic flows. The coordination of the signals is sometimes done dynamically, according to data of currently existing traffic flows – otherwise it is done statically, by the use of timers.

Traffic signal systems are typically categorized in two ways: (1) distributed systems and (2) centralized systems.

- **Distributed Systems.** Distributed systems are those in which, generally, the intersection controller is responsible for control decisions at the intersection. Distributed systems come in many varieties, ranging from small closed-loop systems (described below) to powerful large-scale systems.
- **Centralized Systems.** Centralized systems include a central computer that makes control decisions and directs the actions of individual controllers. Each intersection requires only a standard controller and interfacing unit and does not perform any software functions. These systems also allow for centralized control algorithms. This is an area where centrally controlled systems have a distinct disadvantage over distributed systems. Some control algorithms, such as SCOOTs require a central computer to calculate the optimization algorithm for the entire network. Only a centrally controlled system can provide this capability.

3.1 Environmental Benefits from Traffic Signal Operations

Traffic signal coordination and optimization involves the re-timing and synchronization of traffic signals to minimize vehicle delay and stops for smoother traffic flow.[6] The 2007 National Traffic Signal Report Card estimated that "updating signal timing costs less than $3,000 per intersection," can reduce emissions up to 22 percent, and has a high return on investment. For every dollar that is spent on traffic signal coordination, $40 or more is returned to the public in time and fuel savings. To support routine signal timing updates across the United States, "transportation agencies would need to spend an amount equivalent to less than 0.2 percent of the total national expenditure on highways."[7]

A number of traffic signal coordination projects in the United States have documented emissions savings. Some examples follow:

- In Syracuse, New York the implementation of traffic signal coordination reduced emissions by 9 to 13 percent, reduced delays by 14 to 19 percent, and increased the average speed by 7 to 17 percent.[8]
- In St. Augustine, Texas traffic signal coordination resulted in a savings of 26,000 gallons of fuel, reduced delays by 36 percent, and saved $1.1 million.[9]
- In Los Angeles, California emissions reductions of 14 percent and a reduction of fuel by 13 percent were achieved by implementing traffic signal coordination.[10]
- In Oakland County, Michigan the County's traffic signal coordination project reduced CO by 1.7 to 2.5 percent, NO_x by 1.9 to 3.5 percent, and reduced fuel consumption by 2.7 to 4.2 percent.[11]

Environmental benefits have also been achieved through the implementation of adaptive signal control. In Lee's Summit, Missouri, located 20 miles southeast of Kansas City, the technology was implemented on a 2.5-mile arterial with 12 traffic signals. The project reduced the average number of stops through the corridor, fuel consumption, and emissions for every period where travel times were reduced. Emissions either increased or decreased depending on whether or not the signal favored the direction of travel. When traveling in the direction favored by the signal, emissions decreased. When traveling in the direction not favored by the signal, emissions increased. As shown below, changes in emissions ranged from an increase of 9 percent to a decrease of 50 percent:

- Fuel Consumption: +4.5 percent to -21.4 percent
- HC: +6.2 percent to -42.6 percent
- CO: +4.3 percent to -28.9 percent
- NO_x: +8.8 percent to -50.0 percent.[12]

Stockholm, Sweden, has also seen emissions reductions using adaptive signal control. The primary goal of the city's MATSIS project, which receives funding from both the City of Stockholm and the Swedish Environmental Protection Agency, is to "reduce the emissions of CO_2 through the use of coordinated traffic signaling."[13] Six areas of the city were selected for the project, and the initiative led to a savings of an estimated 2,900 tons of CO_2 emissions per year. In addition to the emissions reductions, delays have been reduced up to 19 percent. The cost per kilogram of CO_2 saved is one of the lowest among all of Stockholm's environmental projects, and 70 percent of the positive effects of the project are expected to remain even if traffic increases in the project areas.[14]

Other benefits of adaptive signal control systems are summarized below:

- Adaptive signal control in Toronto, Canada, yielded emission reductions of three to six percent and fuel savings of four to seven percent.[15]
- In Tucson, Arizona, models indicated adaptive signal control in conjunction with transit signal priority could decrease delay for travelers on the main street by 18.5 percent while decreasing delay for travelers on cross-streets by 28.4 percent.
- In Los Angeles, California, adaptive signal control systems improved travel time by 13 percent, decreased stops by 31 percent, and reduced delay by 21 percent.
- A University of Virginia simulation study found that adaptive signal control reduced delay by 18 to 20 percent when compared to fixed-time signal control.[16]

3.2 Transit Signal Priority

Transit signal priority techniques are generally classified as "active" or "passive". Passive traffic signal priority techniques involve optimizing signal timing or coordinating successive signals to create a “green wave” for traffic along the transit line’s route. Passive techniques require no specialized hardware (such as bus detectors and specialized traffic signal controllers) and rely on simply improving traffic for all vehicles along the transit vehicle's route.

Active transit signal priority techniques rely on detecting transit vehicles as they approach an intersection and adjusting the signal timing dynamically to improve service for the transit vehicle. Unlike passive techniques, active transit signal priority requires specialized hardware. The detection system typically involves a transmitter on the transit vehicle and one or more receivers (detectors), and the signal controller must be “transit signal priority capable” (i.e. sophisticated enough to perform the required timing adjustments). Active transit signal priority strategies include:

- **Green Extension.** This strategy is used to extend the green interval by up to a preset maximum value if a transit vehicle is approaching. Detectors are located so that any transit vehicle that would just miss the green light ("just" meaning by no more than the specified maximum green extension time) extends the green and is able to clear the intersection rather than waiting through an entire red interval. Green Extension provides a benefit to a relatively small percentage of buses (only buses that arrive during a short window each cycle benefit), but the reduction in delay for those buses that do benefit is large (an entire red interval).
- **Early Green (or red truncation).** This strategy is used to shorten the conflicting phases whenever a bus arrives at a red light in order to return to the bus’ phase sooner. The conflicting phases are not ended immediately like they are for emergency vehicle preemption systems but are shortened by a predetermined amount. Early green benefits a large portion of buses (any bus that arrives at a red light) but provides a relatively modest benefit to those buses. Early green can be combined with green extension at the same intersection to increase the average benefits for transit.
- **Early Red.** If a transit vehicle is approaching during a green interval, but is far enough away that the light would change to red by the time it arrives, the green interval is ended early and the conflicting phases are served. The signal can then return to the transit vehicle’s phase sooner than it otherwise would. Early red is largely theoretical and is not commonly used in practice.
- **Phase Rotation.** The order of phases at the intersection can be shuffled so that transit vehicles arrive during the phase they need. For example, it is common for traffic controllers to give protected left turn phases followed by the adjacent through phases ("leading lefts"); however, this order can be reversed so that the through phases are followed by protected lefts ("lagging lefts"). A signal with phase rotation enabled could switch from its normal leading left operation to a lagging left sequence if a left-turning bus is expected to arrive after the normally scheduled leading left phase would end.
- **Actuated Transit Phase(s).** These are phases that are only called if a transit vehicle is present. These might be seen along streetcar lines or on dedicated bus lanes. They could also be used where transit vehicles are allowed to make movements that general traffic is not (“No Left Turn Except Buses”) or at the entrances and exits to transit hubs (e.g. bus stations). Transit signal faces often look different from a standard green/yellow/red face to avoid

confusion with the signals for general traffic. For example, bus traffic signals may show a letter "B" while trams and Light Rail Vehicles may show a letter "T".

- **Phase Insertion.** This strategy allows a signal controller to return to a critical phase more than once in the same cycle if transit vehicles that use that phase are detected. For example, if a left-turning bus arrives at an intersection after the left turn phase has been served, the signal can insert a second left turn phase before proceeding to serve the side street.

In 2007, Research and Innovative Technology Administration (RITA) reported that transit signal priority can reduce bus running time by 2% to 18%. This reduction in running time can decrease fuel consumption between 208 and 1,872 gallons per year (per bus). With this reduction in fuel consumption, a bus emits between 2 and 20 metric tons less of CO_2 (assuming diesel engine buses). On average, for every 1,000 miles traveled in a private automobile that has been displaced by bus travel, up to 0.18 metric tons of CO_2 are prevented from being emitted into the environment.

3.3 Eco-Driving Research on Arterials

Eco-driving is a term used to describe energy efficient use of vehicles. The purpose of eco-driving is for the driver to operate his/her vehicle in a manner than reduces fuel consumption so less fuel is used to travel the same distance. Engine technology and performance of vehicles have improved rapidly over the past decades; however most drivers have not adapted their driving style. Drivers cause all sorts of problems. They hit the brakes too soon, and too often, and accelerate too quickly. This can waste a third of the gas on a typical drive. Eco-driving represents a driving culture which suits modern engines and makes the best use of advanced vehicle technologies. Eco-driving offers numerous benefits, including GHG emission reductions, fuel cost savings, as well as greater safety and comfort. Examples of eco-driving behaviors are provided below:

- Eliminate Stop-and-Go Driving Situations
- Select routes with fewer stops
- Drive less during congested times of day
- Anticipate Traffic Flow
- Watch far enough ahead to anticipate when maintaining speed will result in a stop at a red light or traffic bottleneck
- Drive at Optimal Cruising Speed
- High speeds contribute to very high fuel use because aerodynamic drag increases with the square of vehicle velocity.
- Minimize Unnecessary Accelerations and Decelerations
- Eliminate Idling During Short Stops

The University of California – Riverside (UCR), along with others, has conducted research on eco-driving for arterials with traffic signals. By taking advantage of SPaT information made available through DSRC (or other wireless communications) between traffic signals and vehicles, UCR developed a variety of applications. One of the applications provides alerts to individual vehicles entering the DSRC range that have no or little chance of getting through the intersection before the signal turns red. By doing so, these vehicles can start to coast down to a full stop sooner instead of continuing on the current speed and having to apply a hard brake at the end. Evaluation results show that the fuel and CO_2 benefits for this technology are approximately 12% to 14%. Taking this a step further, UCR developed speed planning algorithms for vehicles traveling on signalized arterial corridors. The goal of these algorithms is to recommend a driving speed that maximizes the probability of the vehicle going through signalized intersections without having to come to a complete stop (e.g., travel in the green wave). Based on initial simulation results, the fuel and CO_2 savings for the technology-equipped vehicles are approximately 12% to 14%, without any significant impact on the travel time.[17]

Additionally, research by Virginia Polytechnic Institute (Virginia Tech) investigated adjustments in vehicle speeds at DSRC-equipped intersections to achieve fuel efficiency through an AERIS Broad Agency Announcement (BAA) project. Their research modeled vehicles using SPaT data to adjust the vehicle's speed in the vicinity of intersections to save fuel by avoiding stops and maintaining a speed closer to its fuel-optimum speed. Simulated cases showed fuel savings of over 50%. These savings depend on signal timing, engine size, distance range of V2I communication, and approach speed of vehicles. The research showed that accelerating at minimum throttle levels, when approaching a signalized intersection, generally produces optimum fuel efficiencies. Additionally, the optimum deceleration level is vehicle type, speed, and signal timing dependent. Finally, fuel savings were higher at higher approach speeds than lower speeds.

4 Limitations of Existing Systems and Justification for Change

Connected vehicle technologies offer tremendous promise for reductions in surface transportation emissions and fuel consumption. Connected vehicle technologies function using a V2V and V2I data communications platform that, like the Internet, supports numerous applications, both public and private. This wireless communications platform provides the foundation to integrate data from the infrastructure (e.g., traffic sensors and environmental sensors) with data from the vehicle (e.g., speed, velocity, and emissions data collected directly from the vehicle) to optimize the transportation network and individual vehicles for the environment. V2I communications offer an environment rich in vehicle and infrastructure data that can be used by applications residing in the vehicle to provide drivers with information that supports “green” driving behavior. Examples of these applications include eco-driving and eco-routing applications. Additionally, connected vehicle technologies provide the ability for agencies operating the transportation network to collect data from vehicles and use these data to optimize the transportations system. Examples include collecting emissions data from vehicles to monitor the system’s performance and optimizing traffic signals, ramp meters, and variable speed limits in real-time to reduce emissions along a corridor. Other examples include establishing eco-lanes or low emissions zones on a Code Red Air Quality Day to reduce emissions in a “hot spot” and to encourage modal shifts through eco-traveler information systems.

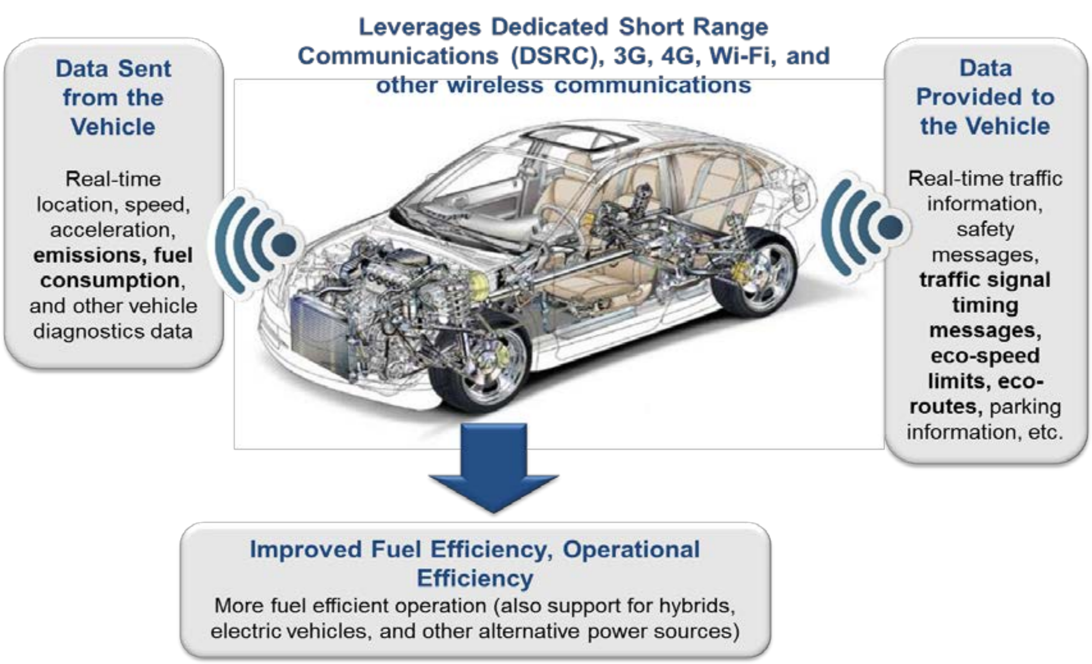

Figure 4-1: A Connected Vehicle (*Source*: *Noblis, 2013*)

Connected vehicle V2V safety applications heavily rely on the basic safety message (BSM), which is one of the messages defined in the Society of Automotive Engineers (SAE) Standard J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary (November 2009). The development of the BSM is ongoing and evolving. At the time of writing, the BSM consists of two parts, with the following characteristics:

- BSM Part 1 contains core data elements, including vehicle position, heading, speed, acceleration, steering wheel angle, and vehicle size. It is transmitted at a rate of about 10 times per second.
- BSM Part 2 contains a variable set of data elements drawn from an extensive list of optional elements. They are selected based on event triggers (such as when the antilock braking system [ABS] is activated). BSM Part 2 data elements are added to Part 1 and sent as part of the BSM message but are transmitted less frequently to conserve data communications bandwidth.

It is important to note that even if a data element is defined in BSM Part 2 of the SAE J2735 standard, it does not necessarily mean that vehicle manufacturers will provide it. Most of the Part 2 data elements are defined as optional information in the standard. Some of the Part 2 data elements are currently available on the internal data bus of some vehicles; others are not. There are currently not environmental data elements included in the BSM – part 1 or 2.

Recognizing the promise of the connected vehicle technologies, the USDOT, along with its state and local stakeholders and the private sector, are investigating the collection of environmental data to create actionable information that can be used by system users and operators to support and facilitate “green” transportation choices for all surface transportation modes. Connected vehicle systems have the advantage of collecting significantly more data than infrastructure based systems and allow for communication to drivers through in-vehicle systems that are more likely to capture the attention of drivers and change their driving behavior. Connected vehicle applications are also likely to be more cost effective than conventional ITS requiring less infrastructure investments.

Section 3 provided an overview of existing systems and examples of environmental benefits. While these systems have shown promise in reducing emissions and fuel consumption, it is envisioned that connected vehicle technologies have the potential to provide additional benefits above current systems. Current traffic signal systems are fundamentally limited by their exclusive reliance upon infrastructure-based data collection and information dissemination. These limitations are listed below along with justifications for connected vehicle applications:

1. **Current systems are limited by the data collected from infrastructure-based sensors.** Current traffic signal systems rely on infrastructure-based detection positioned at the stop bar or the approach to the traffic signal. Infrastructure-based detection provides information about the presence of a vehicle at the intersection, the speed of the vehicle, and can be used to estimate the classification or type of vehicle (e.g., passenger vehicle, bus, or tractor trailer). These detectors, however, are limited in that they are location specific and can only provide data at a single point location. Additionally, shared lanes (e.g., a lane allowing vehicles to go straight or turn left) cannot easily decipher between vehicle movements. Connected vehicle technologies enable data to be collected from vehicles along the entire approach through the transmission of the basic safety message (BSM) which includes the vehicle’s location, speed, acceleration, and other characteristics ten times a second, or at 10 hertz. These data would allow a connected vehicle traffic signal system to be more robust and consider prevailing traffic conditions.

2. **Current systems do not collect and use (or collect and use minimal) environmental data.** Current traffic signal systems do not collect (or collect minimal) environmental data. Environmental data include emissions data near a traffic signal, along a signalized corridor, or for a network. Additionally limited surface related weather data is collected by existing systems. While environmental sensor stations allow these data to be collected, they are not typically deployed as part of a traffic signal system and rarely serve as inputs to traffic signal systems. Connected vehicle technologies allow for environmental data (e.g., vehicle emissions data, average fuel consumption, and road weather data) to be collected from vehicles, sent wirelessly to infrastructure, and used by the traffic signal system software to optimize the traffic signal reducing emissions and fuel consumption at the intersection. Additionally, many of these systems also produce limited performance measures pertaining to the environment.
3. **Emissions data are not collected from vehicles**. Recently there have been major advances in collecting traffic probe data from vehicles using toll tag readers, Bluetooth readers, license plate recognition systems, and tracking the location of vehicles using mobile phone applications. These advances have made it possible to collect an abundance of highly accurate data to estimate traffic conditions. Little progress has been made however in collecting vehicle emissions data for operational purposes. Connected vehicle technologies provide an opportunity to collect emissions data directly from vehicles which in turn could be used by operating to optimize the environmental performance of the transportation network.
4. **The majority of traffic signal systems are not optimized in "real-time".** Adaptive traffic signal systems represent a small percentage of all traffic signal systems in the United States. The vast majority of traffic signal systems are actuated. These systems are typically optimized by traffic engineers over a given time period (e.g., once every two years) based on traffic data collected from traffic sensors or from manual counts which often require data collection about turning movements at the intersection. Traffic signal timing plans are typically determined for specific time periods (e.g., morning peak, mid-day, afternoon peak, etc.). Because these timing plans are only optimized periodically, they can often become outdated especially if new traffic patterns occur in the area. Additionally, these systems are limited in that they cannot respond to current demand, but instead operate a timing plan derived by a traffic engineer for a "typical day". Using connected vehicle technologies would allow traffic signal systems to collect real-time data with minimal infrastructure (e.g., a RSE unit) and use data from vehicles to optimize the system in real-time, similar to current adaptive traffic signal systems.
5. **Adaptive traffic signal systems require an extensive amount of infrastructure-based sensors per approach.** Many transportation agencies shy away from adaptive traffic signal systems because they require an extensive amount of infrastructure-based sensors per approach. These sensors are costly to deploy and maintain, especially if deployed along an entire corridor or for an entire city or jurisdiction. Connected vehicle technologies allow for traffic and environmental data to be collected along an arterial using an RSE unit or other wireless communication infrastructure instead of numerous traffic sensors.
6. **Current traffic signal systems are generally optimized for mobility, not the environment.** Existing traffic signal systems optimize traffic signals to improve mobility by reducing overall delay at an intersection, for a corridor, or a network. Generally, algorithms used to optimize traffic signals attempt to reduce delays (user time), travel times, or stops at traffic signals. Reduction in emissions is another measure of

effectiveness (MOE) that some software systems use to optimize traffic signals, but emissions generally are secondary MOEs to mobility measures. Environmental benefits are usually presented as benefits of signal optimization instead of serving as the measure that the algorithm uses to optimize traffic signals. Since many traffic signal systems do not collect emissions data, it is not possible for the system to be optimized in real-time based on this MOE. Connected vehicle technologies however allow for the collection of real-time emissions data that can be used by traffic signal systems for optimization.

7. **Current traffic signal priority applications do not consider environmental impacts at the signalized intersection.** Traffic signal priority is a technique used to improve vehicle movement, typically buses, through an intersection. Buses normally signal their impending arrival at a signalized intersection using radio systems. Upon receiving the message that a bus is approaching the traffic signal holds the green light until the bus clears the intersection. Many traffic signal priority systems are primitive, granting priority to a transit vehicle regardless schedule adherence, the number of passengers on the transit vehicle, or impacts of extending the green on the traffic signal coordination or impacts to vehicles on the cross-streets.
8. **Current traffic signal systems do not grant priority to commercial vehicles.** Commercial vehicles (e.g., trucks) produce a significant amount of emissions when they are required to stop and restart at signalized intersections. Reducing the number of stops for commercial vehicles, especially along corridors with high percentages of trucks (i.e., corridors near ports), has the potential to provide significant environmental benefits. However, traffic signal priority typically is not considered for commercial vehicles.
9. **Current traffic signal systems do not provide information to drivers to support eco-driving.** Vehicle OEMs are beginning to incorporate information on vehicle dashboards that can be used by drivers to facilitate eco-driving strategies. This includes information about the vehicle’s instantaneous fuel consumption which can be monitored by the driver. These data are collected directly from the vehicle. Current systems however do not consider data from roadside infrastructure such as SPaT data, traffic conditions downstream, or the upcoming road grade as inputs to eco-driving recommendations. While research has been conducted by several universities on the benefit of providing SPaT messages to drivers, these applications have not been incorporated into vehicles mainly because SPaT data is not currently being made available from the public sector.
10. **Electric vehicles are not capable of charging their batteries as they wait at signalized intersections.** Existing traffic signal systems, and other infrastructure located at the signalized intersection, do not provide the capabilities to charge electric vehicle batteries while the vehicle is stopped at a red light at a traffic signal. Recently, there have been advances in wireless charging of electric vehicle batteries using inductive charging. Inductive charging uses an electromagnetic field to transfer energy between two objects – usually done with a charging station or pad. Energy is sent through an inductive coupling to an electrical device, which can use that energy to charge a vehicle’s battery. Inductive charging infrastructure could be installed near the stop bar at a signalized intersection, so while an electric vehicle is stopped at a red light the driver of an electric vehicle could opt-in to an application for his/her vehicle to be charged.

The market penetration of connected technology in vehicles is expected to take on the order of a decade to achieve comprehensive deployment. Infrastructure deployed during this transition must continue to support the environmental needs of non-equipped vehicles while leveraging the capabilities of connected vehicles to realize the safety, mobility, and environmental benefits of V2I communications. As such, it is logical that the first generation of V2I applications builds upon current infrastructure systems for non-equipped vehicles, while at the same time providing data and information to connected vehicles to support better situational awareness and more informed decisions. The remainder of this document provides an overview of a proposed Eco-Traffic Signal System that addresses the limitations of current systems leveraging connected vehicle technologies.

5 Eco-Signal Operations Transformative Concept

5.1 Eco-Signal Operations Transformative Concept Overview

The Eco-Signal Operations Transformative Concept includes the use of connected vehicle technologies to decrease fuel consumption and decrease GHGs and criteria air pollutant emissions on arterials by reducing idling, reducing the number of stops, reducing unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections. As the AERIS Program defined the Eco-Signal Operations Transformative Concept, it initially envisioned four applications: (1) Eco-Traffic Signal Timing, (2) Eco-Traffic Signal Priority, (3) Eco-Approach and Departure at Signalized Intersections, and (4) Connected Eco-Driving. Subsequently, a Wireless Inductive Charging application was added. These applications are summarized below.

- **Eco-Traffic Signal Timing.** This application is similar to current traffic signal systems; however the application's objective is to optimize the performance of traffic signals for the environment. The application collects data from vehicles, such as vehicle location, speed, and emissions data using connected vehicle technologies. It then processes these data to develop signal timing strategies focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region. The application evaluates traffic and environmental parameters at each intersection in real-time and adapts so the traffic network is optimized using available green time to serve the actual traffic demands while minimizing the environmental impact.
- **Eco-Traffic Signal Priority.** This application allows either transit or freight vehicles approaching a signalized intersection to request signal priority. These applications consider the vehicle's location, speed, vehicle type (e.g., alternative fuel vehicles), and associated emissions to determine whether priority should be granted. Information collected from vehicles approaching the intersection, such as a transit vehicle's adherence to its schedule, the number of passengers on the transit vehicle, or weight of a truck may also be considered in granting priority. If priority is granted, the traffic signal would hold the green on the approach until the transit or freight vehicle clears the intersection. This application does not consider signal pre-emption, which is reserved for emergency response vehicles.
- **Eco-Approach and Departure at Signalized Intersections. Eco-Approach and Departure at Signalized Intersections.** This application uses wireless data communications sent from a roadside equipment (RSE) unit to connected vehicles to encourage "green" approaches to signalized intersections. The application, located in a vehicle, collects SPaT and Geographic Information Description (GID) messages using V2I communications and data from nearby vehicles using V2V communications. Upon receiving these messages, the application would perform calculations to determine the vehicle's optimal speed to pass the next traffic signal on a green light or to decelerate to a stop in the most eco-friendly manner. This information is then sent to longitudinal vehicle control capabilities in the vehicle to support partial

automation. The application also considers a vehicle's acceleration as it departs from a signalized intersection and engine start-stop technologies.

- **Connected Eco-Driving.** This application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. Eco-driving advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles based on prevailing traffic conditions, interactions with nearby vehicles, and upcoming road grades. The application also provides feedback to drivers on their driving behavior to encourage drivers to drive in a more environmentally efficient manner. Finally, the application may also include vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy (e.g., changes gears, switches power sources, or reduces its speed in an eco-friendly manner).
- **Wireless Inductive Charging.** Wireless inductive charging includes infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables inductive charging of electric vehicles including cars, trucks, and buses. Roadside charging infrastructure supports static charging capable of transferring electric power to a vehicle parked in a garage or on the street and vehicles stopped at a traffic signal or a stop sign. It also supports charging vehicles moving at highway speeds.

The Transformative Concept is described in more detail through the use of a storyboard described in Figure 5-1 and in Table 5-1.

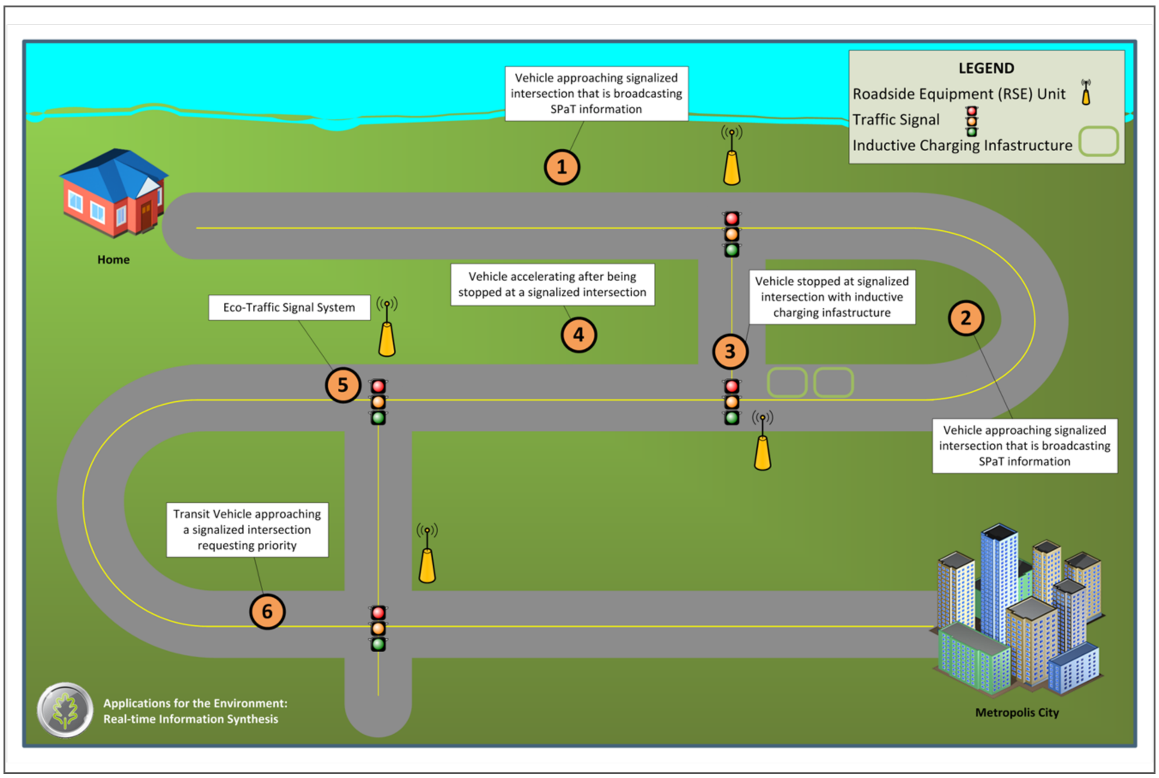

Figure 5-1: Eco-Signal Operations Storyboard (*Source*: Noblis, 2013)

Table 5-1: Eco-Signal Operations Storyboard

Step	Description
1	**Application. Eco-Approach and Departure at Signalized Intersections** **Conditions. Vehicle Approaching a Signalized Intersection that is Broadcasting a SPaT Message** – As the vehicle approaches a traffic signal its OBE unit receives a SPaT message. The vehicle's OBE unit calculates that if the vehicle accelerates within the speed limit, it will be able to pass through the intersection before the traffic light turns red. By traversing the intersection without stopping, the vehicle will save fuel and reduce emissions. The vehicle's OBE unit considers prevailing traffic conditions and other vehicles' trajectories before recommending a speed for the driver to proceed through the intersection. *Note: Future versions of the application would allow vehicle systems to automatically adjust the vehicle's speed to traverse through the intersection, taking into account interactions with other vehicles.*
2	**Application. Eco-Approach and Departure at Signalized Intersections** **Conditions. Vehicle Approaching a Signalized Intersection that is Broadcasting SPaT Message** – As the vehicle approaches the next traffic signal, its OBE unit receives another SPaT message. The vehicle's OBE unit calculates that the vehicle will not be able to pass through the intersection at its current speed before the traffic light turns red – the vehicle will have to stop. The vehicle's OBE unit calculates an eco-approach to the intersection, displaying to the driver the optimal speed to decelerate at the signalized intersection. Following the recommendations from the OBE, the driver adjusts the vehicle's speed, coasting slowly to a stop at the intersection. This trajectory reduced fuel consumption and vehicle emissions. *Note: Future versions of the application would allow vehicle systems to automatically change the vehicle's gears or automatically decelerate the vehicle to a stop, taking into account interactions with other vehicles.*
3	**Application. Wireless Inductive Charging** **Conditions. Vehicle Stopped at a Signalized Intersection with Inductive Charging Infrastructure** – As the vehicle is stopped at the signalized intersection, its OBE unit receives a message that the traffic signal is equipped with wireless inductive charging infrastructure allowing electric vehicles to be charged while waiting at the traffic signal. The driver of the vehicle opts into an application on the vehicle's OBE to use the inductive charging infrastructure. As the vehicle waits at the traffic signal, an inductive charge is provided to the electric vehicle, slowly charging the vehicle's battery. The vehicle also has engine start-stop capabilities that automatically shut down and restart the vehicle's engine reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. This is advantageous for the vehicle as it spends time waiting at traffic lights.

Step	Description
4	**Application. Eco-Approach and Departure at Signalized Intersections** **Conditions. Vehicle Accelerating After Being Stopped at a Signalized Intersection** – The vehicle begins to accelerate after being stopped at a signalized intersection. The vehicle's OBE unit calculates the most environmentally friendly acceleration profile considering prevailing traffic conditions and interactions with other vehicles. The driver of the vehicle follows the recommendations provided by the OBE unit, slowly accelerating to an optimal eco-speed. By slowly accelerating to this speed, the vehicle saves fuel consumption and emissions. *Note: Future versions of the application would allow vehicle systems to automatically adjust the vehicle's speed to traverse through the intersection, taking into account interactions with other vehicles.*
5	**Application. Eco-Traffic Signal Timing** **Conditions. Multiple Vehicles Approaching an Eco-Traffic Signal System** – Multiple vehicles approach an Eco-Traffic Signal System broadcasting data about their location, speed, acceleration, and average emissions to a nearby RSE unit. These data are sent to an Eco-Traffic Signal System which resides at the city's Traffic Management Center. The Eco-Traffic Signal System uses these data, along with data collected from roadside equipment (e.g., traffic sensors) to adjust the signal timing based on traffic conditions as well as emissions and environmental conditions such as weather and pavement conditions. The application is similar to current traffic control systems; however the application's objective is to optimize traffic signals for the environment leveraging connected vehicle data. The Eco-Traffic Signal System determines the optimal operation of the traffic signal system based on the data and implements the timing plan.
6	**Application. Eco-Traffic Signal Priority** **Conditions. Transit Vehicle Approaching a Signalized Intersection Requesting Priority** – A transit vehicle is behind schedule and is full of passengers. As the vehicle approaches a signalized intersection, it makes a request for signal priority (i.e., extension of green). A nearby RSE unit, equipped with a local processor, receives the request for priority and determines if priority should be granted to the vehicle. This decision considers the transit vehicle's occupancy, fuel type, and adherence to its schedule. Impacts to other approaches are also considered. The application determines that signal priority should be granted and extends the green time at the intersection allowing the transit vehicle to traverse the intersection on green. If signal priority had not been granted, the transit vehicle would have had to stop at the traffic signal. This would have put the vehicle behind schedule and while stopped at the intersection, the transit vehicle would have produced more emissions and used more fuel. *Note: Traffic signal priority may also be granted to commercial vehicles.*

5.2 The Potential for CACC and Automation on Arterials

Cooperative Adaptive Cruise Control (CACC) applications allow drivers the convenience of setting their desired speed and having the vehicle safely maintain that speed as well as possible. The CACC system recognizes the presence of a slower vehicle ahead and then automatically adjusts the speed to follow the other vehicle safely. If the vehicle ahead should stop suddenly, or if another vehicle cuts in ahead too closely, the CACC vehicle can react in time to allow it to brake immediately using the combination of the sensors and the communication system. This Transformative Concept also supports vehicle platooning. Vehicle platoons can decrease the distances between cars by wirelessly coupling vehicles together. Vehicle platoons allow for a closer headway between vehicles by eliminating reacting distance needed for human reaction.

CACC and vehicle platoons can decrease the distances between cars using electronic, and possibly mechanical, coupling. This capability would allow many vehicles to accelerate or brake simultaneously. While much vehicle platooning research has been directed towards freeways, there are also opportunities for vehicle platooning on arterial. Instead of waiting after a traffic signal changes to green for drivers ahead to react, a synchronized platoon would move as one, allowing up to a fivefold increase in traffic throughput if spacing is diminished sufficiently.

Figure 5-2 illustrates trajectories of three vehicles along a signalized corridor without CACC or automation technologies. Time is shown on the y-axis and distance is shown on the x-axis. The slope of the line represents the speed of the vehicle. As shown in the figure, once a traffic signal turns from red to green there is typically start-up delay. These delays may take up to two or more seconds for the driver to react to the change in the traffic signal. This delay continues as a shockwave to vehicles in the queue with the last vehicle having to wait many seconds before the vehicle can begin to move. The result is a reduction in the effective green time and a narrower green wave. Additionally, as vehicles begin to accelerate, drivers may not accelerate in the most eco-friendly manner. Human drivers typically accelerate hard resulting in more emissions. Once the vehicles begin traveling through the corridor vehicles typically experience variations in speeds and headways. Additionally, human drivers also accelerate and decelerate too often. The result of these speed variations is that all vehicles may not be able to traverse the corridor in the green wave and may be required to stop at the third traffic signal.

Figure 5-3 depicts the potential for CACC or automated vehicles. As shown in this illustration, with these technologies start-up delay can be reduced through communication between the traffic signal and vehicles, as well as communication between vehicles. With CACC and automation, when a traffic signal turns from red to green, vehicles in the queue react quicker and start moving in unison. Automation can also ensure an eco-friendly acceleration and smooth and constant speed through the corridor. Headways between vehicles can be reduced and vehicles can travel more efficiently through the corridor.

While the automated scenario has the potential to provide significant mobility and environmental benefits, CACC and automation is more complicated on arterials than on freeways. For example, vehicles are more likely to change lanes or turn on arterials. Thus vehicles may need to enter or leave platoons more often. Additionally, what happens if the entire platoon cannot traverse the intersection? Will vehicles in the middle of the platoon need to break-off? Can the green time be extended to allow the entire platoon to traverse the intersection? The AERIS Program expects to discuss vehicle automation in more detail in future reports.

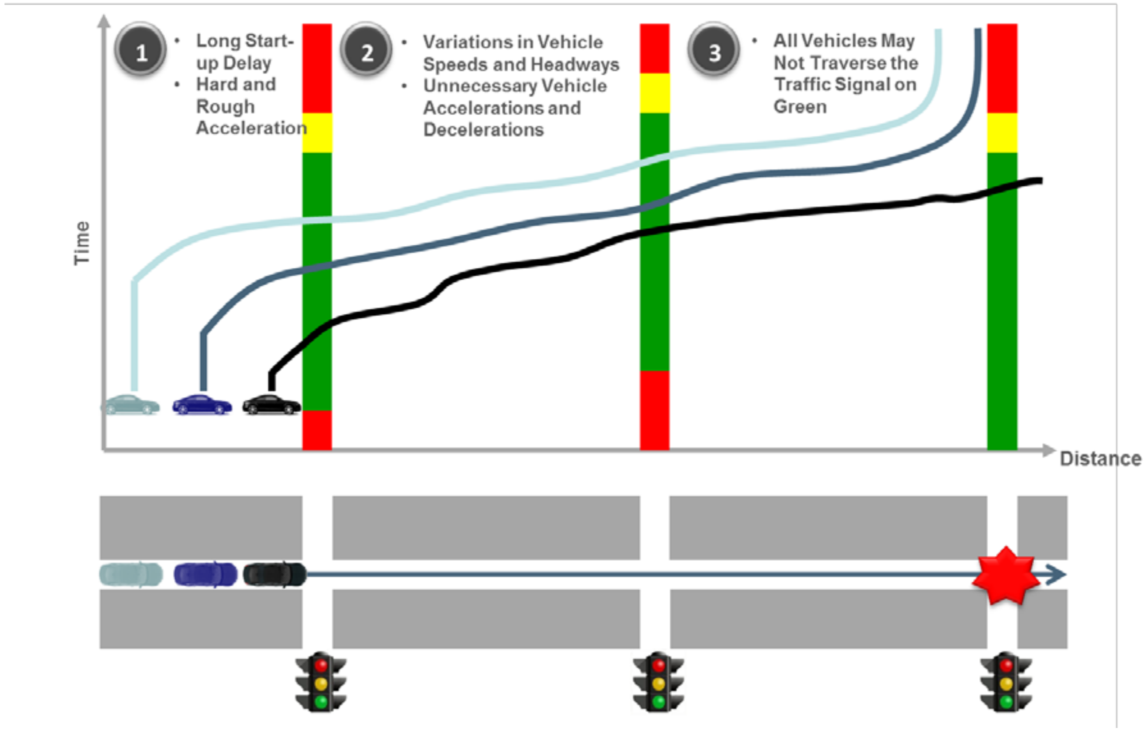

Figure 5-2: Vehicle Trajectories without Automation (*Source*: Noblis, 2013)

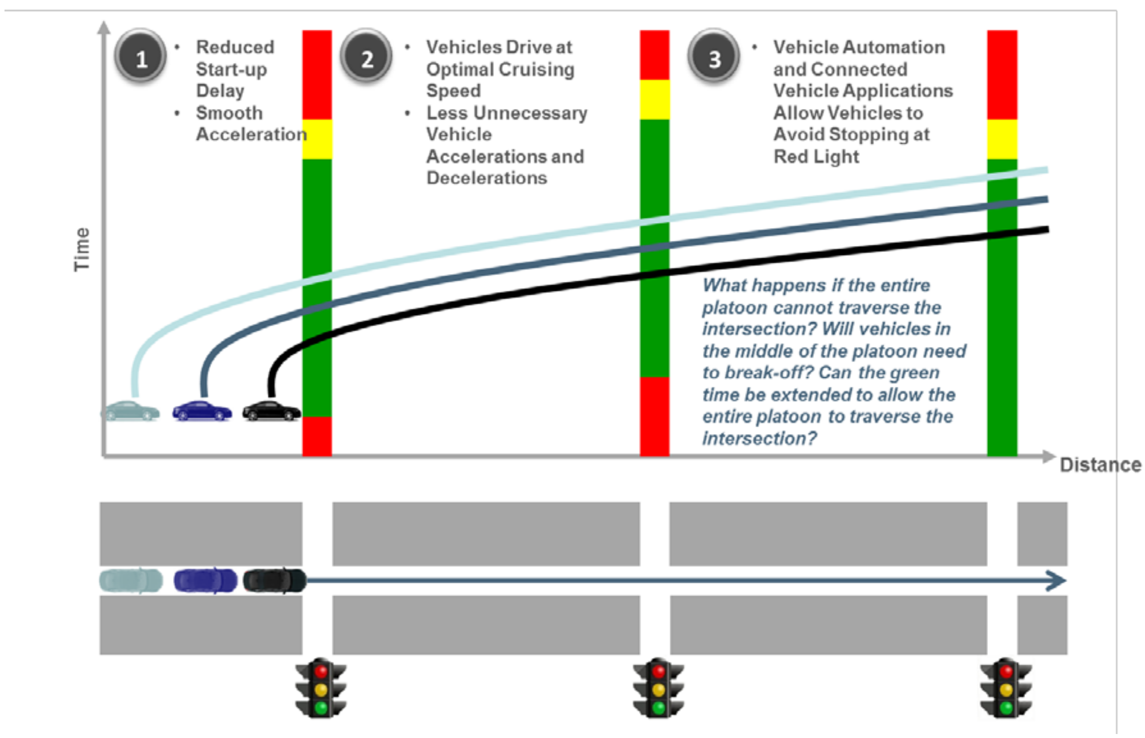

Figure 5-3: Vehicle Trajectories with Automation (*Source*: Noblis, 2013)

5.3 Eco-Signal Operations Systems

Prior to this document, the AERIS Program described the AERIS Transformative Concepts by describing each individual application. This document takes a systematic approach to describe these applications by defining systems that fit within the Transformative Concept. Two systems were identified for the Eco-Signal Operations Transformative Concept; (1) the Eco-Traffic Signal System and (2) the In-Vehicle System. Figure 5-4 depicts the two systems and their core functionality. The Eco-Traffic Signal System is envisioned to be a system that resides in an operations center while the In-Vehicle System is expected to reside in a vehicle.

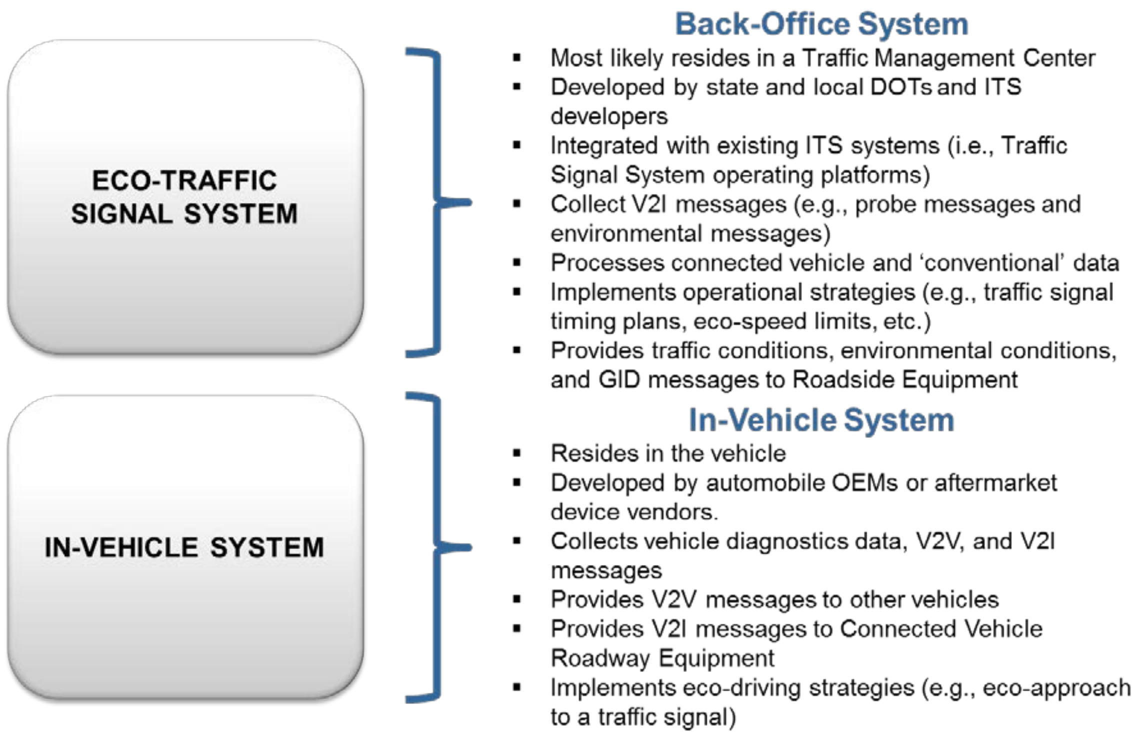

Figure 5-4: Eco-Signal Operations Systems (*Source*: Noblis, 2013)

The two systems do not exist in isolation; instead they interact with several actors or physical entities that communicate with the system. Figure 5-5 depicts the two Eco-Signal Operations Systems and how they interact with each other and various actors. These systems are discussed in terms of the environments within which they will operate. As shown in the diagram, the Eco-Traffic Signal System resides in the ITS Environment. This environment consists of actors that one would typically associate with conventional ITS such as traffic management centers (TMCs) and their associated systems, CCTV cameras, traffic sensors, and dynamic message signs (DMS). It is envisioned that the Eco-Traffic Signal System will be deployed in a manner similar to today's current traffic signal systems – most likely by a state or local DOT as part of their existing systems.

The In-Vehicle System resides in the Vehicle Environment and is expected to be developed by either automobile original equipment managers (OEMs) or aftermarket device vendors. The system will need to interface with other systems on the vehicle such as the vehicle's diagnostic systems and/or vehicle actuator. It is unlikely that the public sector would deploy these systems;

instead they may lead the process of developing communications standards that enable multiple manufacturers to make interoperable equipment. The public sector's role would also be to enable the functionality of eco-driving systems located on the vehicle. For example, SPaT messages provided by public agencies could be used to support eco-driving systems as a vehicle approaches a traffic signal.

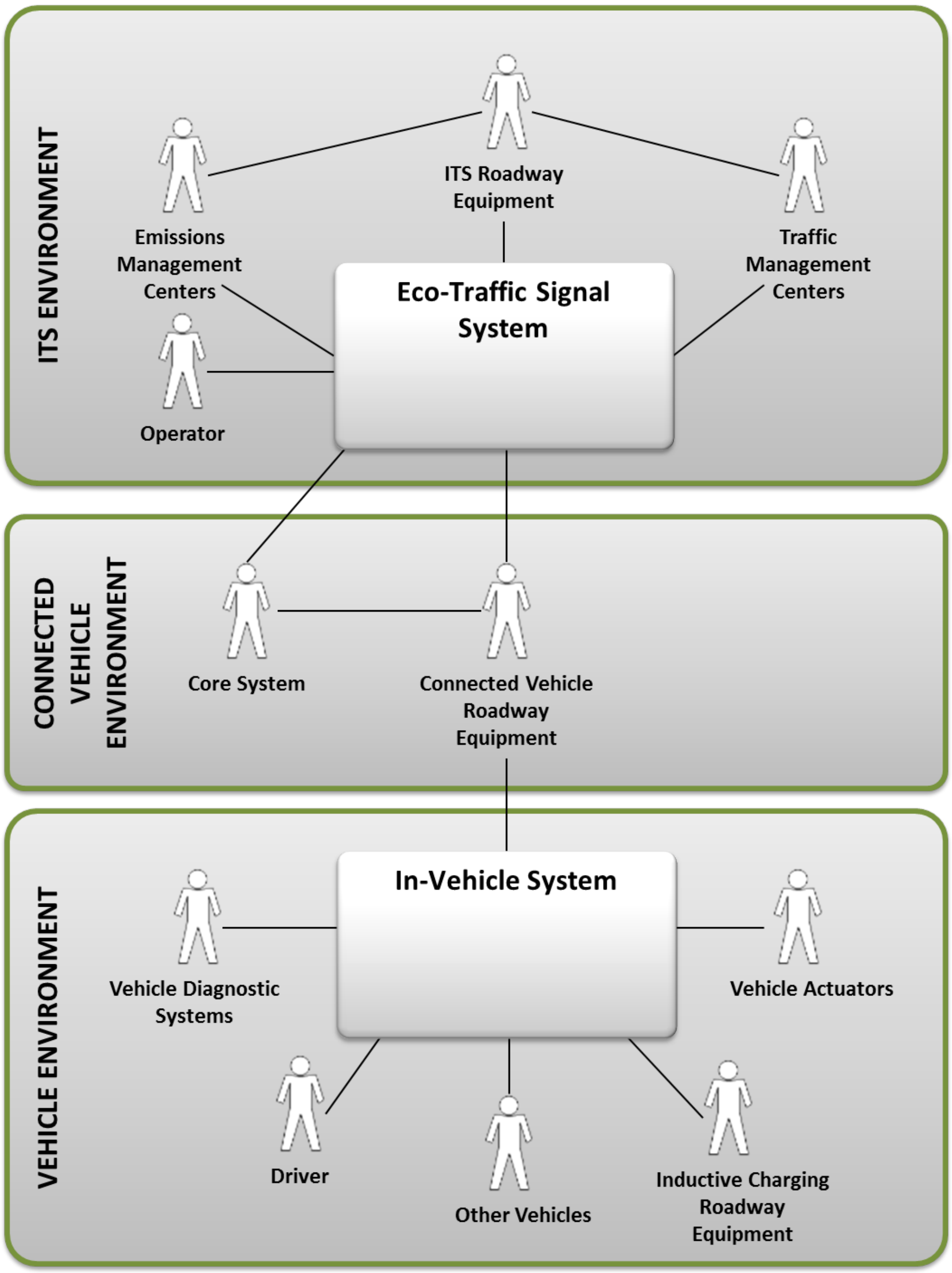

Figure 5-5: Eco-Signal Operations Environments (*Source*: Noblis, 2013)

The Eco-Traffic Signal System and the In-Vehicle System are connected by the Connected Vehicle Environment. This includes the Core System and Connected Vehicle Roadway Equipment such as RSE units. The Core System includes those enabling technologies and services that will provide the foundation for application transactions. The Core System works in conjunction with External Support Systems like the Certificate Authority for DSRC security, as defined in IEEE Standard 1609.2. The system boundary for the Core System is not defined in terms of devices or agencies or vendors but by the open, standardized interface specifications that govern the behavior of all interactions between Core System Users. Connected Vehicle Roadway Equipment provides a V2I and I2V link between the two systems.

The boundaries of the two systems are shown by their rectangles. Entities outside of these boundaries represent external actors that may interface with the systems. Additionally, there are interfaces between these actors that contribute to the Transformative Concept, but do not interface directly with the system. For example, a traffic signal controller (shown as the ITS Roadway actor) will need to send SPaT data to the Connected Vehicle Roadway Equipment for broadcasting the SPaT message that may be received by vehicles. While this is an important component of the Eco-Approach and Departure at a Signalized Intersection application, this interface is outside the scope of this document.

Sections 6 and 7 describe the Eco-Traffic Signal System and In-Vehicle System, respectively. These sections include system context diagrams, logic diagrams, subsystem diagrams, and user needs for each system.

6 Eco-Traffic Signal System

The Eco-Traffic Signal System is envisioned to be a computerized transportation system that employs communication technology to gather traffic and environmental information from multiple sources including ITS Roadway Equipment, Connected Vehicle Roadway Equipment, and other systems. The system then processes these data to develop operational strategies at signalized intersections, focused on reducing fuel consumption and overall emissions at the intersection, along a corridor, or for a region. The Eco-Traffic Signal System evaluates traffic and environmental parameters at each intersection in real-time and uses this information to adapt traffic signal timing plans to fluctuating traffic and environmental conditions through its optimization algorithm. These features allow the system to readily adapt to actual traffic volumes and environmental conditions so that the traffic network operation is optimized using available green time to serve the actual traffic demands while minimizing the environmental impact.

The Eco-Traffic Signal System also supports the implementation of eco-traffic signal priority for both transit and freight vehicles. The system considers criteria such as the location, speed, heading, and emissions profile of the requesting vehicle as well as other vehicles approaching the intersection, and a transit vehicle’s adherence to schedule when granting priority at the signalized intersection. If it is determined that priority should be granted, the Eco-Traffic Signal System alerts the traffic signal controller(s) that a priority needs to be granted and provides information about the amount of time to extend the green.

The remainder of this section presents diagrams describing how the system works. These diagrams begin with a System Context Diagram showing the actors that interact with the system, and then a Logic Diagram focused on processes taking place within the system, and finally a Subsystem Diagram depicting the various subsystems within the system. These diagrams are followed by tables documenting the user needs of the system, which express the underlying objectives of actors in terms of what they are trying to accomplish as they relate to the system.

6.1 Eco-Traffic Signal System – System Context Diagram

Figure 6-1 depicts the System Context Diagram for the Eco-Traffic Signal System showing interactions of actors with the system. The system itself is represented by the large square while the actors are shown as people outside of the system boundary, although actors may be devices or organizations rather than individual people. Actors that interact with the system include: (1) Traffic Management Centers, (2) Connected Vehicle Roadway Equipment, (3) ITS Roadway Equipment, (4) Emissions Management Centers, and (5) Traffic Management Center Operators. Appendix B presents a complete list and descriptions of the actors. Actors that provide inputs to the system are depicted on the left side of the diagram, while actors that receive outputs from the system are shown on the right side of the diagram. Relationships between the actors and the system are illustrated by arrows connecting the actors to the Eco-Traffic Signal System.

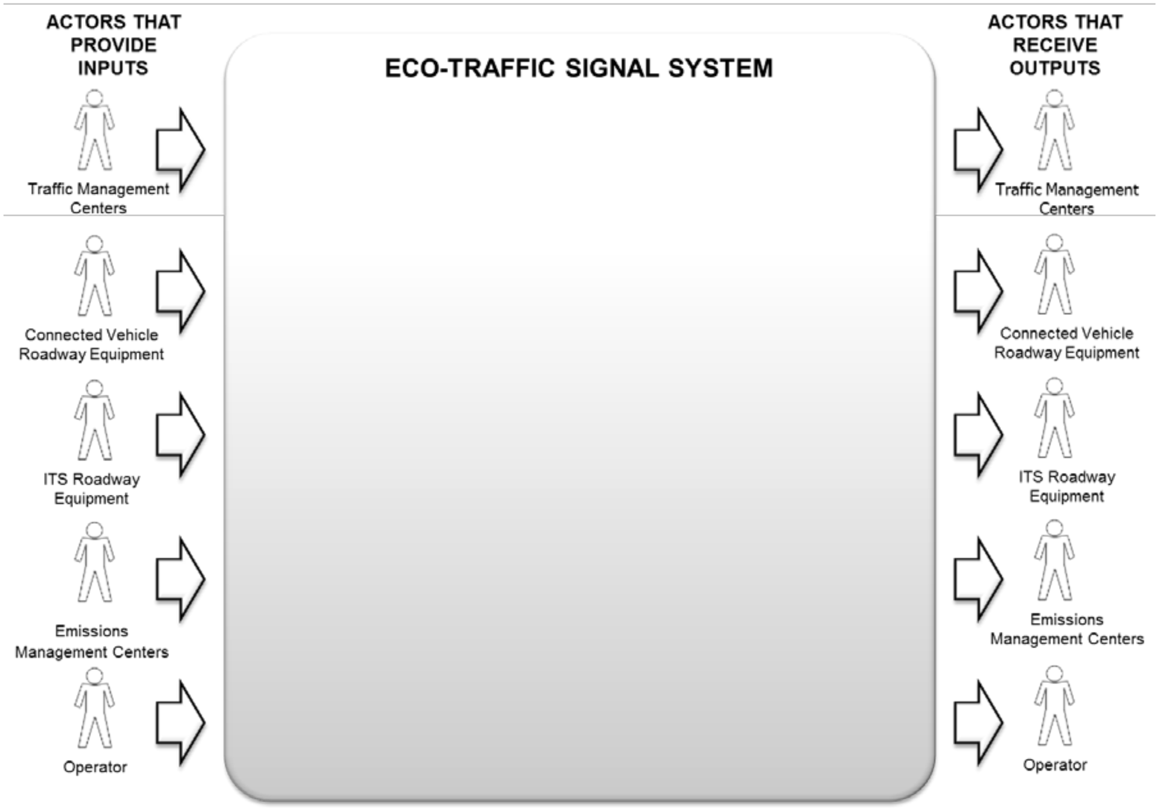

Figure 6-1: Eco-Traffic Signal System – System Context Diagram (*Source*: Noblis, 2013)

6.2 Eco-Traffic Signal System – Logic Diagram

Figure 6-2 depicts a Logic Diagram for the Eco-Traffic Signal System depicting the functionality of the system at a high level. It is important to note that Logic Diagrams are fundamentally different from sequence diagrams or flow charts because they do not make any attempt to represent the order or number of times that the systems actions and sub-actions should be executed. As shown in Figure 6-2, the Logic Diagram has four major components:

- The **actors** with which the system interacts,
- The **system** itself (the large rectangle),
- The **services or functions** that the system performs (depicted as colored ovals inside the rectangle), and
- The **relationships** between these functions and between functions and actors (depicted as arrows where the direction of the arrow represents the direction of data flow).

The Eco-Traffic Signal System performs four types of services or functions. These include (1) data collection which is depicted as red ovals, (2) data processing which is depicted as green ovals, (3) data store and archive which is depicted as blue ovals, and (4) dissemination which is depicted as purple ovals. The colors of these ovals convey to the next diagram and the user needs, described later in this document. As shown in the figure, the Eco-Traffic Signal System collects data from various actors. It then processes these data to determine real-time and predicted traffic and environmental conditions, determine traffic signal timing plans optimized for the environment, and determine strategies for implementing traffic signal priority. This data is archived and disseminated to the actors on the right side of the figure.

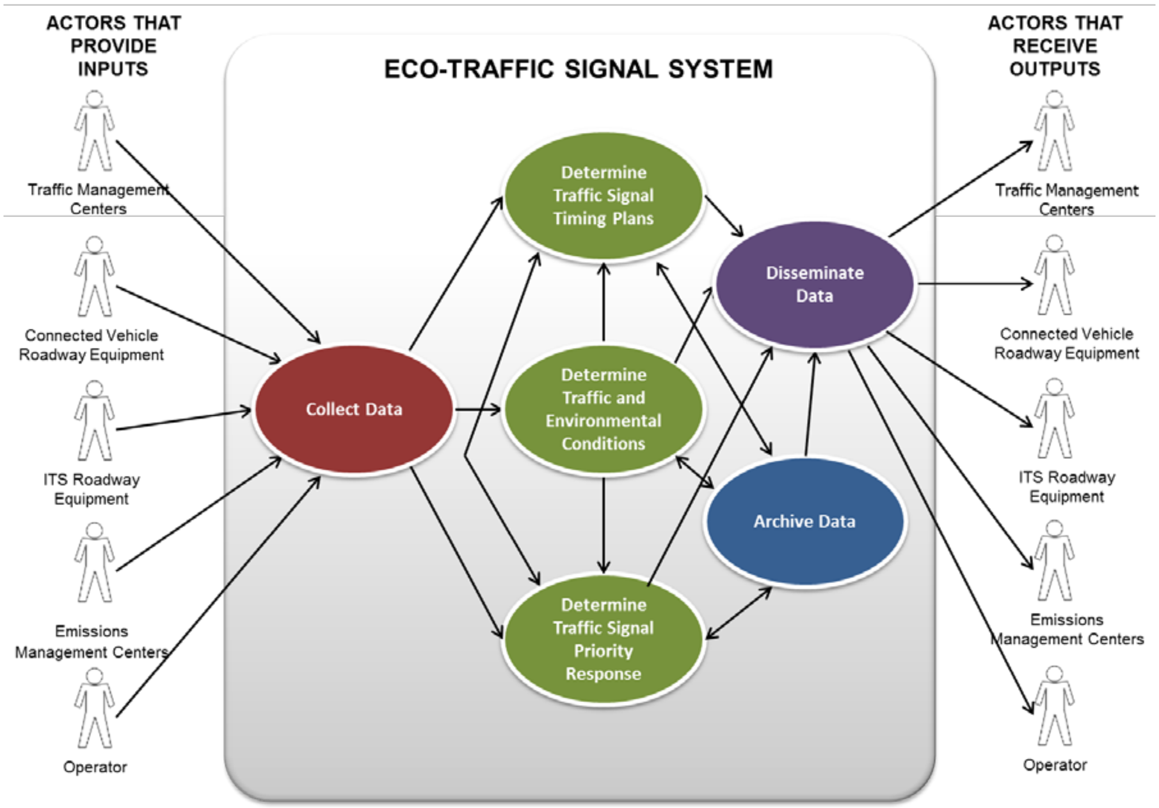

Figure 6-2: Eco-Traffic Signal System – Logic Diagram (*Source*: Noblis, 2013)

6.3 Eco-Traffic Signal System – Subsystem Diagram

Figure 6-3 depicts the subsystem diagram for the Eco-Traffic Signal System. Similar to previous diagrams, the left side of this diagram shows the actors that provide inputs to the Eco-Traffic Signal System while the right side of the diagram shows the actors that receive the outputs. In the center of the diagram are the four elements, or groupings of subsystems, contained within the Eco-Traffic Signal System. Within each element are one or more subsystems. These subsystems break down the functional tasks depicted in Figure 6-2 into smaller, more specific tasks. For example, in the case of data collection subsystems, the name of the subsystem reflects the type of input the subsystem collects. Likewise, in the case of dissemination subsystems, the name of the subsystem reflects the type of information the subsystem disseminates. The elements include:

- **Data Collection Element.** This element consists of the Traffic Signal Priority Request Data Collection Subsystem, Traffic Data Collection Subsystem, Environmental Data Collection Subsystem, Traffic Signal Operational Status Data Collection Subsystem, Geographic Information Description Data Collection Subsystem, and the Operator Input Data Collection Subsystem.

- **Data Processing Element.** This element consists of the Real-Time and Predicted Traffic Conditions Subsystem, Real-Time and Predicted Environmental Conditions Subsystem, Traffic Signal Priority Decision Support Subsystem, and Traffic Signal Timing Subsystem.
- **Data Dissemination Element.** This element consists of the Traffic Signal Priority Dissemination Subsystem, Traffic and Environmental Conditions Dissemination Subsystem, Signal Timing Plans Dissemination Subsystem, and Geographic Information Description (GID) Dissemination Subsystem,.
- **Data Storage & Archive Element.** This element consists of the Data Archive Subsystem.
- **User Interface Element.** This element consists of the User Interface Subsystem.

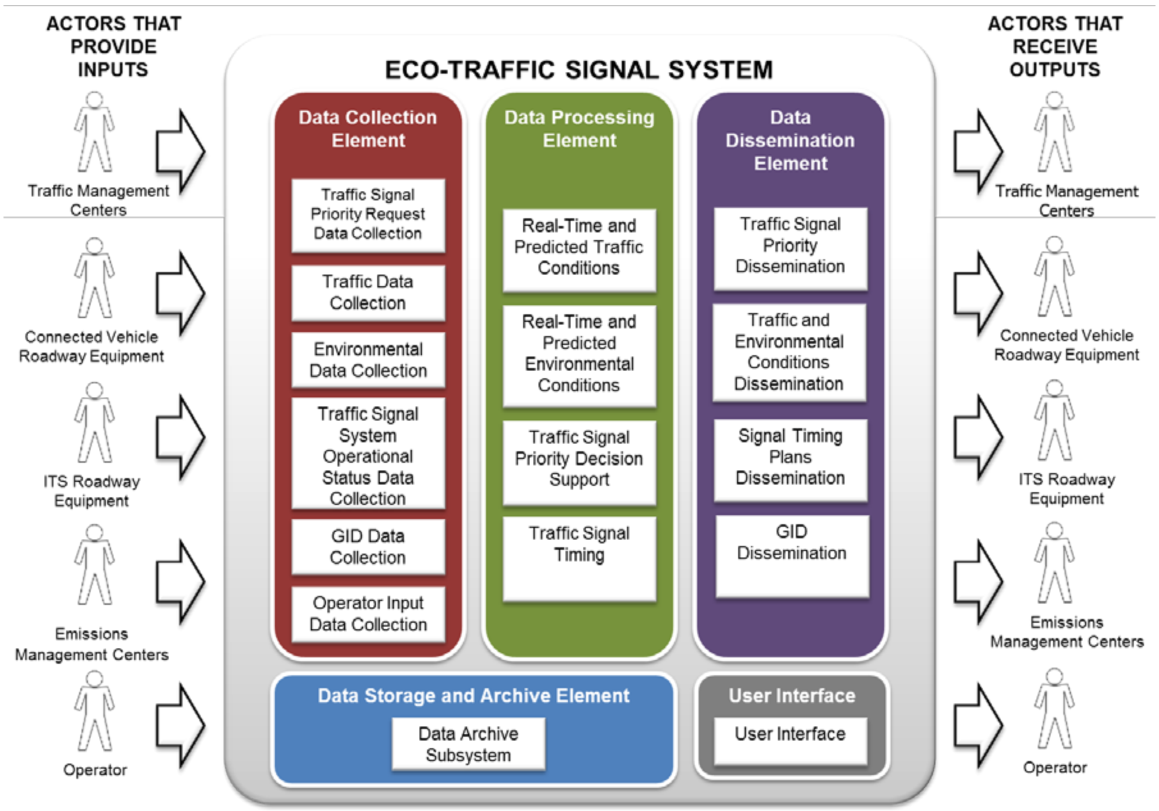

Figure 6-3: Eco-Traffic Signal System – Subsystem Diagram (*Source*: Noblis, 2013)

6.4 Eco-Traffic Signal System User Needs

This section identifies user needs, or desired capabilities, for the Eco-Traffic Signal System. These needs express the underlying objectives of actors in terms of what they are trying to accomplish as it relates to the system. A need is a capability that is identified to accomplish a specific goal or solve a problem. It describes — what is needed while avoiding the implementation specifics, or the "how". Each need is identified uniquely, contains a description and a rationale. Rationale may include examples of how the system capability may be exercised. User Needs are categorized by the elements in the subsystem diagram.

Table 6-1: Eco-Traffic Signal System User Needs

Element	Subsystem	ID	Title	Description
Data Collection	Traffic Signal Priority Request Data Collection Subsystem	ETSS-DC-01	Collect Traffic Signal Priority Requests	**The Eco-Traffic Signal System needs to collect traffic signal priority requests originating from transit vehicles and commercial vehicles equipped with traffic signal priority applications and transponders.** These requests will be considered by the Eco-Traffic Signal System in determining whether a signal priority request should be granted at a signalized intersection to maximize environmental benefits. Traffic signal priority requests may also include information about the vehicle making the request (e.g., the number of passengers on the transit vehicle, the transit vehicle's adherence to its schedule, the engine type, weight of the truck, etc.). This information would be included in the decision for granting a vehicle traffic signal priority at a signalized intersection.
Data Collection	Traffic Data Collection Subsystem	ETSS-DC-02	Collect Traffic Data	**The Eco-Traffic Signal System needs to collect traffic data (e.g., volume, speed, occupancy, vehicle classification, turning movements, incidents, pedestrian calls, or presence at traffic signals, vehicle type, and vehicle position).** Traffic data may be obtained from traffic sensors that detect the presence of vehicles at locations along the network (e.g. using traffic sensors) or directly from messages collected from vehicles that measure vehicle speed, location, and other parameters. Traffic data may be collected from other centers and Information Service Providers (ISPs). Traffic data needs to be processed and then used as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority. Traffic data may also be processed for dissemination of traffic conditions to travelers.

Element	Subsystem	ID	Title	Description
Data Collection	Environmental Data Collection Subsystem	ETSS-DC-03	Collect Environmental Data	**The Eco-Traffic Signal System needs to collect environmental data (e.g. ambient air quality, emissions, temperature, wind speed, and other road weather information).** Environmental data may be obtained from environmental sensors that collect weather and emissions data along the network (e.g. using environmental sensor stations) or directly from messages collected from vehicles. Environmental data may also be collected from other centers. Environmental data will be a key variable as traffic signal operations are optimized to reduce emissions at the signalized intersection. Environmental data can be processed and then used as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority. Environmental data may also be collected for dissemination of environmental conditions to travelers.
Data Collection	Traffic Signal Operational Status Data Collection Subsystem	ETSS-DC-04	Collect Traffic Signal Operational Status Data	**The Eco-Traffic Signal System needs to collect data on the operational status of traffic signal equipment (e.g., traffic signal controller) including the current timing in operation.** This information is used to determine the state of the traffic signal and whether the traffic signal equipment is operating correctly or a repair is needed.
Data Collection	Geographic Information Description Data Collection Subsystem	ETSS-DC-05	Collect Geographic Information Description Data	**The Eco-Traffic Signal System needs to collect descriptions about the static physical geometry at intersections and arterial roadway segments.** Intersection descriptions include lane geometries and the allowable vehicle movements for each lane, barriers, pedestrian walkways, shared roadways, posted speed limits, and rail lines that may affect vehicle movements. Intersection descriptions also need to include road grade which is an important factor for determining eco-approaches and departures at signalized intersections. Locations of inductive charging infrastructure may also be included in the GID. These descriptions need to be transmitted to vehicles along with a traffic signal's current signal phase and timing information to allow for in-vehicle applications that consider a vehicle's approach and departure at a signalized intersection. Information about the location of inductive charging infrastructure may be used by electric vehicles.

Element	Subsystem	ID	Title	Description
Data Collection	Operator Input Data Collection Subsystem	ETSS-DC-06	Collect Operator Input	**The Eco-Traffic Signal System needs to collect data entered by personnel operating the system.** Types of data entered by personnel operating the system may include data for creating new traffic signal timing plans, activating or implementing timing plans, or adding new equipment (e.g., new traffic signals) to the system. This capability also allows the Eco-Traffic Signal System to collect and log actions by Eco-Traffic Signal System operations personnel.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	ETSS-DP-01	Process Traffic Data	**The Eco-Traffic Signal System needs to synthesize traffic data from multiple sources (e.g., fixed sensors, connected vehicle roadway equipment, other centers) to provide traffic analyses aggregated at different levels (e.g., intersection, corridor, and regional levels).** Traffic data should also be synthesized for differing time categories (e.g., times of day, day of week, holidays). These data will support several applications in optimizing for the environment. For example, traffic data (including traffic volumes and turn movements) may be aggregated from various sources and serve as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority.
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	ETSS-DP-02	Generate Predicted Traffic Conditions	**The Eco-Traffic Signal System needs to use historical and current traffic data to predict traffic conditions aggregated at different levels (e.g., intersection, corridor, and regional levels).** The Eco-Traffic Signal System needs to collect traffic data from other systems, or produce and continually update, a predictive model of the traffic flow conditions on the road network. These predictions may use real-time data, historic traffic data, incident data, planned event data, current traffic control strategies, and environmental conditions. These predictions may be used to support applications that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority for projected traffic conditions. For example, timing plans may be adjusted to account for predicted traffic volumes upstream of the traffic signal instead of current traffic conditions.
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	ETSS-DP-03	Process Environmental Data	**The Eco-Traffic Signal System needs to synthesize environmental data from multiple sources (e.g., fixed sensors, connected vehicle roadside equipment, and other centers) to provide emissions analyses aggregated at different levels (e.g., intersection, corridor, and regional levels).** These data will support applications that may require data to be aggregated from various sources and serve as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	ETSS-DP-04	Generate Predicted Emissions Profile	**The Eco-Traffic Signal System needs to synthesize environmental data from multiple sources (e.g., sensors, connected vehicle roadside equipment, and other centers) to generate predicted emissions aggregated at different levels (e.g., intersection, corridor, and regional levels).** This desired capability would require the system to produce and continually update a predictive model of the environmental conditions. The prediction may be based on historic data and current environmental conditions. These predictions may be used to support applications that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority.
Data Processing	Traffic Signal Priority Decision Support Subsystem	ETSS-DP-05	Provide Traffic Signal Priority Decision Support Capabilities	**The Eco-Traffic Signal System needs to include decision support capabilities for determining whether a signal priority request should be granted.** Decisions for granting priority need to consider local traffic conditions, environmental conditions, vehicle emissions from vehicles at or approaching the signalized intersection, and other data collected from vehicles (e.g., a transit vehicle's adherence to schedule, number of passengers on the bus, or weight of the truck) as input for determining whether to grant signal priority or not. If it is determined that priority should be granted, the Eco-Traffic Signal System needs to alert the traffic signal controller that a priority needs to be granted and provide information about the amount of time to extend the green signal or advance the green signal to adjust the signal for the priority.
Data Processing	Traffic Signal Timing Subsystem	ETSS-DP-06	Generate Traffic Signal Timing Strategy	**The Eco-Traffic Signal System needs to generate traffic signal timing plans (e.g., cycle lengths, phases, offsets and other parameters) using processed traffic data, predicted traffic data, and environmental data.** Traffic signal timing plans may include fixed timing plans based on the time of day or capabilities similar to current traffic control systems; however, the objective should be to generate signal timing plans to optimize the environmental impact of traffic at a single intersection, along a corridor, or a region, and to select the appropriate traffic signal timing strategy to be implemented. Timing plans need to be sent to the traffic signal controller for implementation. Signal timing plans also need to accommodate the effects of such things as traffic signal priority and emergency vehicle preemption.

Element	Subsystem	ID	Title	Description
Data Dissemination	Traffic Signal Priority Dissemination Subsystem	ETSS-D-01	Disseminate Traffic Signal Priority Data	**The Eco-Traffic Signal System needs to provide traffic signal priority action data (e.g., time to extend the green or advance the green for priority) to the traffic signal controller(s).** These data will be used by the traffic signal controller(s) to implement traffic signal priority at signalized intersections.
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ETSS-D-02	Disseminate Traffic Information to Other Centers	**The Eco-Traffic Signal System needs to disseminate traffic data and traffic signal timing plans to other jurisdictions to enable coordination of timing plans and other operational strategies for a corridor or a region.** Other Traffic Management Centers may be adjacent geographically, under control of a different jurisdiction, or part of a more complex hierarchy. Some examples that may benefit from these exchanges are: preemption for vehicles traveling through the local network with a destination in an area served by another Traffic Management Center; data about an incident that has an impact on the traffic conditions in the network served by other Traffic Management Centers. The data received from another Traffic Management Center could be used to vary the current traffic control strategy to give signal priority to transit vehicles or enable the passage of commercial vehicles with unusual loads, or as input to the local predictive traffic modeling process.
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ETSS-D-03	Disseminate Traffic Conditions to Vehicles	**The Eco-Traffic Signal System needs to provide traffic condition messages to vehicles. These data need to be formatted for use by in-vehicle systems.** Traffic conditions data should include information that would typically be displayed on a dynamic message sign (e.g., current traffic conditions, predicted traffic conditions, incidents, and speed limits). Applications that recommend speeds and accelerations to vehicles as they approach a signalized intersection may consider traffic conditions downstream of the vehicle when making recommendations to the driver about the vehicle's departure from the traffic signal.

Element	Subsystem	ID	Title	Description
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ETSS-D-04	Disseminate Environmental Conditions to Other Centers	**The Eco-Traffic Signal System needs to disseminate environmental data (e.g., regional and/or local air quality, temperature, precipitation) to other centers.** These data should be shared with other jurisdictions to enable coordination of advisory and operational strategies for a corridor or a region. Other centers may use these data to assist in better defining local and regional air quality. Environmental data can be used by other centers as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority. Environmental data may also be used to support environmental messages (e.g., code red day advisories) that would be disseminated to travelers to encourage green transportation decisions.
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ETSS-D-05	Disseminate Environmental Conditions to Vehicles	**The Eco-Traffic Signal System needs to provide environmental condition messages to vehicles.** Environmental messages may include real-time and predicted environmental and air quality conditions, as well as road weather conditions. These data need to be formatted for use by in-vehicle systems. Data about road weather conditions will serve as inputs to eco-driving systems. For example, eco-driving systems residing in the vehicle may consider road weather conditions as a key variable when recommending speeds and accelerations to drivers as they approach a signalized intersection.
Data Dissemination	Signal Timing Plans Dissemination Subsystem	ETSS-D-06	Disseminate Traffic Signal Timing Plans	**The Eco-Traffic Signal System needs to provide traffic signal timing plans (e.g., cycle lengths, phases, offsets and other parameters) to the traffic signal controller(s).** These data will be used by the traffic signal controller(s) to implement traffic signal timing plans at signalized intersections.
Data Dissemination	Geographic Information Description Dissemination Subsystem	ETSS-D-07	Disseminate Geographic Information Descriptions	**The Eco-Traffic Signal System needs to disseminate descriptions about the static physical geometry at intersections and arterial roadway segments.** Geographic information description information may include lane geometries and the allowable vehicle movements for each lane, barriers, pedestrian walkways, shared roadways, and rail lines that may affect vehicle movements, and road grade. These descriptions need to be transmitted to vehicles along with a traffic signal's phase and timing information to allow for in-vehicle applications that consider a vehicle's approach and departure at a signalized intersection.

Element	Subsystem	ID	Title	Description
Data Storage and Archive	Data Archive Subsystem	ETSS-DA-01	Archive Data	**The Eco-Traffic Signal System needs to archive traffic data, environmental data, operations data (e.g., status of traffic signals), event logs (e.g., signal priority requests), GID data, and other data.** Arching data allows the Eco-Traffic Signal System to keep a record of all data needed for reporting, developing predictive traffic models, developing the predicted emissions profiles, and assessing the impact of various applications on the environment. Archived data is also needed as input to algorithms that determine eco-signal timing plans (e.g., cycle lengths, phases, offsets and other parameters for signal timing plans) and signal priority.
Data Storage and Archive	Data Archive Subsystem	ETSS-DA-02	Determine Performance Measures	**The Eco-Traffic Signal System needs to determine performance measures and make them available to the operator.** A list of potential performance measures is included in Section 10. These performance measures will be used to monitor the performance of the system.

Element	Subsystem	ID	Title	Description
User Interface	User Interface	ETSS-UI-01	User Interface	**The Eco-Traffic Signal System needs to provide a user interface.** The user interface allows an operator to interact with the Eco-Traffic Signal System with minimal effort keyboarding.

7 In-Vehicle System

The In-Vehicle System is envisioned to allow drivers of vehicles of all types (e.g., passenger vehicles, transit vehicles, and commercial vehicles) to opt-in to applications that provide real-time driving recommendations so that they can adjust their driving behavior to save fuel and reduce vehicular emissions. Driving recommendations provided by the vehicle may include recommended driving speeds, optimal acceleration, and optimal deceleration profiles on arterials. The system may also consider vehicle-assisted strategies where vehicle system automatically implement longitudinal control strategies (i.e., control of the vehicle's speed and braking) to perform eco-driving strategies. The In-Vehicle System includes capabilities that provide eco-driving recommendations at signalized intersections, stop signs, yield signs, and on arterials between intersections. Additional details on eco-driving strategies for freeways are described in the Eco-lanes Operational Description document.

The In-Vehicle System collects traffic data, environmental data, vehicle status data from other vehicles, terrain information, and SPaT information available through DSRC or other wireless communication, between traffic signals and vehicles. These data are then processed to determine optimal eco-driving strategies which in turn are disseminated to the driver through an operator interface. As a driver approaches a signalized intersection, the system may alert the driver that he or she cannot traverse the signalized intersection before the signal turns red. After receiving the alert, the driver may slowly decelerate to the stop bar instead of continuing at the current speed and having to apply a hard brake at the end. The system will consider potential interactions with other vehicles, traffic conditions downstream, and traffic signal timing at other traffic signals downstream. Additionally, the system considers the vehicle's acceleration from the signalized intersection if the vehicle slows down or comes to a stop at the signalized intersection.

The In-Vehicle System also includes engine start-stop capabilities that automatically shut down and restart the vehicle's engine when the vehicle is stopped thus reducing the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. This capability is advantageous for vehicles as they spend significant amounts of time waiting at traffic lights or frequently are stopped due to traffic congestion.

The remainder of this section presents diagrams describing how the system works. These diagrams begin with a System Context Diagram showing the actors that interact with the system, then a Logic Diagram focused on processes taking place within the system, and finally a Subsystem Diagram depicting the various subsystems within the system. These diagrams are followed by tables documenting the user needs of the system which express the underlying objectives of actors in terms of what they are trying to accomplish as they relate to the system.

7.1 In-Vehicle System – System Context Diagram

Figure 7-1 depicts the System Context Diagram for the In-Vehicle System. As depicted, the In-Vehicle System is the rectangle in the middle of the diagram. This diagram represents the external actors that interact with the system. These actors are shown as people outside of the system boundary, although actors may be devices or organizations rather than individual people. Actors that interact with the system include: (1) Driver, (2) Connected Vehicle Roadway Equipment, (3) Vehicle Diagnostic Systems, (4) Other Vehicles, (5) Other On-board Sensors, and

(6) Inductive Charging Roadway Equipment, and (7) Vehicle Actuators. Appendix B presents a complete list and descriptions of the actors. Actors that provide inputs to the system are depicted on the left side of the diagram, while actors that receive outputs from the system are depicted on the right side of the diagram. Relationships between the actors and the system are illustrated by arrows connecting the actors to the In-Vehicle System.

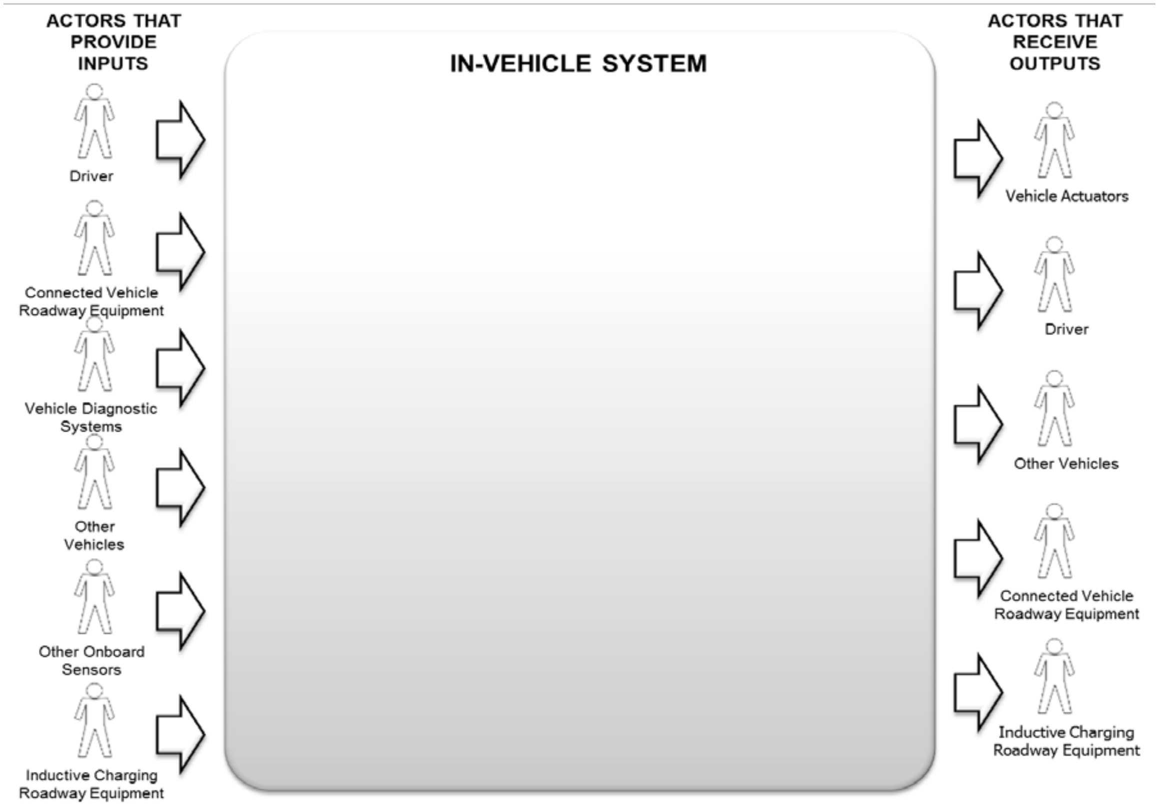

Figure 7-1: In-Vehicle System – System Context Diagram (*Source*: Noblis, 2013)

7.2 In-Vehicle System – Logic Diagram

Figure 7-2 depicts a Logic Diagram for the In-Vehicle System. This diagram depicts the functionality of the system at a high level. It is important to note that Logic Diagrams are fundamentally different from sequence diagrams or flow charts because they do not make any attempt to represent the order or number of times that the systems actions and sub-actions should be executed. As shown in Figure 7-2, the Logic Diagram has four major components:

- The **actors** with which the system interacts,
- The **system** itself (the large rectangle),
- The **services or functions** that the system performs (depicted as colored ovals inside the rectangle), and

- The **relationships** between these functions and between functions and actors (depicted as arrows where the direction of the arrow represents the direction of data flow).

The In-Vehicle System performs four types of services or functions. These include (1) data collection which are depicted as red ovals, (2) data processing which are depicted as green ovals, (3) vehicle assisted control depicted as teal ovals, and (4) data dissemination which are depicted as purple ovals. The colors of these ovals convey to the next diagram and the headings for the user needs.

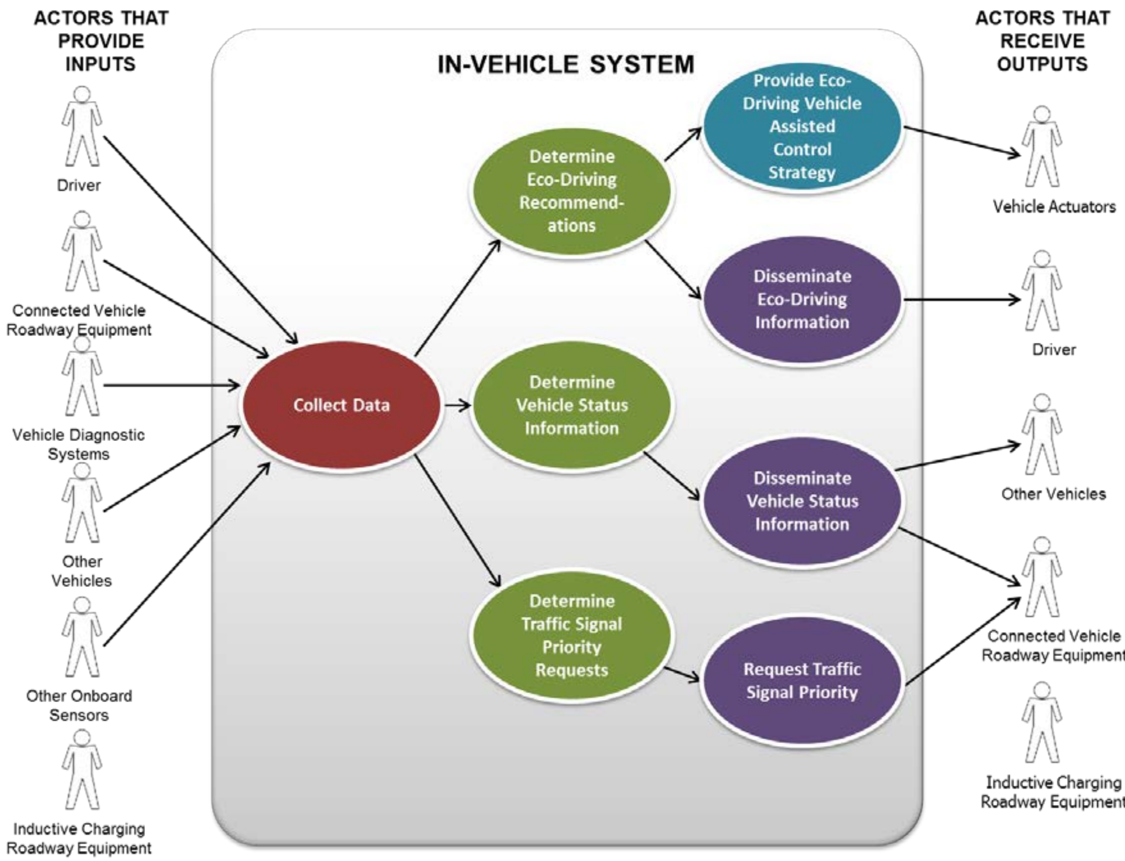

Figure 7-2: In-Vehicle System – Logic Diagram (*Source*: Noblis, 2013)

7.3 In-Vehicle System – Subsystem Diagram

Figure 7-3 depicts the subsystem diagram for the In-Vehicle System. Similar to previous diagrams, the left side of this diagram shows the actors that provide inputs to the In-Vehicle System while the right side of the diagram shows the actors that receive the outputs. In the center of the diagram are the four elements, or groupings of subsystems, contained within the In-Vehicle System. Within each element are one or more subsystems. These subsystems break down the functional tasks depicted in Figure 7-2 into smaller more specific tasks. In the case of data collection subsystems, the name of the subsystem reflects the type of input the subsystem collects. In the case of dissemination subsystems, the name of the subsystem reflects the type of information the subsystem disseminates. The elements include:

- **Data Collection Element.** This element consists of the Driver Input Data Collection Subsystem, Traffic Conditions Data Collection Subsystem, Environmental Conditions Data Collection Subsystem, Signal Phase and Timing (SPaT) and Geographic Information Description (GID) Data Collection Subsystem, Transit or Freight Specific Data Collection Subsystem, 'Other Vehicle' Vehicle Status Data Collection Subsystem, and Vehicle Diagnostics Data Collection Subsystem.
- **Data Processing Element.** This element consists of the Eco-Driving and Eco-Approach and Departure at Signalized Intersections Strategies Subsystem, Signal Priority Request Subsystem, and Vehicle Status Subsystem.
- **Vehicle Assisted Control Element.** This element consists of the Eco-Driving Vehicle Assisted Control Strategy Subsystem.
- **Data Dissemination Element.** This element consists of the Eco-Driving Information Dissemination Subsystem, Signal Priority Request Dissemination Subsystem, and Vehicle Status Dissemination Subsystem.
- **Driver Interface Element.** This elements consists of the Driver Interface Subsystem.

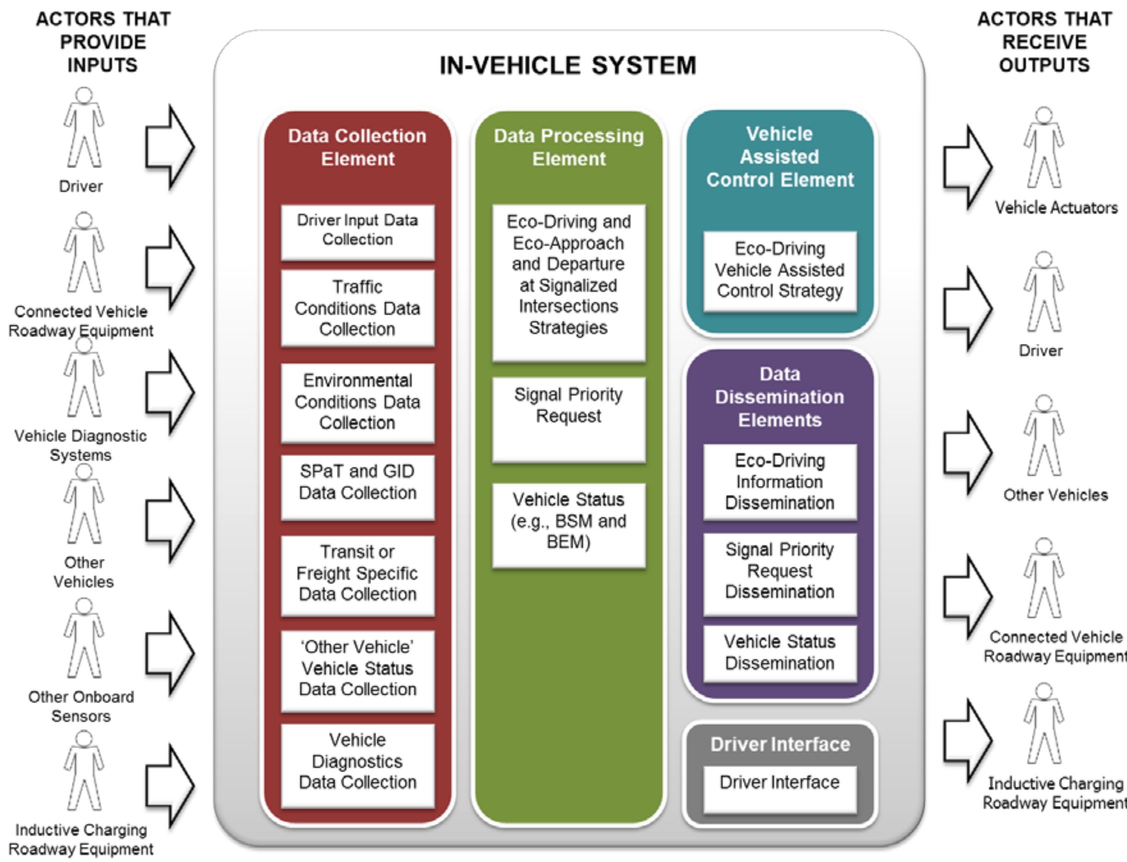

Figure 7-3: In-Vehicle System – Subsystem Diagram (*Source*: Noblis, 2013)

7.4 In-Vehicle System User Needs

This section identifies user needs, or desired capabilities, for the In-Vehicle System. These needs express the underlying objectives of actors in terms of what they are trying to accomplish as they relate to the system. A need is a capability that is identified to accomplish a specific goal or solve a problem. It describes what is needed while avoiding the implementation specifics, or the "how". Each need is identified uniquely, and contains a description and a rationale. The rationale may include examples of how the system capability may be exercised. User Needs are categorized by the elements in the subsystem diagram.

Table 7-1: In-Vehicle System User Needs

Element	Subsystem	ID	Title	Description
Data Collection	Driver Input Data Collection Subsystem	IVS-DC-01	Collect Driver Input	**The In-Vehicle System needs to collect data from the driver to activate applications.** The driver also needs to be able to configure parameters of the system or override certain system functions. The system should include an interface that supports inputs from the driver in manual or verbal form. This allows the driver to activate applications such as automated driving capabilities and inductive charging applications. This capability also allows the driver to update configurable parameters to customize the provision of information and to override certain vehicle characteristics like trailer attached, number of axles, height of vehicle, number of passengers in the vehicle, weight of the vehicle, etc.
Data Collection	Traffic Conditions Data Collection Subsystem	IVS-DC-02	Receive Traffic Conditions Data	**The In-Vehicle System needs to receive traffic conditions data for input to eco-driving strategies.** Traffic conditions data should include information that would typically be displayed on a dynamic message sign (e.g., current traffic conditions, predicted traffic conditions, link speeds, queues, and incidents). The In-Vehicle System may consider traffic conditions (e.g., speeds) downstream of the vehicle when making recommendations to the driver about the vehicle's departure from the signalized intersection.
Data Collection	Environmental Conditions Data Collection Subsystem	IVS-DC-03	Receive Environmental Conditions Data	**The In-Vehicle System needs to receive environmental conditions data, including road weather conditions.** This may include real-time and predicted environmental and air quality conditions, as well as road weather conditions. The In-Vehicle System may consider road weather conditions (e.g., pavement conditions) as a key variable when recommending speeds and accelerations to drivers as they approach a signalized intersection. These data should include information that would typically be displayed on a dynamic message sign about code red day alerts.

Element	Subsystem	ID	Title	Description
Data Collection	SPaT and GID Data Collection Subsystem	IVS-DC-04	Collect Signal Phase and Timing (SPaT) Data	**The In-Vehicle System needs to collect signal phase and timing (SPaT) data as the vehicle approaches a signalized intersection.** The In-Vehicle System uses SPaT messages as input for determining driver recommendations that encourage “green” approaches to signalized intersections. Upon receiving this information, the In-Vehicle System can calculate and provide speed profile advice to the driver of the vehicle, allowing the driver to adapt the vehicle’s speed to pass the next signal on green or to decelerate to a stop in the most environmentally efficient manner. Information about the time to green or time to red may also be presented to the driver. Finally, the In-Vehicle System may also need to receive SPaT data for a corridor or a segment of roadway allowing the vehicle’s application to determine a trajectory through the corridor in the “green wave”.
Data Collection	SPaT and GID Data Collection Subsystem	IVS-DC-05	Collect Geographic Information Description Data	**The In-Vehicle System needs to receive Geographic Information Description (GID) data.** These data include descriptions about the static physical geometry at intersections and arterial roadway segments. This information may include lane geometries and the allowable vehicle movements for each lane, barriers, pedestrian walkways, shared roadways, and rail lines that may affect vehicle movements, posted speed limits, and road grade. These descriptions need to be transmitted to vehicles along with a traffic signal’s phase and timing information to allow for in-vehicle applications that consider a vehicle’s approach and departure at a signalized intersection. Additionally, applications that reside in vehicles may use road grade as an input for eco-driving recommendations.
Data Collection	Transit or Freight Specific Data Collection	IVS-DC-06	Collect Data for Signal Priority Requests	**The In-Vehicle System needs to collect data from on-board systems about transit or freight vehicles.** Data about a transit vehicle’s adherence and the number of passengers would be collected from other systems located on the vehicle. These data may be sent in a message requesting signal priority at a signalized intersection. For freight vehicles, information about the vehicle’s load weight may be collected.

Element	Subsystem	ID	Title	Description
Data Collection	'Other Vehicle' Vehicle Status Data Collection Subsystem	IVS-DC-07	Receive Vehicle Status Data from Other Vehicles	**The In-Vehicle System needs to collect vehicle status data from other vehicles, including data that is currently in the SAE J2735 basic safety message (BSM) (e.g., data about the vehicle's location, heading, speed, acceleration, braking status, and size).** This information should be broadcast frequently to support V2V safety, mobility, and environmental applications. This information will support In-Vehicle Systems that may require knowing what nearby vehicles are doing before providing recommendations to the driver. These data will be used by the In-Vehicle System to avoid providing eco-driving recommendations that may result in a collision between two vehicles.
Data Collection	Vehicle Diagnostics Data Collection Subsystem	IVS-DC-08	Collect Vehicle Diagnostics Data	**The In-Vehicle System needs to collect diagnostics data from on-board systems and on-board sensors located on the vehicle to obtain vehicle status and vehicle emissions data.** Vehicle diagnostic data includes data from the controller area network (CAN) bus, GPS, environmental sensors, and other sensors located on the vehicle. This includes data about the vehicle's location, speed, acceleration, trajectory, vehicle type, engine type, fuel consumption, and emissions. All data needs to be time stamped. These data will be processed by the In-Vehicle System and may be used to provide vehicle status data to other vehicles or transmit traffic or environmental data to the Eco-Traffic Signal System. For example, the Eco-Traffic Signal System may use these data as probe data to support algorithms for traffic signal timing plans. Likewise, these data may also be sent to other vehicles to support V2V applications such as connected eco-driving.
Data Collection	Vehicle Diagnostics Data Collection Subsystem	IVS-DC-09	Receive Inductive Charge	**Electric Vehicles need to receive inductive charges from wireless inductive charging pads. Electric vehicles need to receive energy sent through inductive coupling to an electrical device, which can use that energy to charge a vehicle's battery.** This desired capability supports inductive charging of electric vehicles. Inductive chagrining infrastructure could be installed near the stop bar at a signalized intersection, so while an electric vehicle is stopped at a red light the driver of an electric vehicle could opt-in to an application allowing his/her vehicle's electric battery to be charged.

Element	Subsystem	ID	Title	Description
Data Processing	Eco-Driving and Eco-Approach and Departure at Signalized Intersections Strategies Subsystem	IVS-DP-01	Determine Eco-Driving Recommendations	**The In-Vehicle System needs to determine driving recommendations with the objective of promoting a driving style that lowers vehicle emissions and fuel consumption.** Eco-driving recommendations may include desired speeds, accelerations, and decelerations based on upcoming traffic conditions, and roadway geometry and potential interactions with nearby vehicles. The In-Vehicle System may also have vehicle systems implement the eco-driving tactics (e.g., change gears, switch power sources, or reduce speed in an eco-friendly manner as the vehicle approaches a traffic signal).
Data Processing	Eco-Driving and Eco-Approach and Departure at Signalized Intersections Strategies Subsystem	IVS-DP-02	Determine Eco-Approach and Departure at Signalized Intersections	**The In-Vehicle System needs to use signal phase and timing (SPaT) data, Geographic Information Description (GID) data, traffic data, vehicle sensor data, and vehicle status data from other vehicles to encourage "green" approaches to and departures from signalized intersections.** Upon receiving this information, in-vehicle systems need to calculate and provide speed advice to the driver of the vehicle, allowing the driver (or vehicle assisted systems) to adapt the vehicle's speed to pass through the upcoming signalized intersection on green or to decelerate to a stop in the most environmentally efficient manner. The application also needs to calculate the optimal speed and acceleration as a vehicle accelerates away from the intersection. Finally, the application should consider recommended driving speeds for the vehicle to travel in the green wave through multiple intersections along its route. Information about traffic conditions downstream and other vehicles (e.g., location of nearby vehicles along with the speed and accelerations of those vehicles) also need to be considered when calculating the most environmentally efficient strategy.
Data Processing	Signal Priority Request Subsystem	IVS-DP-03	Determine Traffic Signal Priority Request Strategy	**The In-Vehicle Systems needs to use data collected from on-board systems to determine if a request needs to be made for priority at a signalized intersection.** The In-Vehicle System may collect data about the vehicle's adherence to its schedule, the number of passengers on the vehicle, weight of the truck, and other characteristics about the vehicle (e.g., vehicle type, average emissions, etc.). These data would be packaged into a message that would be sent as a request to the traffic signal for priority through the intersection.

Element	Subsystem	ID	Title	Description
Data Processing	Vehicle Status Subsystem	IVS-DP-04	Determine Vehicle Emissions and Fuel Consumption Data	**The In-Vehicle System needs to calculate estimates of tailpipe emissions and fuel consumption if these data cannot be collected directly from the vehicle.** Emissions estimates may be based on data collected from sensors located on the vehicle. Information such as the vehicle type, engine type, fuel type, second-by-second speed and acceleration, and accessory use (e.g., air conditioning) may be used to estimate tailpipe emissions and fuel consumption. If these values are transmitted to the infrastructure, the emissions and fuel use need not be computed by the vehicle; instead emissions may be estimated at a center. Additionally, estimates for emissions and fuel consumption may not be required if these data can be collected directly from vehicle sensors. Emissions and fuel consumption data are needed to support Eco-Signal Operations applications. For example, eco-traffic signal timing algorithms may need to collect emissions data from vehicles as input to signal timing plans that have an objective of reducing emissions for a traffic signal, corridor, or a network. Additionally, estimates of vehicle emissions may also be provided to the driver through an in-vehicle interface to inform drivers of their environmental footprint.

Element	Subsystem	ID	Title	Description
Data Dissemination	Eco-Driving Information Dissemination Subsystem	IVS-D-01	Provide Eco-Driving Information to the Driver	**The In-Vehicle System needs to provide drivers with eco-driving information that encourages them to drive in a more environmentally efficient manner.** Eco-driving information may be provided via the driver interface. Eco-driving information may include the optimal cruising speed, recommended driving speed for a vehicle to pass through a traffic signal on green, travel in the green wave, decelerate to a stop at a traffic signal, or accelerate after being stopped at a traffic signal.
Data Dissemination	Signal Priority Request Dissemination Subsystem	IVS-D-02	Send Traffic Signal Priority Request	**The In-Vehicle System needs to request traffic signal priority at a signalized intersection.** Signal priority requests allow a vehicle to make a request at a signalized intersection for extending the green time for that vehicle's approach thus allowing the vehicle to pass through the signalized intersection without stopping. The signal priority request may include information about a transit vehicle's adherence to its schedule or the number of passengers on the transit vehicle. Commercial vehicles may include information about the vehicle's weight since heavy trucks often produce significantly more emissions than lighter trucks when accelerating from a stop.
Data Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-03	Disseminate Vehicle Status Data	**The In-Vehicle System needs to broadcast vehicle status data or data that is currently included in the SAE J2735 basic safety message (BSM) (e.g., data about the vehicle's location, heading, speed, acceleration, braking status, and size).** Vehicle status data should be broadcast frequently to support V2V and V2I safety, mobility, and environmental applications. This data may also be used by the Eco-Traffic Signal System as input to algorithms used to optimize the traffic signal system.

Element	Subsystem	ID	Title	Description
Data Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-04	Disseminate Vehicle Environmental Data	**The In-Vehicle System needs to broadcast environmental data messages based on data collected from sensors located on-board the vehicle, or data that it processed.** Environmental data messages include data such as the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption. These data support V2I safety, mobility, and environmental applications. For example, an eco-traffic signal timing application may receive these data and use them as an input to determine the most environmentally efficient timing plan at a signalized intersection.

Element	Subsystem	ID	Title	Description
Vehicle Assisted Control	Eco-Driving Vehicle Assisted Control Strategy Subsystem	IVS-VC-01	Provide Eco-Driving Vehicle Assisted Control Strategy	**The In-Vehicle System needs to process and provide data to vehicle actuators to support vehicle assisted and automated driving vehicle controls.** Vehicle assisted control allows for automated control of the vehicle based on outputs from applications (e.g., eco-approach and departure at signalized intersections or eco-driving applications), vehicle sensors, and vehicle status messages received from other vehicles. Automated control may include both lateral and longitudinal control of the vehicle.
Vehicle Assisted Control	Eco-Driving Vehicle Assisted Control Strategy Subsystem	IVS-VC-02	Provide Start-Stop Capabilities	**The In-Vehicle System needs to provide start-stop capabilities allowing the vehicle's engine to be automatically shut down and restarted.** Engine start-stop capabilities reduce the amount of time the engine spends idling, thereby reducing fuel consumption and emissions. This capability is advantageous for vehicles as they spend significant amounts of time waiting at traffic lights or frequently are stopped due to traffic congestion.

Element	Subsystem	ID	Title	Description
Driver Interface	Driver Interface Subsystem	IVS-DI-01	Provide Driver Interface	**The In-Vehicle System needs to provide a driver interface through which traffic conditions, environmental conditions, driving recommendations, and feedback on driving behavior can be provided to the driver. The interface also needs to allow the user to opt-in to applications**. The user-configurable traffic and environmental condition alert subscriptions need to be supported and resultant alerts need to be output to the driver. In-vehicle signage needs to be output to the driver; including SPaT information, traffic conditions, and environmental conditions such as that typically displayed on a DMS. The interface also needs to provide drivers with speed recommendations that support eco-driving and eco-approaches and departures at signalized intersections. Finally, drivers need to be able to receive information from vehicle systems about an electric vehicle’s charge and the charge received through inductive charging. The system should include an interface that may provide its outputs in audible or visual forms. Visual output should not impair the driver's ability to control the vehicle in a safe manner.

8 Eco-Signal Operations Interfaces and Data Exchanges

To better understand how the Eco-Signal Operations Transformative Concept will function, it is important to understand the interfaces between systems (or actors) and the data that is exchanged with other systems (or actors). Figure 8-1 depicts a physical representation of the Transformative Concept, showing the various actors and relationships between the actors. For illustrative purposes, this figure depicts an example of how the Transformative Concept might be deployed; however the locations of some of the systems may differ for regional deployments. For example, some of the functionality of the Eco-Traffic Signal System may actually reside at the roadside. The intent of this figure is to help readers visually depict “what” the system may look like when deployed in the real-world.

Interfaces between actors are shown by the arrowed lines with the direction of the arrow depicting the direction of data flow. Solid orange lines represent wired or wireless communications, dashed blue lines represent wireless communications, and solid green lines represent the transfer of energy for wireless inductive charging applications. In the diagram, three options are shown to for data exchanges between the Eco-Traffic Signal System and the In-Vehicle System. The first option includes data exchanges through the Connected Vehicle Roadway Equipment or a RSE unit that most likely is connected to the back-office using wired or wireless communications and communicates most likely via DSRC to the In-Vehicle System. Low latency data exchanges would be supported through this option. The second option includes data exchanges through a cell tower using 3G or 4G communications. This option results in higher latency (i.e., typically a few seconds delay) than the previous option. The third and final option depicts the highest latency option. Satellite communications may be used for data exchanges for high latency communications. Examples of data that may be exchanged using satellite communications include traffic conditions, incident information, and GID messages.

Table 8-1 provides details about the data exchanges between actors. The numbered circles in Figure 8-1 correspond to the numbered items in Table 8-1. The table also maps these data exchanges back to the User Needs identified in Chapters 6 and 7.

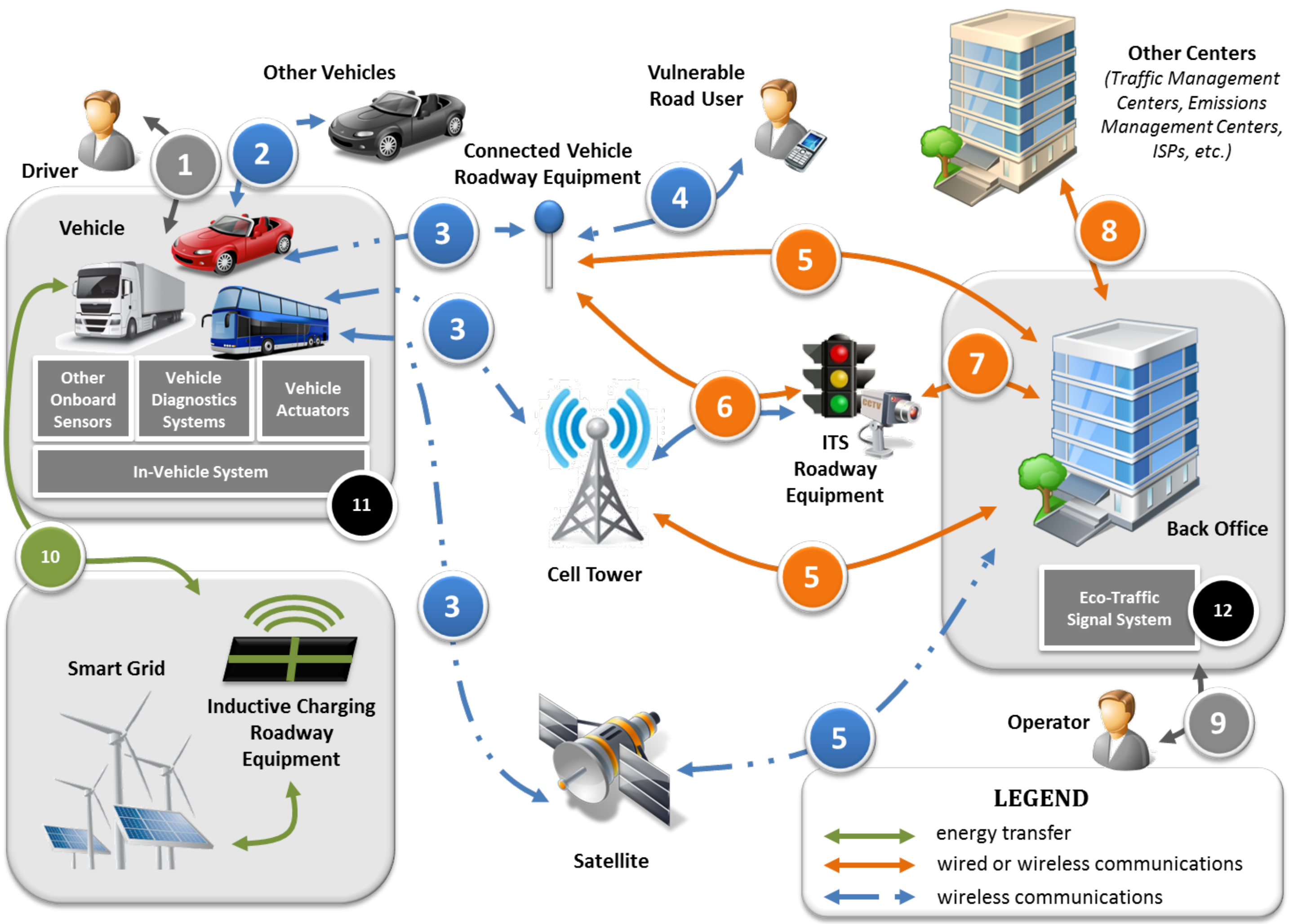

Figure 8-1: Eco-Signal Operations Interface and Data Exchange Diagram (*Source*: Noblis, 2013)

Table 8-1: Eco-Signal Operations Interfaces and Data Exchanges

<table>
<tr><th>Item</th><th>Actors</th><th>Data Exchange / Action</th><th>Related User Needs</th></tr>
<tr><td>1</td><td>In-Vehicle System and Driver</td><td><u>In-Vehicle System sends to Driver</u>
Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.)
SPaT information (e.g., time to red, etc.)
Traffic conditions
Environmental conditions (e.g., code red air quality alerts)
Road weather conditions
Status of an electric vehicle’s electric charge and charge received from inductive charging field infrastructure
<u>Driver Sends to In-Vehicle System</u>
Activation of Application (e.g., activate eco-driving application)
Updates to configurable parameters</td><td>IVS-DC-01: Collect Driver Input
IVS-D-01: Provide Eco-Driving Information to the Driver
IVS-DI-01: Provide Driver Interface</td></tr>
<tr><td>2</td><td>In-Vehicle System and Other Vehicles</td><td><u>In-Vehicle System sends to Other Vehicles</u>
Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)
<u>Other Vehicles send to In-Vehicle System</u>
Vehicle status data (e.g., BSM data including vehicle’s location, heading, speed, acceleration, braking status, size, etc.)</td><td>IVS-DC-07: Receive Vehicle Status Data from Other Vehicles
IVS-D-03: Disseminate Vehicle Status Information</td></tr>
</table>

3	In-Vehicle System and Connected Vehicle Roadway Equipment In-Vehicle System and Cell Tower In-Vehicle System and Satellite	<u>In-Vehicle System sends to Connected Vehicle Roadway Equipment, Cell Tower, and Satellite</u> • Traffic signal priority requests • Vehicle status data (e.g., BSM data including vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Vehicle status environmental data (e.g., BEM data including the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption) <u>Connected Vehicle Roadway Equipment, Cell Tower, and Satellite send to the In-Vehicle System</u> • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality information, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) • Signal Phase and Timing (SPaT) data • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.)	• IVS-DC-02: Receive Traffic Conditions • IVS-DC-03: Receive Environmental Conditions • IVS-DC-04: Collect Signal Phase and Timing (SPaT) Data • IVS-DC-05: Collect Geographic Information Description Data • IVS-D-02: Send Traffic Signal Priority Request • IVS-D-03: Disseminate Vehicle Status Data • IVS-D-04: Disseminate Vehicle Status Environmental Data
4	Connected Vehicle Roadway Equipment and Vulnerable Road User	<u>Vulnerable Road User sends to Connected Vehicle Roadway Equipment</u> • Traffic data (e.g., pedestrian presence at signalized intersections)	• ETSS-DC-02: Collect Traffic Data

5	Connected Vehicle Roadway Equipment and Eco-Traffic Signal System Cell Tower and Eco-Traffic Signal System Satellite and Eco-Traffic Signal System	<u>Connected Vehicle Roadway Equipment, Cell Tower, and Satellite send to Eco-Traffic Signal System</u> • Traffic signal priority requests • Vehicle status data (e.g., vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Vehicle status environmental data (e.g., BEM data including the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption) • Pedestrian presence at signalized intersections <u>Eco-Traffic Signal System sends to Connected Vehicle Roadway Equipment, Cell Tower, and Satellite</u> • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality information, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.)	• ETSS-DC-01: Collect Traffic Signal Priority Requests • ETSS-DC-02: Collect Traffic Data • ETSS-DC-03: Collect Environmental Data • ETSS-D-03: Disseminate Traffic Conditions to Vehicles • ETSS-D-05: Disseminate Environmental Conditions to Vehicles • ETSS-D-07: Disseminate Geographic Information Descriptions
6	Connected Vehicle Roadway Equipment and ITS Roadway Equipment Cell Tower and ITS Roadway Equipment	<u>ITS Roadway Equipment sends to Connected Vehicle Roadway Equipment and Cell Tower</u> • Signal Phase and Timing (SPaT) data • Geographic Information Description (e.g., lane geometries, lane configurations, posted speed limits, etc.) <u>Connected Vehicle Roadway Equipment and Cell Tower send to ITS Roadway Equipment</u> • Traffic signal priority request • Vehicle status data (e.g., BSM data including vehicle's location, heading, speed, acceleration) • Pedestrian presence at signalized intersections	• IVS-DC-04: Collect Signal Phase and Timing (SPaT) Data • ETSS-DC-01: Collect Traffic Signal Priority Requests • ETSS-D-07: Disseminate Geographic Information Descriptions

7	ITS Roadway Equipment and Eco-Traffic Signal System	ITS Roadway Equipment sends to Eco-Traffic Signal System • Traffic data (e.g., speed, volume, occupancy, pedestrian calls, etc.) • Environmental data (e.g., air quality data, etc.) • Road weather data (e.g., road friction, precipitation, temperature, etc.) • Traffic signal operational status (e.g., current timing in operation) Eco-Traffic Signal System sends to ITS Roadway Equipment • Traffic signal priority data (e.g., time to extend the green or advance the green for priority) • Traffic signal timing plans • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.)	• ETSS-DC-02: Collect Traffic Data • ETSS-DC-03: Collect Environmental Data • ETSS-DC-04: Collect Traffic Signal Operational Status Data • ETSS-D-01: Disseminate Traffic Signal Priority Data • ETSS-D-06: Disseminate Traffic Signal Timing Plans
8	Eco-Traffic Signal System and Other Centers	Eco-Traffic Signal System sends to Other Centers • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Traffic signal timing plans in operation • Environmental conditions (e.g., air quality data, code red air quality alerts) • Road weather data (e.g., road conditions) • Geographic Information Description Data (lane geometries, lane configurations, posted speed limits, etc.) Other Centers sends to Eco-Traffic Signal System • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Traffic signal timing plans in operation • Environmental conditions (e.g., air quality data, code red air quality alerts) • Road weather data (e.g., road conditions) • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.)	• ETSS-DC-02: Collect Traffic Data • ETSS-DC-03: Collect Environmental Data • ETSS-DC-05: Collect Geographic Information Description Data • ETSS-D-02: Disseminate Traffic Information to Other Centers • ETSS-D-04: Disseminate Environmental Conditions to Other Centers

9	Eco-Traffic Signal System and Operator	<u>Eco-Traffic Signal System sends to Operator</u> • Traffic conditions • Environmental conditions • Road weather conditions • Performance measures • Traffic signal system operational status • Archived data <u>Operator sends to Eco-Traffic Signal System</u> • Operator inputs (e.g., creating new traffic signal timing plans, implementing timing plans, or adding new equipment (e.g., new traffic signals) to the system) • Geographic Information Description Data (lane geometries, lane configurations, posted speed limits, etc.)	• ETSS-DC-05: Collect Geographic Information Description Data • ETSS-DC-06: Collect Operator Input • ETSS-UI-01: User Interface
10	Inductive Charging Roadway Equipment and Vehicle	<u>Inductive Charging Roadway Equipment sends to Vehicle</u> • Request for charge • Inductive charge • Request for payment <u>Vehicle sends to Inductive Charging Roadway Equipment</u> • Approval to receive inductive charge • Payment information • Provide energy back into the Smart Grid	• IVS-DC-09: Receive Inductive Charge

11	In-Vehicle System	<u>Collect Data</u> • Driver input (e.g., activation of application, system parameters, etc.) • Traffic conditions (e.g., current and predicted traffic speeds, travel times, incidents, queues, etc.) • Environmental conditions (air quality information, code red day alert, etc.) • Road weather conditions (e.g., pavement conditions) • Signal phase and timing (SPaT) data • Geographic Information Description data (e.g., lane geometries, lane configurations, posted speed limits, etc.) • Data for transit vehicle signal priority requests (e.g., passenger data and adherence to transit schedules) • Data for freight vehicle signal priority requests (e.g., truck load, truck weight, etc.) • Vehicle diagnostics data (e.g., engine, emissions, GPS, and onboard sensor data) • Vehicle status data from nearby vehicles (e.g., BSM data including vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Inductive charge <u>Process Data</u> • Determine eco-driving recommendations (e.g., recommended speeds) • Determine eco-approach and departure at signalized intersections (e.g., recommended speeds, start-stop recommendations) • Determine traffic signal priority request strategy • Determine vehicle emissions data (e.g., determine BEM for disseminate) <u>Disseminate Data</u> • Eco-driving recommendations to driver • Traffic signal priority requests • Vehicle status data (e.g., BSM data including vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Vehicle environmental data (e.g., BEM data including the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption) <u>Vehicle Control</u> • Vehicle assisted control (e.g., control of vehicle acceleration and speed) • Start-stop control (e.g., turn the vehicle's engine on or off)	• IVS-DC-01: Collect Driver Input • IVS-DC-02: Receive Traffic Conditions Data • IVS-DC-03: Receive Environmental Conditions • IVS-DC-04: Collect Signal Phase and Timing (SPaT) Data • IVS-DC-05: Collect Geographic Information Description Data • IVS-DC-06: Collect Data for Signal Priority Requests • IVS-07: Receive Vehicle Status Data from Other Vehicles • IVS-DC-08: Collect Vehicle Diagnostics Data • IVS-DC-09: Receive Inductive Charge • IVS-DP-01: Determine Eco-Driving Recommendations • IVS-DP-02: Determine Eco-Approach and Departure at Signalized Intersections • IVS-DP-03: Determine Traffic Signal Priority Request Strategy • IVS-DP-04: Determine Vehicle Emissions and Fuel Consumption Data
		<u>Driver Interface</u> • Activation of Application (e.g., activate eco-driving application) • Updates to configurable parameters • Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.) • SPaT information (e.g., time to red, etc.) • Traffic conditions	• IVS-D-01: Provide Eco-Driving Information to Driver • IVS-D-02: Send Traffic Signal Priority Request

12	Eco-Traffic Signal System	<u>Collect Data</u> • Traffic signal priority requests and justifications (e.g., schedule, number of passengers, schedule adherence) • Traffic data (e.g., speeds, volumes, occupancy, vehicle types, turning movements, CCTV images, incidents, pedestrian calls at traffic signals, etc.) • Environmental data (e.g., vehicle emissions, local air conditions, etc.) • Road weather conditions (e.g., road friction, precipitation, temperature, etc.) • Operational status of traffic signal system and other devices • Geographic Information Description data (e.g., lane geometries, lane configurations, posted speed limits, etc.) • Operator input (i.e., new roadway configuration, new signal installation, new timing plans, activation timing plan, etc.) <u>Process Data</u> • Process traffic data • Generate predicted traffic conditions • Process environmental data • Generate predicted emissions profile • Provide traffic signal priority decision support capabilities • Generate traffic signal timing strategy (e.g., determine eco-timing strategy) <u>Disseminate Data</u> • Traffic signal priority data (e.g., time to extend the green or advance the green for priority) • Traffic signal timing plans • Traffic conditions (e.g., current and predicted traffic speeds, travel times, volumes, incidents, queues, etc.) • Environmental conditions (e.g., air quality, vehicle emissions at intersection level, corridor level, etc.) • Road weather conditions (e.g., pavement conditions) • Geographic Information Description data (e.g., lane geometries, lane configurations, posted speed limits, etc.) <u>Operator Interface</u> • Traffic conditions • Environmental conditions • Road weather conditions • Performance measures • Traffic signal system operational status • Archived data • Operator inputs (e.g., creating new traffic signal timing plans, implementing timing plans, or adding new equipmentto the system)	• ETSS-DC-01: Collect Traffic Signal Priority Requests • ETSS-DC-02: Collect Traffic Data • ETSS-DC-03: Collect Environmental Data • ETSS-DC-04: Collect Traffic Signal Operational Status Data • ETSS-DC-05: Collect Geographic Information Description Data • ETSS-DC-06: Collect Operator Input • ETSS-DP-01: Process Traffic Data • ETSS-DP-02: Generate Predicted Traffic Conditions • ETSS-DP-03: Process Environmental Data • ETSS-DP-04: Generate Predicted Emissions Profile • ETSS-DP-05: Provide Traffic Signal Priority Decision Support Capabilities • ETSS-DP-06: Generate Traffic Signal Timing Strategy • ETSS-D-01: Disseminate Traffic Signal Priority Data • ETSS-D-02: Disseminate Traffic Information to Other Centers • ETSS-D-03: Disseminate Traffic Conditions to

9 Scenarios

This section describes scenarios for the Eco-Signal Operations Transformative Concept. A scenario is a step-by-step description of how the proposed systems should operate, with actor interactions and external interfaces described under a given set of circumstances. Scenarios help the readers of the document understand how all the pieces interact to provide operational capabilities. Scenarios are described in a manner that allows readers to walk through them and gain an understanding of how all the various parts of the Transformative Concept will function and interact. Each scenario includes events, actions, stimuli, information, and interactions as appropriate to provide a comprehensive understanding of the operational aspects of the proposed systems. These scenarios provide readers with operational details for the proposed systems; this enables them to understand the actors' roles, how the systems should operate, and the various operational features to be provided. These scenarios may also support the development of simulation models that help in the definition and allocation of derived requirements, identification, and preparation of prototypes to address key issues.

9.1 Scenario: Eco-Approach and Departure at Signalized Intersections

Actors. Eco-Traffic Signal System, In-Vehicle System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. A vehicle equipped with the In-Vehicle System approaches a signalized intersection that is broadcasting SPaT and GID messages. Upon receiving these messages, the In-Vehicle System determines eco-driving strategies including speed profile recommendations that encourage "green" approaches to signalized intersections. The in-vehicle system application leverages connected vehicle technology to receive signal timing messages. Upon receiving this information, in-vehicle systems calculate and provide speed advice to the driver of the vehicle, allowing the driver to adapt the vehicle's speed to pass the next signal on green or to decelerate to a stop in the most environmentally efficient manner. It also considers the vehicle's acceleration as it departs from the signalized intersection.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of vehicles equipped with connected vehicle technologies. Because of these high penetration rates, conventional ITS equipment is not shown collecting traffic and environmental data.
- The Connected Vehicle Roadway Equipment is located near a traffic signal and connected to the Eco-Traffic Signal System.
- The Vehicle is equipped with an In-Vehicle System.

- The Connected Vehicle Roadway Equipment receives SPaT data from the ITS Roadway Equipment (i.e., traffic signal controller) for broadcasting.
- Vehicle assisted systems or automated driving are not considered in this scenario.

Steps. The following table describes the steps for the scenario depicted in Figure 9-1.

Table 9-1: Eco-Approach and Departure at Signalized Intersections: Scenario Steps

Step	Description
1	The ITS Roadway Equipment (i.e., the traffic signal controller) sends the traffic signal's current SPaT data to the Connected Vehicle Roadway Equipment. SPaT data includes the signal state of the intersection and how long this state will persist for each approach and lane that is active. Movements are given to specific lanes and approaches by use of the lane numbers present in the message.
2	The Eco-Traffic Signal System sends traffic conditions data to the Connected Vehicle Roadway Equipment, including average speeds on the link ahead and incidents along the roadway. The Eco-Traffic Signal System also sends GID messages to the Connected Vehicle Roadway Equipment describing the static physical geometry of one or more intersections (e.g., lane geometries and the allowable vehicle movements for each lane, barriers, pedestrian walkways, shared roadways, posted speed limits, and rail lines that may affect vehicle movements). The contents of this message are referred to within SAE J2735 as the Geographic Information Description (GID) layer. *Note: The Connected Vehicle Roadway Equipment is capable of storing intersection geographic information descriptions locally. Thus, the Eco-Traffic Signal System will only send this information to the Connected Vehicle Roadway Equipment when the geometry of the intersection changes.*
3	The Connected Vehicle Roadway Equipment broadcasts SPaT, GID, and traffic conditions messages. SPaT messages are broadcasted 10 times per second. The other messages are broadcasted less frequently.
4	Other Vehicles, nearby, broadcast vehicle status messages including the vehicle's location, motion (e.g., heading and acceleration), braking status, size, and vehicle type. These data are broadcasted frequently to surrounding vehicles to support V2V safety, mobility, and environmental applications. These messages are consistent with the basic safety message (BSM) identified in the SAE J2735 standard.
5	The In-Vehicle System receives the SPaT, GID, and traffic conditions messages from the Connected Vehicle Roadway Equipment. The In-Vehicle System also receives vehicle status messages from nearby vehicles. Using these data, the In-Vehicle System determines the vehicle's optimal trajectory (e.g., speed, acceleration, and braking) as the vehicle approaches or departs from the signalized intersection. The application also uses the vehicle's current speed, location, and interactions with impeding vehicles to determine different trajectories to the signalized intersection and first attempts to identify a speed for the vehicle to traverse the intersection during a green light. If the application determines that the vehicle cannot traverse the intersection on a green light, then it will determine a strategy for the vehicle to decelerate to the intersection in the most environmentally efficient manner. If the vehicle is stopped or slows down, the application will recommend the most environmentally efficient acceleration as the vehicle departs from the signalized intersection. Speed and acceleration recommendations are provided to the driver via a user interface. When stopped the In-Vehicle System also includes start-stop capabilities that automatically shut down and restart the vehicle's engine while the vehicle is waiting for the traffic signal to turn green. This reduces the amount of time the engine spends idling, thereby reducing fuel consumption and emissions.

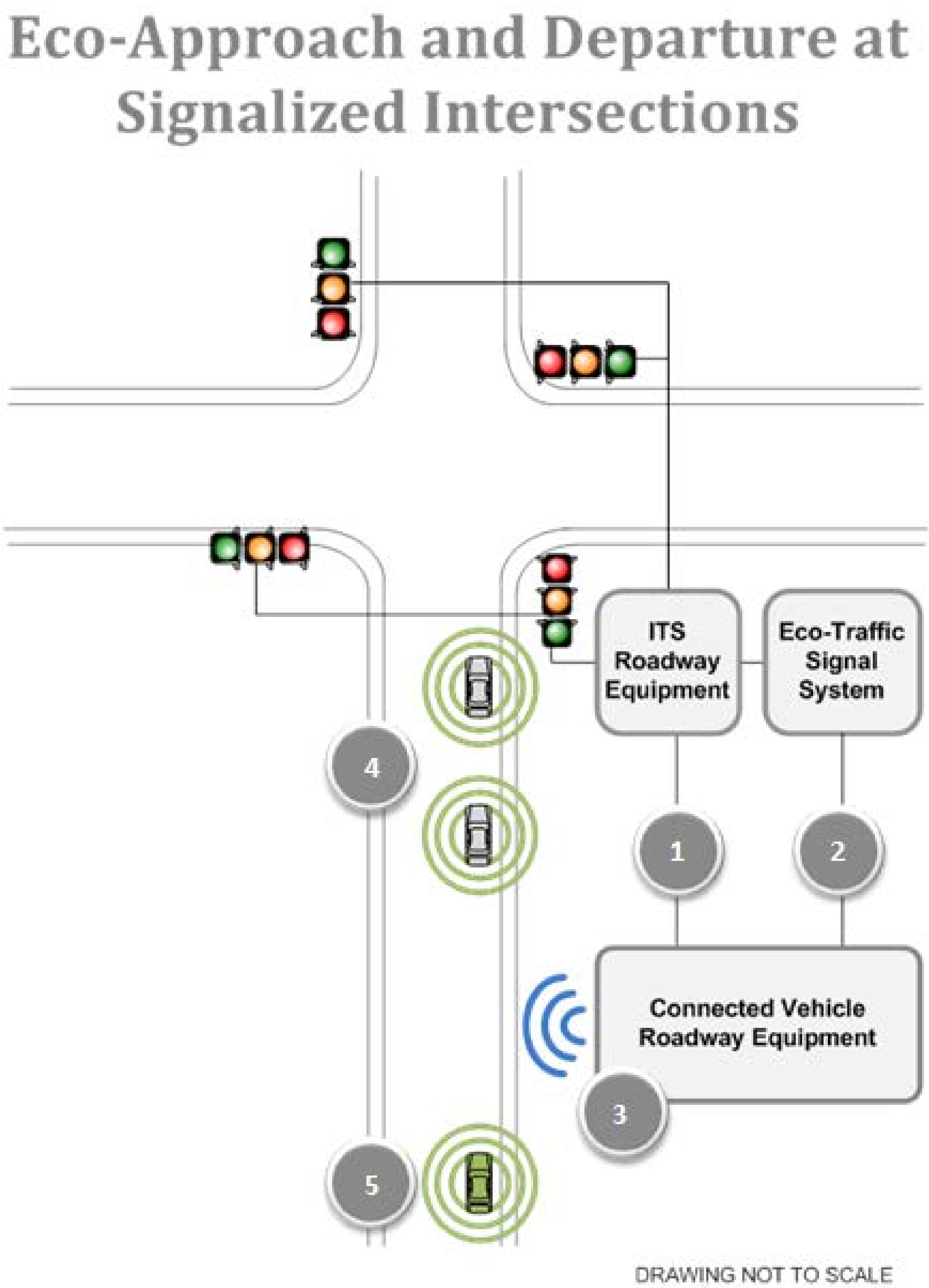

Figure 9-1: Eco-Approach and Departure at Signalized Intersections Scenario
(*Source*: Noblis, 2013)

9.2 Scenario: Eco-Approach and Departure at Signalized Intersections – Automated Control

Actors. Eco-Traffic Signal System, In-Vehicle System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. A vehicle equipped with the In-Vehicle System approaches a signalized intersection that is broadcasting SPaT and GID messages. Data from nearby vehicles includes vehicle speeds, locations, brake status, etc. are also broadcast. Upon receiving these messages, the In-Vehicle System determines eco-driving strategies including speed profile recommendations that encourage “green” approaches to signalized intersections. The In-Vehicle Systems calculates speed recommendations, and sends information to the vehicle’s actuators. The actuators automatically control the vehicle’s speed, acceleration, and deceleration (i.e., longitudinal control) allowing the vehicle to pass the next signal on green or to decelerate to a stop in the most environmentally efficient manner. Drivers maintain control of the vehicle’s steering (i.e., lateral control) and can take over control of the vehicle by pressing a button, or engaging the vehicle’s accelerator or brake at any time.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle “knows” its current location.
- The scenario assumes very high penetration rates of vehicles equipped with connected vehicle technologies. Nearly all vehicles are equipped with DSRC capabilities.
- The Connected Vehicle Roadway Equipment is located near a traffic signal and connected to the Eco-Traffic Signal System.
- The Vehicle is equipped with an In-Vehicle System.
- The Connected Vehicle Roadway Equipment receives SPaT data from the ITS Roadway Equipment (i.e., traffic signal controller) for broadcasting.
- The Vehicle with the In-Vehicle System has automated driving capabilities where the vehicle’s speed is automatically controlled. Steering of the vehicle is maintained by the driver.
- The Vehicle includes other sensors, such as radar sensors, allowing the vehicle to detect the location of other vehicles that are not equipped with DSRC radios.

Steps. The following table describes the steps for the scenario depicted in Figure 9-2.

Table 9-2: Eco-Approach and Departure at Signalized Intersections – Automated Control: Scenario Steps

Step	Description
1	A vehicle is equipped with an eco-driving application that recommends driving speeds and accelerations to the driver to promote “green” driving – a driving style that reduces emissions and fuel consumption. The application provides eco-driving recommendations for drivers on arterials, considering approaches and departures at stop signs, yield signs, and traffic signals. It also includes a feature allowing for automated control of the vehicle (e.g., the feature controls the speed and acceleration of the vehicle, but still requires the driver to steer the vehicle). The driver turns on the automated driving capability using a human machine interface (HMI) in the vehicle. The driver may disengage automated control by pressing a button or engaging the vehicle’s brake or accelerator.
2	The ITS Roadway Equipment (i.e., the traffic signal controller) sends the traffic signal’s current SPaT data to the Connected Vehicle Roadway Equipment. The SPaT message describes the signal state of the intersection and how long this state will persist for each approach and lane that is active. Movements are given to specific lanes and approaches by use of the lane numbers present in the message.
3	The Eco-Traffic Signal System sends traffic conditions to the Connected Vehicle Roadway Equipment, including average speeds ahead, and incidents along the roadway. The Eco-Traffic Signal System also sends GID messages to the Connected Vehicle Roadway Equipment describing the static physical geometry of one or more intersections (e.g., lane geometries and the allowable vehicle movements for each lane, barriers, pedestrian walkways, shared roadways, posted speed limits, and rail lines that may affect vehicle movements). The contents of this message are referred to within SAE J2735 as the Geographic Information Description (GID) layer. *Note: The Connected Vehicle Roadway Equipment is capable of storing intersection geographic information descriptions locally. Thus, the Eco-Traffic Signal System will only send this information to the Connected Vehicle Roadway Equipment when the geometry of the intersection changes.*
4	The Connected Vehicle Roadway Equipment broadcasts SPaT, GID, and traffic condition messages. SPaT messages are broadcasted 10 times per second. Other messages are broadcast less frequently.
5	Other Vehicles broadcast vehicle status messages including the vehicle’s location, motion (e.g., heading and acceleration), braking status, size, and vehicle type. These data are broadcasted frequently to surrounding vehicles to support V2V safety, mobility, and environmental applications. These data are used by the In-Vehicle System to ensure that collisions do not occur between vehicles.

Step	Description
6	The In-Vehicle System receives SPaT, GID, and traffic condition messages from the Connected Vehicle Roadway Equipment. It also receives vehicle status messages from nearby vehicles. Using these data, the In-Vehicle System determines the vehicle's optimal trajectory (e.g., speed, acceleration, and braking) as the vehicle approaches or departs from the signalized intersection. The application uses the vehicle's current speed, location, and interactions with impeding vehicles (e.g., vehicles in front of the vehicle) to determine different trajectories to the signalized intersection and first attempts to identify a speed for the vehicle to traverse the intersection during a green light. If the application determines that the vehicle cannot traverse the intersection on a green light, then it will determine a strategy for the vehicle to decelerate to the intersection in the most environmentally efficient manner. If the vehicle is stopped or slows down, the application will recommend the most environmentally efficient acceleration as the vehicle departs from the signalized intersection. Traffic conditions downstream may be considered in determining departing speeds and accelerations. As a vehicle approaches an intersection, traffic data about queues at intersections may also be considered.
7	Once eco-driving recommendations are determined by the application, data is sent to vehicle actuators which automatically adjust the speed, accelerations/decelerations, and braking of the vehicle. The driver maintains control of the steering of the vehicle. The vehicle drives along the arterial automatically adjusting its speed reducing emissions and fuel consumption. Data collected from other vehicles using V2V communications are considered to ensure that the vehicle does not collide with other vehicles. The vehicle traverses the intersection. The driver may resume longitudinal control of the vehicle by pressing a button, or engaging the vehicle's brake or accelerator at any time.

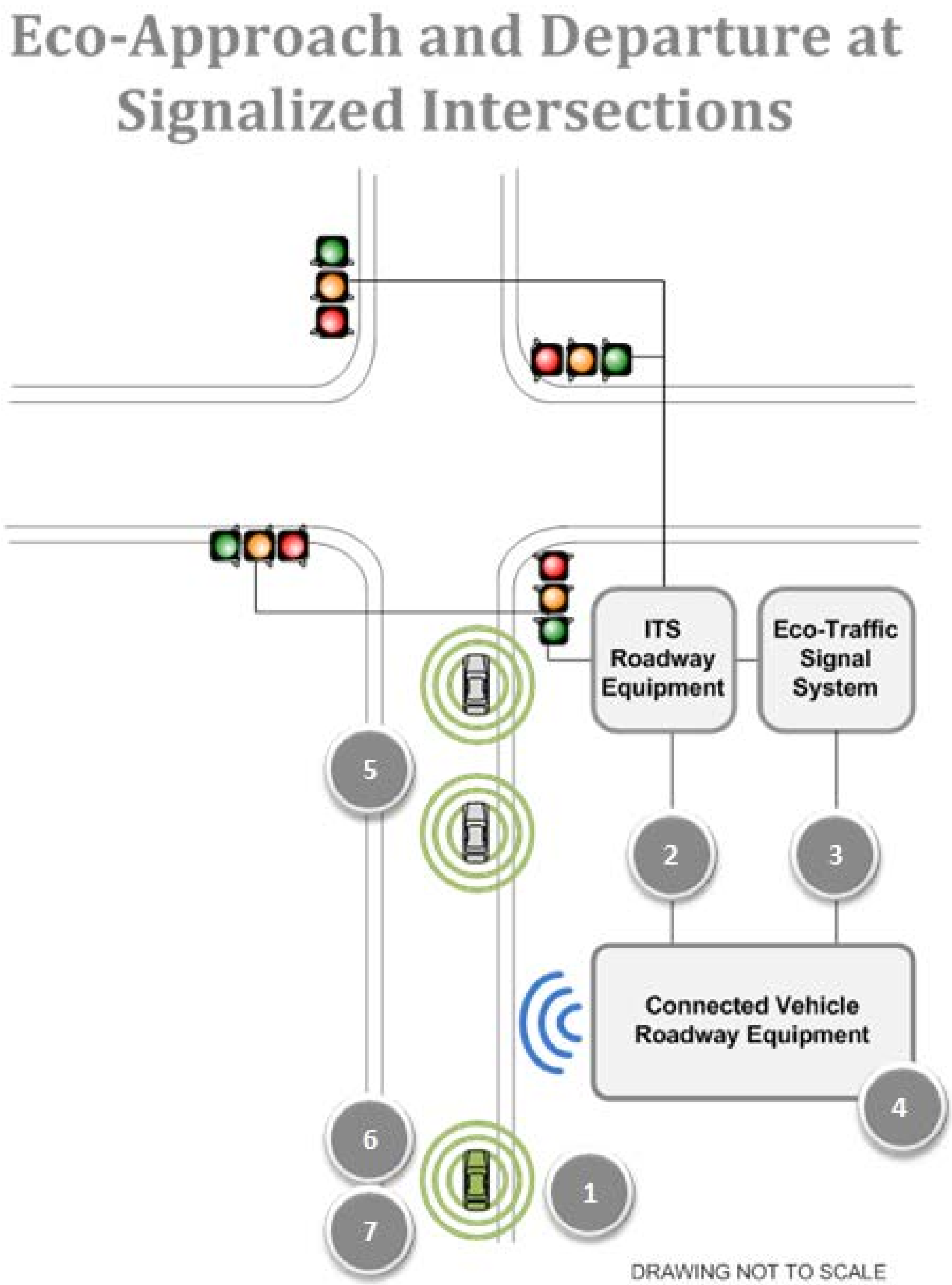

Figure 9-2: Eco-Approach and Departure at Signalized Intersections – Automated Control Scenario (*Source*: Noblis, 2013)

9.3 Scenario: Wireless Inductive Charging at Signalized Intersections

Actors. Inductive Charging Roadway Equipment, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. An electric vehicle capable of receiving a wireless inductive charge approaches a signalized intersection broadcasting SPaT and GID messages. Once the vehicle is stopped at a red light at the signalized intersection, the driver of the vehicle opts-in to an application so his/her vehicle can begin receiving a wireless inductive charge. If the vehicle is positioned over the wireless charging pad and the driver of the electric vehicle activates the application, energy is sent from the wireless inductive charging pad to the vehicle. This exchange of energy allows the electric vehicle's battery to be charged.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle "knows" its current location.
- Wireless inductive charging pads are installed in the pavement at a signalized intersection.
- The Connected Vehicle Roadway Equipment is located near a traffic signal and connected to the Eco-Traffic Signal System.
- The vehicle approaching the signalized intersection is an electric vehicle capable of receiving an inductive charge. The vehicle may be a transit vehicle, commercial vehicle, or a passenger vehicle.
- The Vehicle is equipped with an In-Vehicle System.
- The Connected Vehicle Roadway Equipment receives SPaT data from the ITS Roadway Equipment (i.e., traffic signal controller) for broadcasting.
- Connected Vehicle Roadway Equipment broadcasts information about the location of inductive charging infrastructure.

Steps. The following table describes the steps for the scenario depicted in Figure 9-3.

Table 9-3: Wireless Inductive Charging at Signalized Intersections: Scenario Steps

Step	Description
1	The ITS Roadway Equipment (i.e., the traffic signal controller) sends the traffic signal's current SPaT data to the Connected Vehicle Roadway Equipment. The data is converted into a SAE J2735 SPaT message.
2	The Connected Vehicle Roadway Equipment broadcasts SPaT and GID messages. GID messages would sent from the Eco-Traffic Signal System to the Connected Vehicle Roadway Equipment. The GID message includes the locations of inductive charging infrastructure near signalized intersections.
3	The In-Vehicle System receives SPaT and GID messages – including the location of inductive charging infrastructure. The driver of the electric vehicle opts into an inductive charging application. The application informs the driver of the location of inductive charging infrastructure.
4	As the vehicle approaches the inductive charging pad at a red light, the vehicle establishes a wireless connection with the inductive charging infrastructure. A handshake process begins, payment information is sent to inductive charging equipment, and an electric charge is transferred from the pad to the vehicle.
5	The In-Vehicle System continues to receive SPaT messages as it sits at the red light. Five seconds before the traffic signal turns green, the charge terminates. The In-Vehicle System notifies the driver that the charge is complete.
6	The traffic signal turns green and the vehicle accelerates away from the intersection. The In-Vehicle System notifies the driver about the vehicle's charge level.

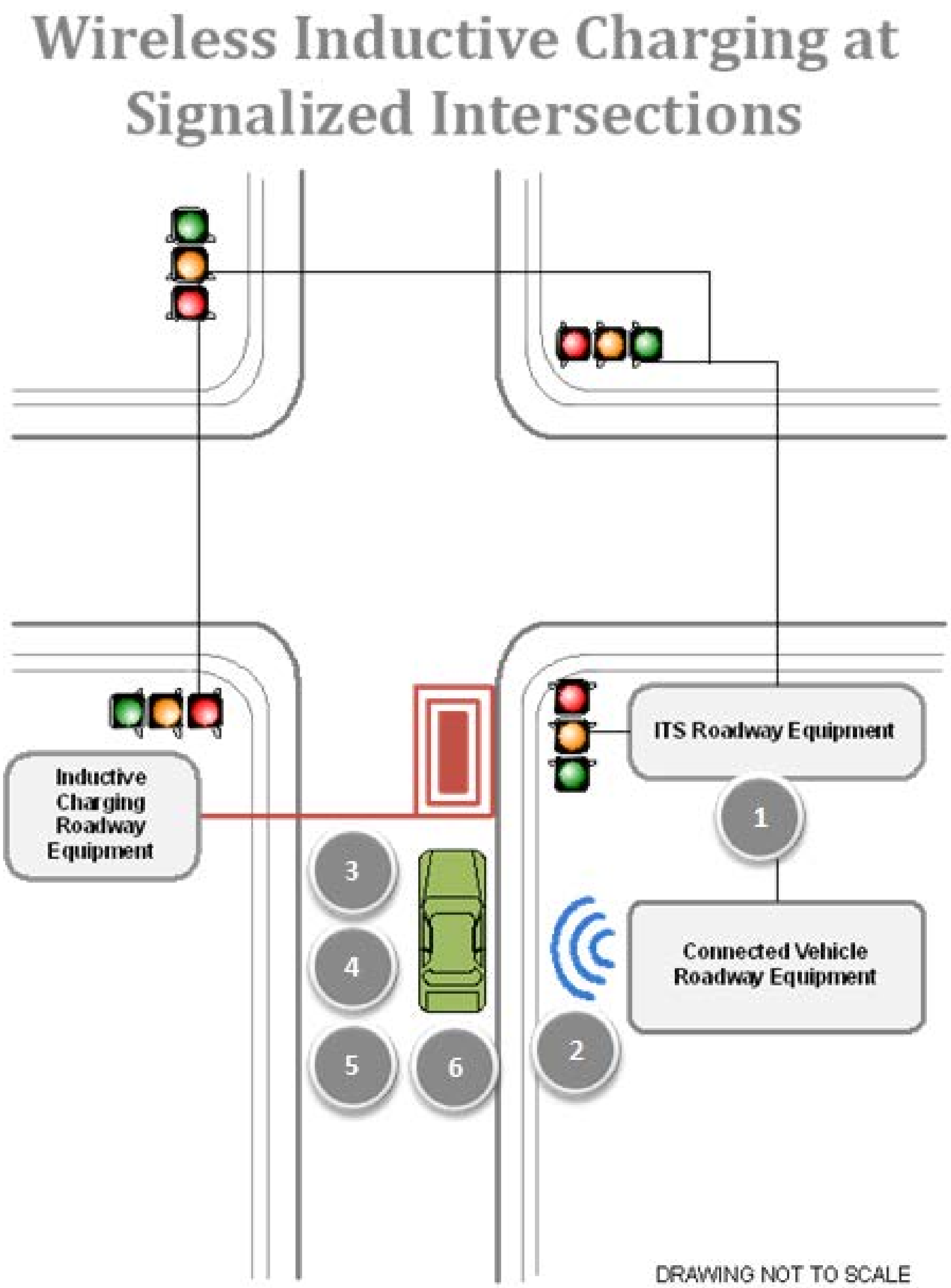

Figure 9-3: Wireless Inductive Charging at Signalized Intersections Scenario
(*Source*: Noblis, 2013)

9.4 Scenario: Eco-Traffic Signal Timing

Actors. Eco-Traffic Signal System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. The Eco-Traffic Signal System collects vehicle status, traffic, and environmental data and uses these data to develop eco-traffic signal timing plans. The Eco-Traffic Signal System interacts with the traffic signal controller to adjust signal timing based on traffic, vehicle emissions, and other environmental conditions such as road weather. The application is similar to current traffic control systems; however, the application's objective is to optimize traffic signals for the environment using connected vehicle data. The application collects data such as vehicle location, speed, and emissions from vehicles using connected vehicle technologies and determines the optimal operation of the traffic signal system based on the data.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of vehicles equipped with connected vehicle technologies. Because of these high penetration rates, conventional ITS equipment is not shown collecting traffic and environmental data.
- The Connected Vehicle Roadway Equipment is located near a traffic signal and connected to the Eco-Traffic Signal System.

Steps. The following table describes the steps for the scenario depicted in Figure 9-4.

Table 9-4: Eco-Traffic Signal Timing: Scenario Steps

Step	Description
1	Vehicles send vehicle status data to the Connected Vehicle Roadway Equipment. Vehicle status data includes data about the vehicle's location, motion (e.g., heading and acceleration), braking status, size, and vehicle type as well as environmental status data such as the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption. These data are collected directly from the vehicle or estimated based on calculations performed on the vehicle.
2	The Connected Vehicle Roadway Equipment sends the vehicle status data to the Eco-Traffic Signal System.
3	The Eco-Traffic Signal System processes the vehicle status data to develop real-time and predicted traffic and environmental conditions for the roadway segment. Together the traffic and environmental data are used to generate eco-traffic signal timing plans (e.g., cycle lengths, phases, offsets and other parameters). This may include fixed timing plans based on the time of day or capabilities similar to current traffic control systems; however, the objective is to generate signal timing plans to minimize the environmental impact of traffic at a single intersection, along a corridor, or a region, and to select the appropriate traffic signal timing strategy to be implemented.
4	The Eco-Traffic Signal System sends the traffic signal timing plans to the ITS Roadway Equipment (i.e., traffic signal controller) which implements the signal timing plan.

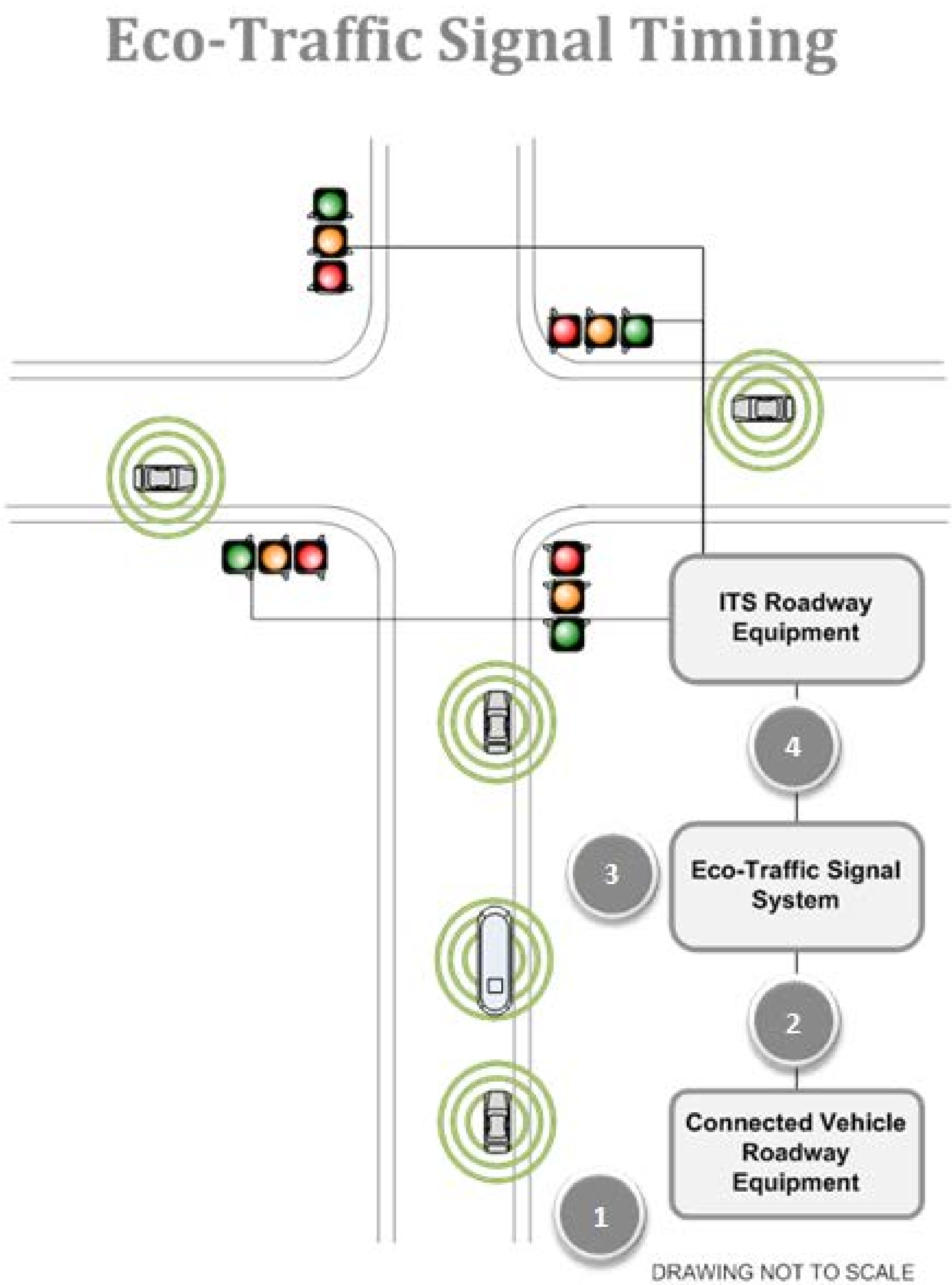

Figure 9-4: Eco-Traffic Signal Timing Scenario *(Source: Noblis, 2013)*

9.5 Scenario: Eco-Traffic Signal Priority

Actors. Eco-Traffic Signal System, ITS Roadway Equipment, Connected Vehicle Roadway, Transit Vehicles, and Passenger Vehicles

Description. A vehicle approaching a signalized intersection requests traffic signal priority. The application considers criteria such as the vehicle's location, speed, vehicle class, adherence to pre-determined transit schedule, and/or passenger load as input for determining when to grant a vehicle priority. If priority is granted, the traffic signal would either hold the green on the approach, while accounting for intersection performance, until the vehicle clears the intersection or the signal reaches the maximum hold time, or advance the start of green to reduce the delay incurred by a vehicle. Granting signal priority is based on multiple variables with the objective of producing the least amount of emissions at the signalized intersection, corridor, or network.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the intersections along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of vehicles equipped with connected vehicle technologies. Vehicles broadcast vehicle status data. Because of these high penetration rates, conventional ITS equipment is not shown collecting traffic and environmental data.
- The Connected Vehicle Roadway Equipment is located near a traffic signal and connected to the Eco-Traffic Signal System.
- This scenario assumes a Transit Vehicle is requesting traffic signal priority. The transit vehicle includes on-board systems that collect information about the number of passengers on the vehicles and the transit vehicle's adherence to its schedule. *Note: While this scenario assumes traffic signal priority for a transit vehicle, traffic signal priority may also be granted to other vehicle types.*

Steps. The following table describes the steps for the scenario depicted in Figure 9-5.

Table 9-5: Eco-Traffic Signal Priority: Scenario Steps

Step	Description
1	The Transit Vehicle sends a request for signal priority to the Connected Vehicle Roadway Equipment. In addition to the signal priority request, the transit vehicle also collects and transmits data from on-board systems including the number of passengers on the transit vehicle and the transit vehicle's adherence to its schedule.
2	Vehicles in the vicinity of the signalized intersection send vehicle status data to the Connected Vehicle Roadway Equipment. Vehicle status data includes the vehicle's location, motion (e.g., heading and acceleration), braking status, size, and vehicle type as well as the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption. These data are collected directly from the vehicle or estimated based on calculations performed on the vehicle.
3	The Connected Vehicle Roadway Equipment sends the vehicle status data to the Eco-Traffic Signal System. The Connected Vehicle Roadway Equipment also sends the signal priority request to the Eco-Traffic Signal System.
4	The Eco-Traffic Signal System processes the vehicle status data to develop real-time and predicted traffic and environmental conditions for the roadway segment. Upon receiving the signal priority request from the vehicle, the Eco-Traffic Signal System uses the traffic and environmental conditions data to determine if signal priority should be granted. The Eco-Traffic Signal Priority application considers the current state of the traffic signal, traffic volumes for all approaches to the traffic signal, vehicle emissions from vehicles at all approaches to the traffic signal, traffic conditions downstream of the intersection, the number of passengers on the transit vehicle, and the transit vehicle's adherence to its schedule to determine if priority should be granted. The Eco-Traffic Signal System will determine the solution that results in the least emissions at the signalized intersection. This solution may be either (a) granting signal priority or (b) not acting on the signal priority request.
5	If it is determined that signal priority should be granted, the Eco-Traffic Signal System sends the request for signal priority to the ITS Roadway Equipment which implements the traffic signal control strategy (i.e., signal priority). If priority is granted, the vehicle traverses the intersection without stopping.

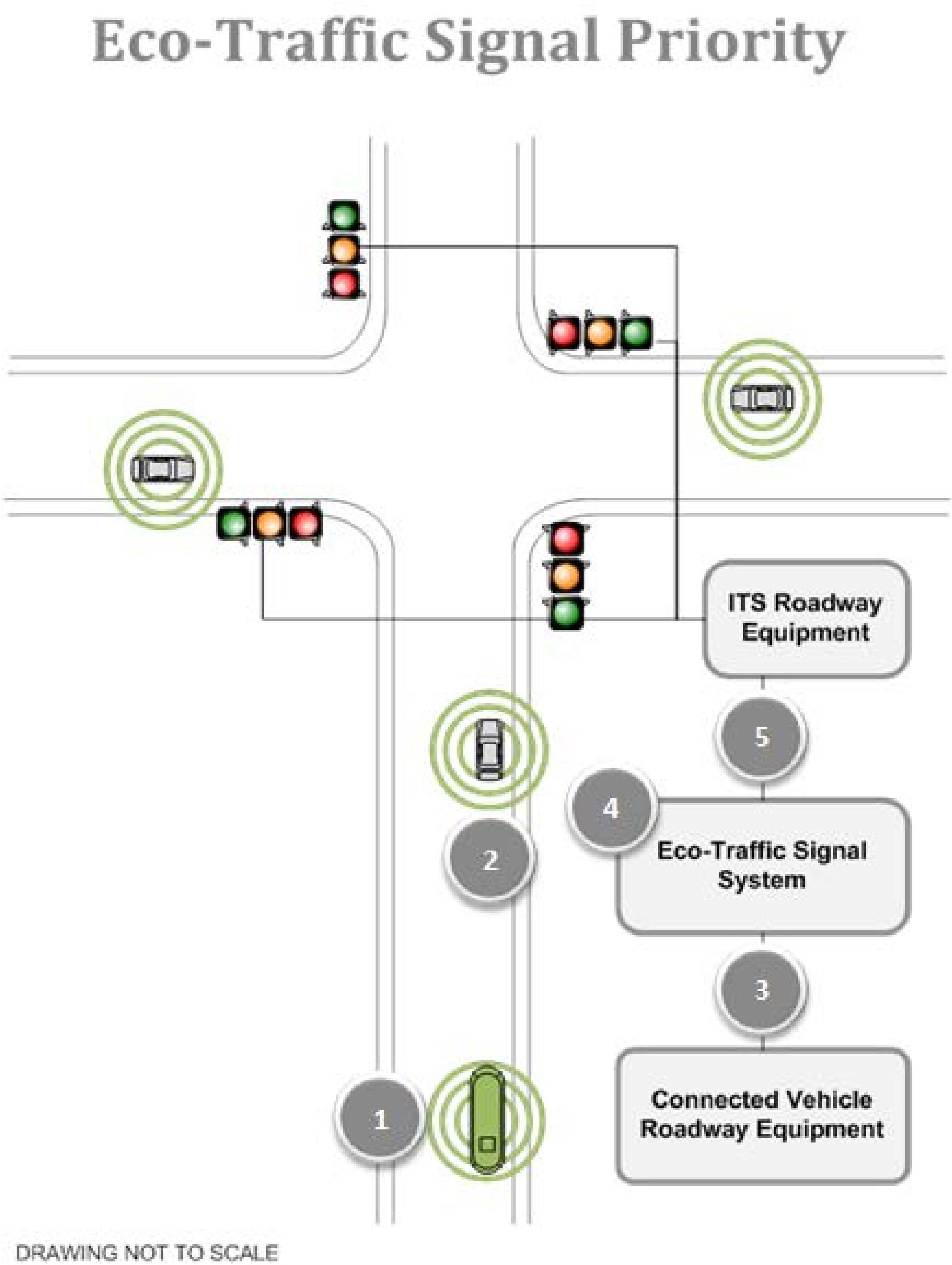

Figure 9-5: Eco-Traffic Signal Priority Scenario (*Source*: Noblis, 2013)

10 Goals, Objectives, and Performance Measures

This section presents an analysis of the goals, objectives, and potential performance measures for the Eco-Signal Operations Transformative Concept. With successful implementation, this Transformative Concept is expected to meet the following goals and objectives. The goals and objectives illustrate potential measures that a jurisdiction operating an Eco-Traffic Signal System may want to measure. Objectives include “X’s” and “Y’s” for performance measures. For example, X may be a percentage reduction and Y may be a timeframe. Values for these objectives should be determined by entities operating the transportation system based on baseline performance measures. It is envisioned that a public agency may choose to use some or all of these goals and objectives in monitoring the performance of the system.

Four goals are identified for the Eco-Signal Operations Transformative Concept. The first goal looks at reductions in emissions and energy consumption. The second goal is focused on supporting green transportation decisions by drivers, including the awareness of eco-driving benefits. The third goal is focused on improving mobility – a secondary benefit of environmental applications. At this time the trade-offs between environmental improvements and mobility are unknown. In some cases, optimizing the transportation network for the environment will also result in mobility improvements. However, there may be other instances where optimizing for the environment may reduce mobility. For example, reducing speed limits on a freeway may result in environmental improvements, but may increase the travel time of a motorist. Thus, the objectives in the goal may need to be customized so that mobility is improved or application impacts on mobility are minimized. The fourth goal looks at improving safety. Similar to the mobility goal, this goal and its objectives are seen as secondary; however safety measures should be monitored. It is expected that environmental applications may provide safety benefits. For example, drivers traveling at slower speed in accordance to eco-speed limits, receiving information about when a traffic signal will turn red, or simply mode switching to transit may result in safety benefits including reductions in fatalities, injuries, and property damage.

Goal #1 Reduce Environmental Impacts

- Reduce Emissions from Surface Transportation Vehicles
  - Reduce carbon dioxide (CO_2) emissions by X percent by Y.
  - Reduce carbon monoxide (CO) emissions by X percent by Y.
  - Reduce nitric oxide (NO_x) emissions by X percent by Y.
  - Reduce sulfur dioxide (SO_2) emissions by X percent by Y.
  - Reduce emissions of coarse particulates (PM10) by X percent by Y.
  - Reduce emissions of fine particulates (PM2.5) by X percent by Y.
  - Reduce volatile organic compounds (VOCs) by X percent by Y.
- Reduce Energy Consumption Associated with Surface Transportation Vehicles

  - Reduce excess fuel consumed by X percent by Y.
  - Reduce excess energy consumption by X percent by Y.
  - Reduce total fuel consumption per capita for surface transportation by X percent by Y.
  - Reduce total energy consumption per capita for surface transportation by X percent by Y.

Goal #2 Support "Green Transportation Decisions" by Travelers

- Increase Eco-Driving Awareness and Practice
  - Increase the number of eco-driving marketing/outreach activities by X percent by Y.
  - Increase the number of drivers practicing eco-driving strategies by X percent by Y.
- Reduce Range Anxiety for Drivers of Electric Vehicles
  - Reduce Drivers fear of Range Anxiety while driving electric vehicles by X by Y.
- Increase the Range of Electric Vehicles
  - Increase the distance that electric vehicles can travel without stopping at a charging station by X percent by Y.

Goal #3 Enhance Mobility on the Transportation System (Secondary Goal and Objectives)

- Improve the Efficiency of the Transportation System
  - Reduce the annual monetary cost of congestion per capita by X by Y.
  - Reduce hours of delay per capita by X percent by Y.
  - Reduce hours of delay per driver by X percent by Y.
- Improve the Efficiency of Arterials
  - Decrease the seconds of control delay per vehicle on arterial roads by X by Y. (Control delay is defined as the portion of the total delay attributed to traffic signal operation for signalized intersections).
  - Increase the miles of arterials in the region operating at level of service (LOS) Z by X percent by Y.
- Improve Transit Operating Efficiency
  - Improve average transit travel time compared to passenger vehicles in major corridors by X minutes by Y.
  - Maintain or reduce a travel time differential between transit and passenger vehicles during peak periods of X percent by Y.
  - Decrease system-wide signal delay on transit routes by X percent by Y.
  - Increase implementation of transit signal priority strategies on X number of routes (or at X number of intersections) by Y.
- Improve the Efficiency of Freight Operating Efficiency
  - Decrease hours of delay per 1,000 vehicle miles traveled on selected freight-significant routes by X percent by Y.

  - Decrease point-to-point travel times on selected freight-significant routes by X minutes by Y.
  - Increase ratings for customer satisfaction with freight mobility in the region among shippers, receivers, and carriers by X percent by Y.

Goal #4 Improve the Safety of the Transportation System (Secondary Goal and Objectives)

- Reduce Crashes, Injuries, and Fatalities
  - Reduce the total number of crashes in the region by X percent by Y.
  - Reduce the total number of injuries in the region by X percent by Y.
  - Reduce the total number of fatalities in the region by X percent by Y.
  - Reduce crashes, injuries, and fatalities at intersections by X percent by Y.
    - Reduce crashes, injuries, and fatalities at railroad crossings by X percent by Y.
    - Reduce crashes, injuries, and fatalities due to red-light running by X percent by Y.
    - Reduce crashes, injuries, and fatalities at intersections due to adverse road weather conditions by X percent by Y.
    - Reduce crashes, injuries, and fatalities by X percent by Y.
  - Reduce secondary crashes at intersections by X percent by Y.

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APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
AERIS	Applications for the Environment: Real-Time Information Synthesis
AFV	Alternative Fuel Vehicle
ANSI	American National Standards Institute
BAA	Broad Agency Announcement
BEM	Basic Environmental Message
BSM	Basic Safety Message
CAN	Controller Area Network
CCTV	Closed Circuit Television
CERT	Center for Environmental Research and Technology
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DCM	Data Capture and Management
DMS	Dynamic Message Sign
DOT	Department of Transportation
EPA	Environmental Protection Agency
ETSS	Eco-Traffic Signal System
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration

Acronym	Meaning
FTA	Federal Transit Administration
GHG	Greenhouse Gas
GHz	Gigahertz
GID	Geographic Information Description
GPS	Global Positioning System
HAR	Highway Advisory Radio
HC	Hydrocarbon
HMI	Human Machine Interface
HOV	High-Occupancy Vehicle
ICM	Integrated Corridor Management
IEEE	Institute of Electrical and Electronics Engineers
ISP	Information Service Provider
ITS	Intelligent Transportation Systems
IVS	In-Vehicle System
I2V	Infrastructure-to-Vehicle
JPO	Joint Program Office
LOS	Level of Service
MOE	Measure of Effectiveness
mpg	Miles per Gallon
NHTSA	National Highway Traffic Safety Administration
NO_x	Nitric Oxide
NTCIP	National Transportation Communications for ITS Protocol
NWS	National Weather Service

Acronym	Meaning
OBD	On-Board Diagnostics
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
PM	Particulate Matter
RITA	Research and Innovative Technology Administration
RSE	Roadside Equipment
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimization Technique
SO_2	Sulfur Dioxide
SPAT	Signal Phase and Timing
TCIP	Transit Communications Interface Profiles
TMDD	Traffic Management Data Dictionary
TOD	Time of Day
UCR	University of California – Riverside
U.S.	United States
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Wi-Fi	Wireless Fidelity
X2D	Vehicle or Infrastructure-to-Device
3G	Third Generation

Acronym	Meaning
4G	Fourth Generation

APPENDIX B. Actor Definitions

Appendix B includes definition of the actors used in this document. Actors represent roles played by human users, external hardware or software, a center, or a vehicle. Actors do not necessarily represent a specific physical entity, but merely a particular facet (i.e., “role”) of some entity that is relevant to the specification of its associated use cases. Additionally, a single physical entity (i.e., a traffic management center) may play the role of several different actors and, conversely, a given actor may be played by multiple different instances. For example, a traffic management center may play the traffic management and emissions management roles. While it plays multiple roles, the traffic management center is a single physical entity. Conversely, there is likely more than one traffic management center in a region or a state. The definitions of the actors are based on the National ITS Architecture subsystem and terminator definitions. Some of these definitions have been modified for this document to better define the actor for this Transformative Concept.

- **Commercial Vehicle.** The Commercial Vehicle actor resides in a commercial vehicle and provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. Both one-way and two-way communications options, including 5.9 Gigahertz (GHz) band approved for DSRC use by the Federal Communications Commission (FCC) and other wireless communications such as cellular, support a spectrum of information services. These capabilities allow the vehicle actor to transmit information about its status (i.e., current speed, acceleration, braking, and average emissions) to other vehicles or to the Connected Vehicle Roadway Equipment actor. Advanced sensors, processors, enhanced driver interfaces, and actuators complement the driver information services so that, in addition to making informed mode and route selections, the driver travels these routes in a safer and more consistent manner.
- **Connected Vehicle Roadway Equipment.** The Connected Vehicle Roadway Equipment actor includes the RSE units distributed on and along the roadway. These devices are capable of both transmitting and receiving data using DSRC radios, using the 5.9 GHz band approved for DSRC use by the FCC. The devices may also support other wireless communications, such as cellular and Wi-Fi communications. RSE units support the appropriate IEEE and SAE standards (IEEE 802.11p, IEEE 1609 family, and SAE J2735). The Connected Vehicle Roadway Equipment actor also includes local processing capabilities to support processing of data at the roadside.
- **Driver.** The Driver actor represents the human entity that operates a licensed vehicle on the roadway. Included are operators of passenger, transit, and commercial vehicles where the data being sent or received is not particular to the type of vehicle. Thus, this actor originates driver requests and receives driver information that reflects the interactions which might be useful to all drivers, regardless of vehicle classification.
- **Emissions Management Center.** The Emissions Management Center actor provides the capabilities for air quality managers to monitor and manage air quality. These capabilities include collecting emissions data from distributed emissions sensors and from Vehicle actors (e.g., passenger vehiucles, transit vehicles, and commercial vehicles), and ingesting regional air quality data from external sources and sensors such as those operated by the National Weather Service (NWS) or the EPA. These sensors monitor general air quality for an area and also monitor the emissions of individual vehicles on the roadway. The sector emissions measures are collected, processed, and used to identify sectors exceeding or predicted to exceed pre-defined pollution levels. This information is provided to Traffic Management Center actors to implement strategies intended to reduce emissions in and around the

problem areas. This actor provides any functions necessary to inform the violators and otherwise ensure timely compliance with emissions standards. This actor may co-reside with the Traffic Management Center actor or may operate in its own distinct location depending on regional preferences and priorities.

- **Inductive Charging Roadway Equipment.** The Inductive Charging Roadway Equipment actor includes roadside infrastructure deployed along the roadway that uses magnetic fields to wirelessly transmit large electric currents between metal coils placed several feet apart. This infrastructure enables inductive charging of electric vehicles including cars, trucks, and buses. It also supports charging vehicles moving at highway speeds. Roadside Charging Infrastructure supports static charging capable of transferring electric power to a vehicle parked in a garage or on the street and vehicles stopped at a traffic light.
- **ITS Roadway Equipment.** The ITS Roadway Equipment actor includes the equipment distributed on and along the roadway that monitors and controls traffic and monitors and manages the roadway itself. Equipment includes traffic detectors, environmental sensors, traffic signals, highway advisory radios (HAR), DMSs, CCTV cameras, and video image processing systems, grade crossing warning systems, and freeway ramp metering systems. HOV lane management, reversible lane management functions, and barrier systems that control access to transportation infrastructure such as roadways, bridges, and tunnels are also supported. This actor also provides the capability for environmental monitoring including sensors that measure pavement conditions, surface weather, and vehicle emissions. In adverse conditions, automated systems can be used to apply anti-icing materials, disperse fog, etc.
- **Operator.** The Operator actor represents the human entity that directly interfaces with the Eco-Traffic Signal System.
- **Other On-Board Sensors.** The Other On-board Sensors actor represents sensors that may be installed on vehicles to collect traffic or environmental conditions data. For example, a vehicle may be equipped with a sensor to measure atmospheric or pavement conditions.
- **Passenger Vehicle.** The Passenger Vehicle actor provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. Both one-way and two-way communications options, including 5.9 GHz band approved for DSRC use by the FCC and other wireless communications such as cellular, support a spectrum of information services. This capability allows the Passenger Vehicle actor to disseminate information about its status (i.e., current speed, acceleration, braking, and average emissions) to other vehicles or to the Connected Vehicle Roadway actor. Advanced sensors, processors, enhanced driver interfaces, and actuators in the Passenger Vehicle actor complement the driver information services so that, in addition to making informed mode and route selections, the driver travels these routes in a safer and more consistent manner. This actor may also include more advanced functions that assume limited control of the vehicle to maintain safe headway.
- **Transit Vehicle.** The Transit Vehicle actor resides in a transit vehicle and provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. The types of transit vehicles containing this actor include buses, paratransit vehicles, light rail vehicles, other vehicles designed to carry passengers, and supervisory vehicles. Both one-way and two-way communications options, including 5.9 GHz band approved for DSRC use by the FCC and other wireless communications such as cellular, support a spectrum of information services. These capabilities allow the Transit Vehicle actor to disseminate information about its status (i.e.,

current speed, acceleration, braking, and average emissions) to other vehicles or to the Connected Vehicle Roadway actor. Advanced sensors, processors, enhanced driver interfaces, and actuators complement the driver information services so that the driver travels these routes in a safer and more consistent manner. Initial collision avoidance functions provide 'vigilant co-pilot' driver warning capabilities. The Transit Vehicle actor also supports a traffic signal prioritization function that communicates with the ITS Roadway Equipment actor and Connected Vehicle Roadway Equipment actor to improve on-schedule performance. Automated vehicle location functions enhance the information available to the Transit Management Center actor enabling more efficient operations.

- **Traffic Management Center.** The Traffic Management Center actor monitors and controls traffic and the road network. It represents the functionality provided by centers that manage a broad range of transportation facilities including freeway systems, rural and suburban highway systems, and urban and suburban arterial traffic control systems. This actor communicates with the ITS Roadway Equipment actor to monitor and manage traffic flow and monitor the condition of the roadway, surrounding environmental conditions, and field equipment status (e.g., traffic signals). This actor also manages traffic and transportation resources to support allied agencies in responding to, and recovering from, incidents ranging from minor traffic incidents through major disasters. The Traffic Management Center actor supports HOV lane management and coordination, road pricing, and other demand management policies that can alleviate congestion and influence mode selection. The actor communicates with other Traffic Management Center actors to coordinate traffic information and control strategies in neighboring jurisdictions.
- **Vehicle Diagnostic Systems.** The Vehicle Diagnostic Systems actor represents computer-based systems, located on vehicles, designed to monitor the performance of some of an engine's major components including those responsible for controlling emissions.
- **Vehicle Actuators.** The Vehicle Actuator actor represents an electromechanical device such as a relay, solenoid, or motor. Within the vehicle, computers use sensor data to control different systems on the vehicle through the use of actuators. Actuators can adjust engine idle speed, change suspension height, regulate the fuel metered into the system, accelerate or decelerate the vehicle, or implement the braking system.
- **Vulnerable Road User.** A pedestrian, including a runner, physically disabled person, child, skater, highway construction and maintenance worker, tow truck operator, utility worker, other worker with legitimate business in or near the road or right-of-way, or stranded motorist or passenger. The Vulnerable road user also includes a person operating equipment other than a motor vehicle, including, but notlimited to, a bicycle, handcycle, horse-driven conveyance, or unprotected farm equipment; or a person operating a motorcycle, moped, motor-driven cycle, or motorassisted scooter.

APPENDIX C. Communication Needs and Standards

The following table provides a summary and working documentation of the data communications that will be required to support the Eco-Signal Operations Transformative Concept. The columns of the table are documented as follows:

- **Subsystem.** The subsystems for the Eco-Signal Operations Transformative Concept as portrayed in Figure 6-3 and Figure 7-3.
- **Need.** The system needs are listed in the Operational Concept document. This spreadsheet lists only the data collection needs and the data dissemination needs since they are the needs that involve data communication.
- **Data to be Transmitted.** This field describes the type of information that is to be transmitted, or lists the principle data elements that will be transmitted.
- **From.** The entity from which the data messages are to be transmitted.
- **To.** The entity to which the data messages are to be transmitted or displayed.
- **Type of Communication.** The type of communication most likely to be used for the message transmission. The most common values are V2V, V2I, I2V, backhaul (landlines), and CAN bus. The term human machine interface (HMI) sometimes appears here. Strictly speaking, input or display of data via a HMI is not a communications message, but it is included for completeness.
- **Latency.** The latency of the information contained in the message. Low means under five seconds. Medium-low means between 5 seconds and 5 minutes or a communication that requires low latency in one implementation but medium in a different implementation. Medium means 5 minutes to an hour. High is anything longer than an hour, when time to receive a message is not important.
- **Applicable Standards.** The ITS standard that is applicable to the data transmission. In general, any communication between centers is covered by the Traffic Management Data Dictionary (TMDD), and any communication between the infrastructure and a vehicle or between vehicles is covered by J2735. J7235 is currently being updated, and additional updates will be required to provide the functionality envisioned by the AERIS Transformative Concepts. Additional Transit Communications Interface Profiles (TCIP) and National Transportation Communications for ITS Protocol (NTCIP) standards have specialized functions for landline communications.
- **Use.** An indication of the application or function for which the data will be used.
- **Other Comments.** Other comments about some aspects of the data transmissions, or questions to be discussed.

Table C-1: Eco-Traffic Signal System Communication Needs and Standards

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Traffic Signal Priority Request Data Collection Subsystem	Collect Traffic Signal Priority Requests (ETSS-DC-01)	Priority requests and justifications (e.g., schedule, # passengers)	Transit and Commercial Vehicles	Eco-Traffic System via RSEs on Signals	V2I	Low	TCIP Transit Signal Priority message	Decision whether to grant priority request	Lead time depends on speed and distance
Traffic Data Collection Subsystem	Collect Traffic Data (ETSS-DC-02)	Vehicle location, speed, turning movements	Vehicles	RSEs, then Eco-Traffic Signal System	V2I, then backhaul	Medium	Current J2735 BSM	Optimizing signal timing, deciding whether to grant priority, traffic information dissemination	Eco-Traffic Signal System will not update more frequently than 5 minutes.
Traffic Data Collection Subsystem	Collect Traffic Data (ETSS-DC-02)	Speeds, volumes, occupancy, CCTV images, incidents, pedestrian calls, etc.	Infrastructure Sensors	Eco-Traffic Signal System	Backhaul	Medium	TMDD	Optimizing signal timing, deciding whether to grant priority, traffic information dissemination	Eco-Traffic Signal System will not update more frequently than 5 minutes.
Traffic Data Collection Subsystem	Collect Traffic Data (ETSS-DC-02)	Speeds, volumes, occupancy, CCTV images, incidents, pedestrian calls, etc.	Other Traffic Management Centers	Eco-Traffic Signal System	Backhaul	Medium	TMDD	Optimizing signal timing, deciding whether to grant priority, traffic information dissemination	Eco-Traffic Signal System will not update more frequently than 5 minutes.
Environmental Data Collection Subsystem	Collect Environmental Data (ETSS-DC-03)	Environmental readings from mobile sensors	Vehicles	RSEs, then to Eco-Traffic Signal System	V2I, then Backhaul	Medium	J2735SE	Optimizing signal timing, signal priority decisions, dissemination	Needed for background, not real-time
Environmental Data Collection Subsystem	Collect Environmental Data (ETSS-DC-03)	Environmental readings from fixed sensors	Infrastructure Sensors	Eco-Traffic Signal System	Backhaul	Medium	NTCIP 1204	Optimizing signal timing, signal priority decisions, dissemination	Needed for background, not real-time
Environmental Data Collection Subsystem	Collect Environmental Data (ETSS-DC-03)	Environmental readings from environmental centers	Environmental or Emissions Management Centers	Eco-Traffic Signal System	Backhaul	Medium	TMDD	Optimizing signal timing, signal priority decisions, dissemination	Needed for background, not real-time
Traffic Signal Operational Status Data Collection Subsystem	Collect Traffic Signal Operational Status Data (ETSS-DC-04)	Operational status of the signal	Signal Controller	Eco-Traffic Signal System	Backhaul	Low	NTCIP	Real-time actuated signal control and periodic environmental optimization	None

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Geographic Information Description Data Collection Subsystem	Collect Geographic Information Description Data (ETSS-DC-05)	Roadway and signal geometry	TMC or Operator	Eco-Traffic Signal System	Backhaul	High	J2735 GID or MAP message	Eco-driving recommendations, dissemination to vehicles approaching intersection	One-time loading of info into the system
Operator Input Data Collection Subsystem	Collect Operator Input (ETSS-DC-06)	New timing plans, implementation, or add new equipment	Operator at TMC	Eco-Traffic Signal System	Backhaul	Medium-low	NTCIP 1202, custom to ETSS	System updates and short-term signal management, logging	None
Traffic Signal Priority Dissemination Subsystem	Disseminate Traffic Signal Priority Data (ETSS-D-01)	Recommendation to grant priority	Eco-Traffic Signal System	Signal Controllers	Backhaul	Low	TCIP 1202		If priority granted, controller implements
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Information to Other Centers (ETSS-D-02)	Speeds, volumes, occupancy, CCTV images, timing plans	Eco-Traffic Signal System	Other Centers	Backhaul	Medium	TMDD, NTCIP 1202 (timing plans)	Enable coordination on a regional basis	Combines with existing TMC coordination
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Information to Other Centers (ETSS-D-02)	Signal timing plans	Eco-Traffic Signal System	Other TMCs	Backhaul	Medium	NTCIP 1202		Regional coordination of signal timing
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Conditions to Vehicles (ETSS-D-03)	Current and predicted traffic, incidents, etc.	Eco-Traffic Signal System	Vehicles	I2V	Medium	J2735	Updates on the order of 5 min., formatted for in-vehicle signage, recommendations for eco-driving	Data includes info typically displayed on a DMS
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Other Centers (ETSS-D-04)	Environmental conditions gathered from all sources	Eco-Traffic Signal System	Emissions Management Centers	Backhaul	Medium	TMDD	Enable coordination on a regional basis	Combines with existing TMC coordination
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Vehicles (ETSS-D-05)	Current and predicted weather conditions relevant to driving	Eco-Traffic Signal System	Vehicles	I2V	Medium	J2735SE	Updates on the order of 5 min., formatted for in-vehicle signage, recommendations for eco-driving	Data includes info typically displayed on a DMS

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Geographic Information Description Dissemination Subsystem	Disseminate Geographic Information Descriptions (ETSS-D-07)	Intersection geometry	Eco-Traffic Signal System	Vehicles	I2V	Low	J2735 GID or MAP message	Approach to signalized intersections	Includes pedestrian walkways

Table C-2: In-Vehicle System Communication Needs and Standards

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Driver Input Data Collection Subsystem	Collect Driver Input (IVS-DC-01)	In-vehicle system parameters and O/Ds	Driver	In-Vehicle System	HMI (not communications)	Low		Allows driver to input O/D, vehicle configuration, other customizing info	Input and output should not impair the driver's ability to control the vehicle in a safe manner
Traffic Conditions Data Collection Subsystem	Receive Traffic Conditions Data (IVS-DC-02)	Current and predicted traffic conditions	Eco-Traffic Signal System	Vehicles	I2V	Medium-low	J2735 SE	Input to eco-driving strategies.	Includes data found on DMS
Environmental Conditions Data Collection Subsystem	Receive Environmental Conditions Data (IVS-DC-03)	Current and predicted environmental conditions	Eco-Traffic Signal System	Vehicles	I2V	Medium	J2735 SE	Input to eco-driving strategies.	Includes data found on DMS
SPaT and GID Data Collection Subsystem	Collect Signal Phase And Timing (SPaT) Data (IVS-DC-04)	SPaT messages	RSE	In-Vehicle System	I2V	Low	J2735 SPaT messages	Eco-approach to signalized intersections	
SPaT and GID Data Collection Subsystem	Collect Geographic Information Description (GID) Data (IVS-DC-05)	GID messages	RSE	In-Vehicle System	I2V	Low	J2735 GID (MAP) messages	Eco-approach to signalized intersections	
'Other Vehicle' Vehicle Status Data Collection Subsystem	Receive Vehicle Status Data From Other Vehicles (IVS-DC-07)	Vehicle locations, speeds, and trajectories	Other Vehicles	In-Vehicle System	V2V	Low	J2735 BSM	Adjust eco-driving recommendation to account for nearby vehicles	
Vehicle Diagnostics Data Collection Subsystem	Collect Vehicle Diagnostics Data (IVS-DC-08)	Engine, emissions, GPS data, on-board sensor data	OBD, External Sensors	In-Vehicle System	CAN Bus	Low	J1939	Supports data dissemination from the vehicle	Data transmission on-board the vehicle

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Eco-Driving Information Dissemination Subsystem	Provide Eco-Driving System Information to Driver (IVS-D-01)	Eco-driving recommendations	In-Vehicle System	Driver	HMI	Low	TBD	Provides information to drivers to implement eco-driving strategies or eco-driving feedback	Input and output should not impair the driver's ability to control the vehicle in a safe manner
Signal Priority Request Dissemination Subsystem	Send Traffic Signal Priority Request (IVS-D-02)	Signal priority request	Vehicles	Traffic signal controller	V2I	Medium		Provides signal priority request to traffic signal equipment	
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Data (IVS-D-03)	Vehicle location, motion, braking status, type, etc.	Vehicles	Other Vehicles and In-Vehicle System	V2V and V2I	Low	J2735 BSM	Provides vehicle status to other drivers and the Eco-driving application	
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Environmental Data (IVS-D-04)	Vehicle fuel type, engine type, emissions, etc.	Vehicles	In-Vehicle System	V2I	Medium-low	J2735 SE	Signal optimization or DLEZ charges or general background for Eco-signal operation	Low latency required If used for signal optimization or DLEZ charges

APPENDIX D. Relationship to the National ITS Architecture

Appendix D is intended to show the relationship of the Eco-Signal Operations Transformative Concept to the National ITS Architecture. It provides a Subsystem Interconnect Diagram (also referred to as a Sausage Diagram) and a sample Market Package Diagram for the Transformative Concept. This appendix will appeal to readers familiar with the National ITS Architecture. It should be noted that these diagrams do not conform entirely to the National ITS Architecture. They have been adapted slightly to increase the readability.

Figure D-0-1 shows the various actors and the interactions between them. This diagram has been adapted from the National ITS Architecture and categorizes actors into four categories: (1) centers, (2) travelers, (3) vehicles and (4) roadside. The pink rectangles in the diagram describe communications technologies and how these actors are connected. These communication technologies include:

- Wide area wireless communications
- Fixed point to fixed point communications
- V2V communications
- I2V and V2I communications

Actors and interconnects that are not relevant to the Transformative Concept have been ‘grayed out’.

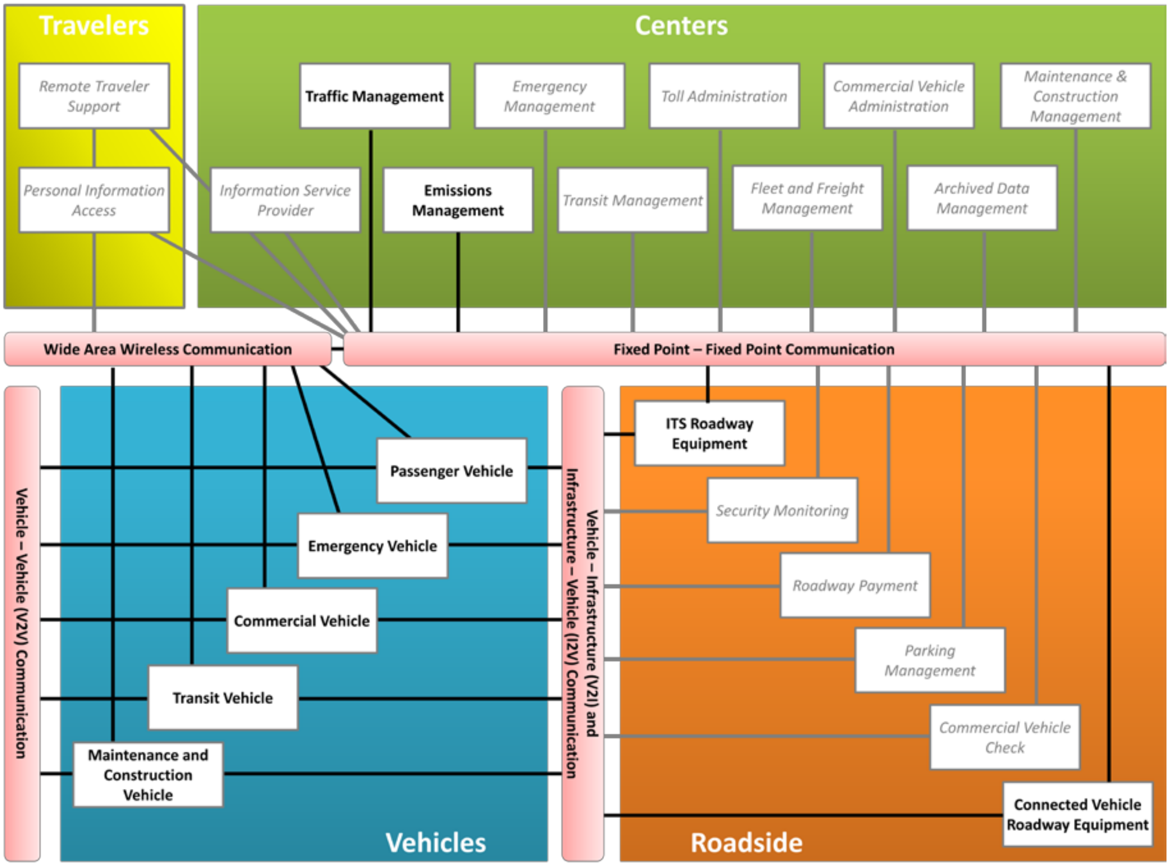

Figure D-1: Eco-Signal Operations Interconnect Diagram (*Source*: Adapted from the National ITS Architecture by Noblis, 2013)

That National ITS Architecture uses Market Packages diagrams to provide a graphical representation of the "flow" of information between subsystems. Figure D-0-2 includes a sample Market Package diagram for the Eco-Signal Operations Transformative Concept. It depicts what kinds of information will be input and output from each actor, where the data will come from and go to, and where the data will be stored. It does not show information about the timing of processes, or information about whether processes will operate in sequence or in parallel (which is shown on a flowchart). In summary, the information flow diagrams show:

- The actors and interactions between actors for the Transformative Concepts
- The type of information that needs to be exchanged between actors to enable environmental applications and AERIS Transformative Concepts

It should be noted that the names of the information flows in this diagram have been adapted from the National ITS Architecture to improve readability in this document.

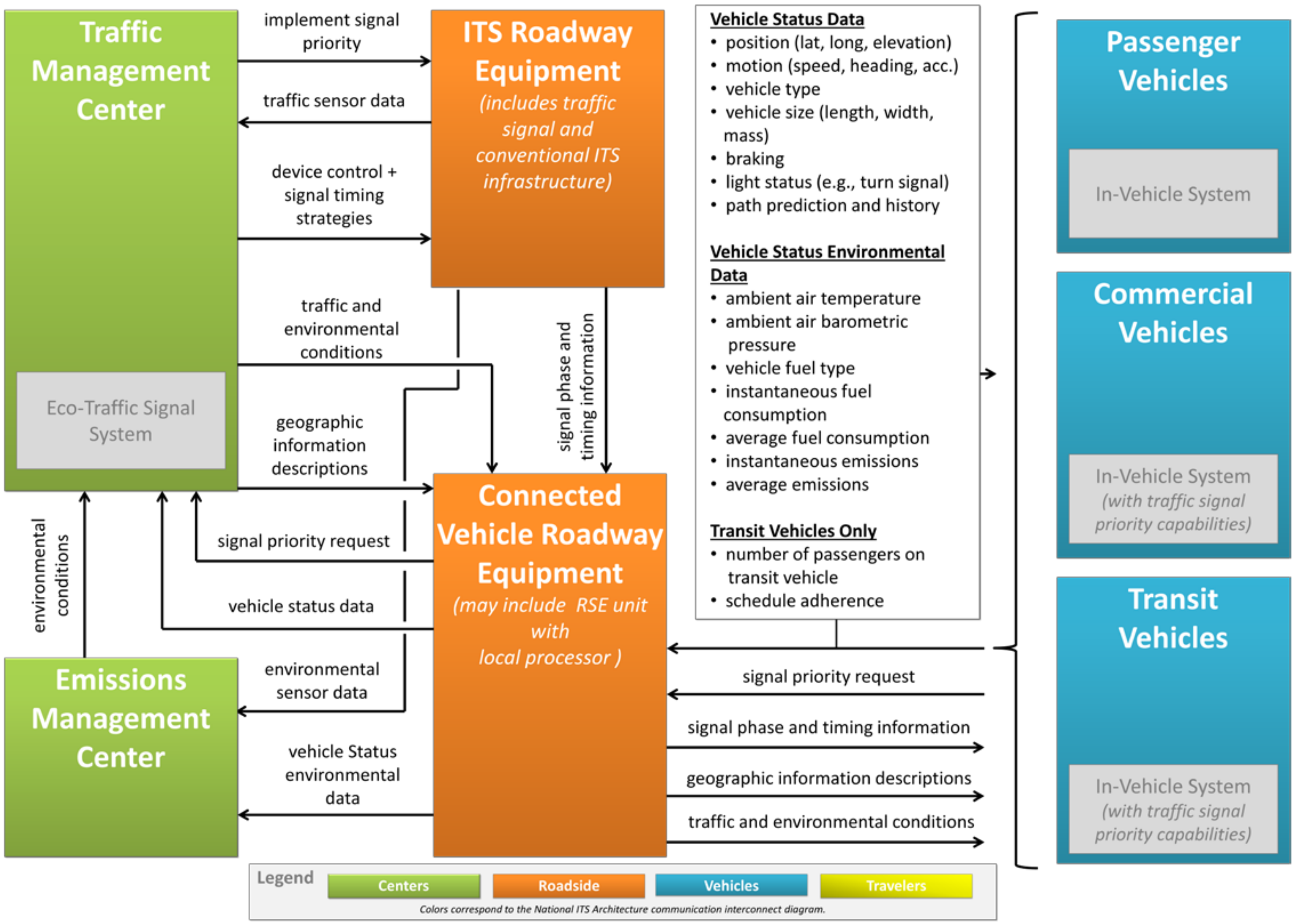

Figure D-2: Eco-Signal Operations Information Flow Diagram (*Source*: Noblis, 2013)

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