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

Eco-Lanes: Operational Concept

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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-Lanes Transformative Concept. The Eco-Lanes Transformative Concept features dedicated lanes on freeways optimized for the environment, referred to as eco-lanes. Eco-lanes are similar to high-occupancy vehicle (HOV) lanes, but are optimized for the environment leveraging connected vehicle technologies. Eco-lanes are targeted toward low-emission, high-occupancy, freight, transit, and alternative-fuel vehicles (AFVs). Once in the lanes, drivers would be able to opt in to take advantage of eco-friendly applications such as eco-cooperative adaptive cruise control (CACC), vehicle platooning, and connected eco-driving applications. This Transformative Concept includes seven applications: (i) Eco-Lanes Management, (ii) Eco-Speed Harmonization, (iii) Eco-Cooperative Adaptive Cruise Control, (iv) Eco-Ramp Metering, (v) Connected Eco-Driving, (vi) Multi-Modal Traveler Information, and (vii) Wireless Inductive Charging.

At the heart of this Transformative Concept is an administrative application that supports the management and operation of eco-lanes, including establishing parameters for entering the lanes and defining or geo-fencing the eco-lane boundaries. Eco-lanes parameters may include the types of vehicles allowed to use the lanes, emissions parameters for entering the eco-lanes, number of lanes dedicated as eco-lanes along a freeway, and the start and end of the eco-lanes. Applications may also be implemented to convey pre-trip and en-route traveler information about the eco-lanes to travelers. Information disseminated to travelers may include real-time traffic conditions in the eco-lanes, a comparison of travel times or fuel savings between adjacent regular lanes and the eco-lanes.

Eco-lanes are envisioned to use operational strategies implemented by the operating entity (e.g., Traffic Management Center) to reduce vehicle emissions in the lanes and along the freeway segment. Operational strategies include eco-speed harmonization and eco-ramp metering. Once in the eco-lanes, drivers will be provided with speeds limits optimized for the environment. These eco-speed limits will be implemented to help to reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing greenhouse gas (GHG) and other emissions. Eco-speed limits may differ from posted speed limits and will leverage variable speed limit capabilities to help smooth traffic as vehicles approach queues or bottlenecks ahead. Eco-Ramp Metering applications determine the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of vehicles entering the freeway.

Eco-Cooperative Adaptive Cruise Control applications allow individual drivers to opt-into applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions. This Transformative Concept also supports vehicle platooning. Vehicle platoons can decrease the distances between cars by wireless coupling vehicles together. Vehicle platoons allow for a closer headway between vehicles by eliminating reacting distance needed for human reaction.

Finally, this Transformative Concept supports wireless inductive charging for electric vehicles in the eco-lanes. Wireless inductive charging 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 is envisioned that this charging infrastructure would be deployed in the eco-lanes supporting the wireless charging of electric vehicles moving at highway speeds.

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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-Lanes 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-Lanes Transformative Concept will operate. This Transformative Concept includes seven applications:

- Eco-Lanes Management
- Eco-Speed Harmonization
- Eco-Cooperative Adaptive Cruise Control
- Eco-Ramp Metering
- Connected Eco-Driving
- Eco-Traveler Information Applications
- Wireless Inductive Charging

The Eco-Lanes Transformative Concept features dedicated lanes on freeways optimized for the environment, referred to as eco-lanes. Eco-lanes are similar to high-occupancy vehicle (HOV) lanes, but are optimized for the environment leveraging connected vehicle technologies. Eco-lanes are targeted toward low-emission, high-occupancy, freight, transit, and alternative-fuel vehicles (AFVs). Once in the lanes, drivers would be able to opt in to take advantage of eco-friendly applications such as eco-cooperative adaptive cruise control (CACC), vehicle platooning, and connected eco-driving applications.

At the heart of this Transformative Concept is an administrative application that supports the management and operation of eco-lanes, including establishing parameters for entering the lanes and defining or geo-fencing the eco-lane boundaries. Eco-lanes parameters may include the types of vehicles allowed to use the lanes, emissions parameters for entering the eco-lanes, number of lanes dedicated as eco-lanes along a freeway, and the start and end of the eco-lanes. Applications may also be implemented to convey pre-trip and en-route traveler information about the eco-lanes to travelers. Information disseminated to travelers may include real-time traffic conditions in the eco-lanes, a comparison of travel times or fuel savings between adjacent regular lanes and the eco-lanes.

Eco-lanes are envisioned to use operational strategies implemented by the operating entity (e.g., Traffic Management Center) to reduce vehicle emissions in the lanes and along the freeway segment. Operational strategies include Eco-Speed Harmonization and Eco-Ramp Metering. Once in the eco-lanes, drivers will be provided with speeds limits optimized for the environment. These eco-speed limits will be implemented to help to reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing greenhouse gas (GHG) and other emissions. Eco-speed limits may differ from posted speed limits and will leverage variable speed limit capabilities to help smooth traffic as vehicles approach queues or bottlenecks ahead. Eco-

Ramp Metering applications determine the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of vehicles entering the freeway.

Eco-Cooperative Adaptive Cruise Control (CACC) applications allow individual drivers to opt-in to applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions. These applications consider terrain, roadway geometry, and vehicle interactions to determine a driving speed for a given vehicle that uses the momentum of the vehicle, when suitable, to avoid unnecessary accelerations, and reduce emissions. With CACC applications, drivers have 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 wireless coupling vehicles together. Vehicle platoons allow for a closer headway between vehicles by eliminating reacting distance needed for human reaction.

Finally, this Transformative Concept supports wireless inductive charging for electric vehicles in the eco-lanes. Wireless inductive charging 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 is envisioned that this charging infrastructure would be deployed in the eco-lanes supporting the wireless charging of electric vehicles moving at highway speeds.

1.1 Goals

The Eco-Lanes 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 implementation of eco-lanes optimized for the environment. Eco-lanes allow entities operating the lanes to implement strategies focused on optimizing the transportation network for the environment including Eco-Speed Harmonization, Eco-Ramp Metering, and vehicle platooning.
- **Goal #2: Support "Green Transportation Decisions" by Travelers and Operating Entities.** This Transformative Concept is expected to encourage drivers to use alternative fuel vehicles and increase the awareness and practice of eco-driving strategies. Additionally, parameters for the eco-lanes may encourage transit vehicles, carpools, and vanpools to use the lanes providing improved operations for these vehicles. Bus Rapid Transit (BRT) may also be supported by these lanes. As a result, this Transformative Concept is expected to increase modal shifts to transit, carpooling, and vanpooling through the implementation of dynamic emissions pricing strategies.
- **Goal #3: Enhance Mobility on the Transportation System.** This Transformative Concept is expected to improve the efficiency of the transportation system by reducing the number of car trips, especially single-occupancy vehicles, on freeways. This reduction in vehicle trips is expected to result in lower traffic volumes, thus increasing mobility along the freeway.

Applications such as Eco-Speed Harmonization, Eco-Ramp Metering, and vehicle platooning are also expected to provide mobility benefits through improved operations of the transportation network.

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-Lanes 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?

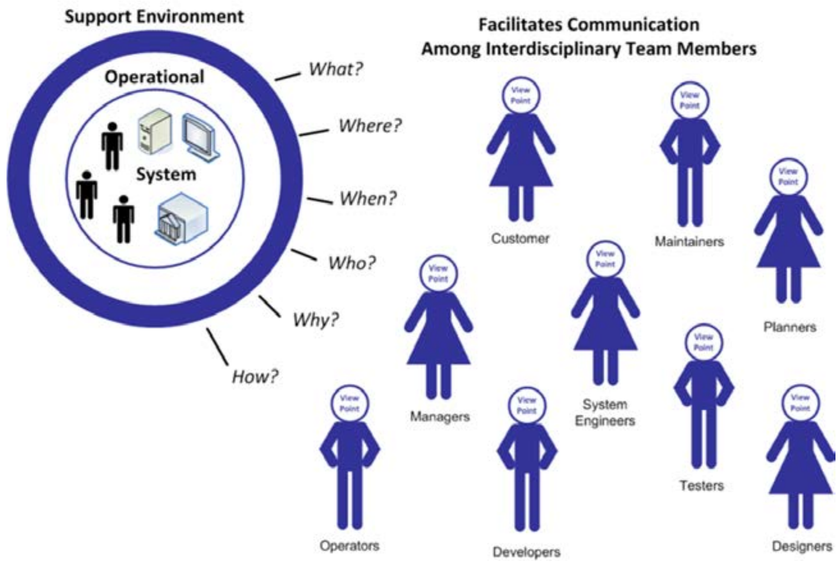


Figure 1-1: Conceptual Representation of the Operational Concept Document
(*Source: Noblis, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

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 applications similar to the applications included in the Eco-Lanes Transformative Concept. This section is meant to familiarize the reader with the current state of the practice regarding current applications 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-Lanes 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-Lanes 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-Lanes 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-Lanes 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-Lanes 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.

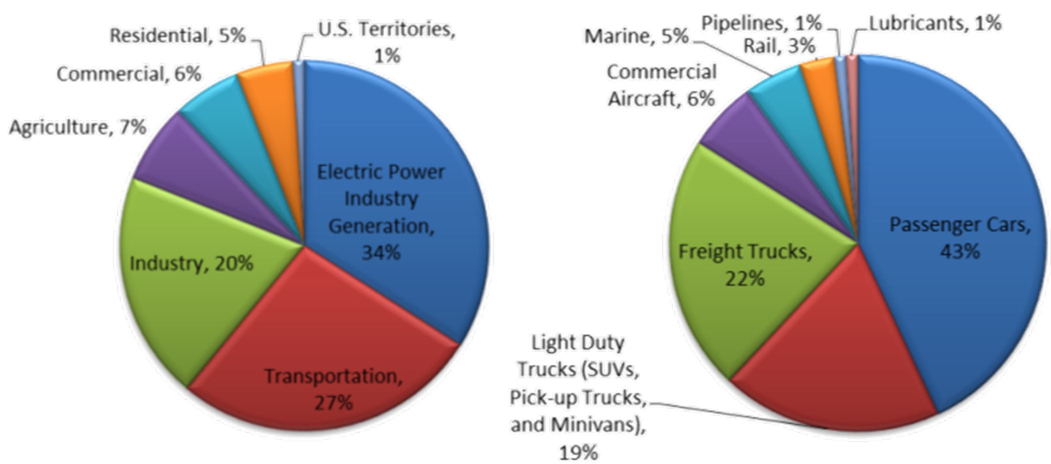


Figure 2-1: Transportation's Impact on the Environment *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012).*

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.

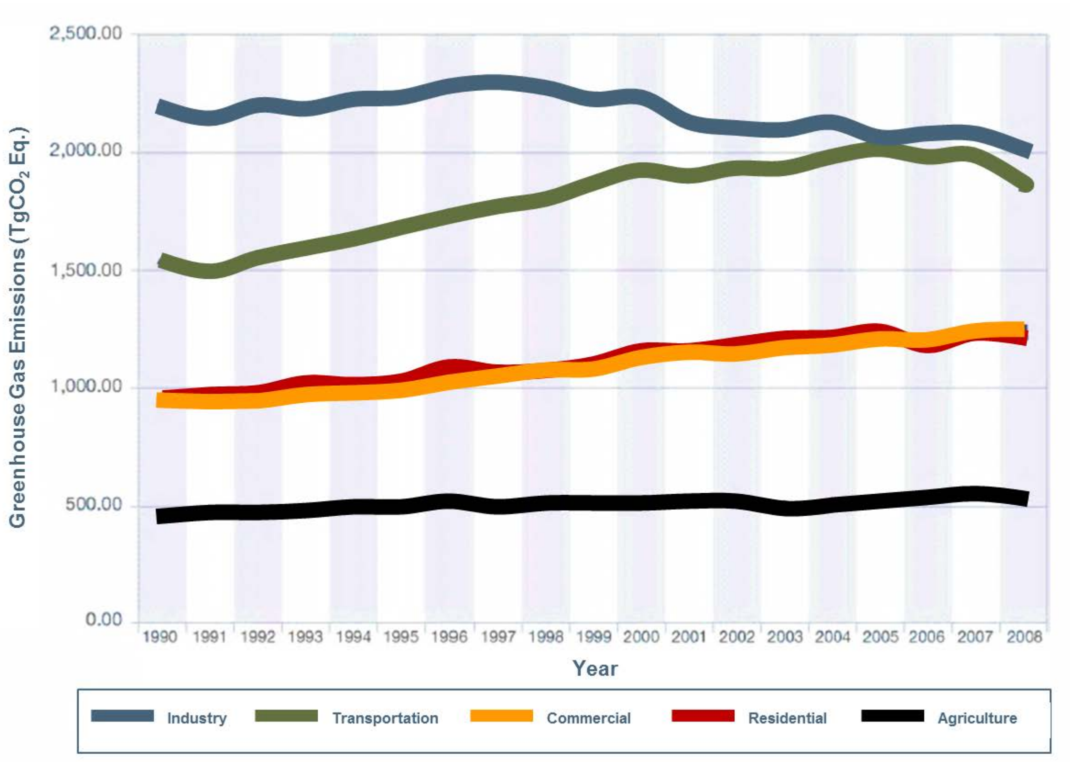


Figure 2-2: GHG Trends 1990 to 2008 *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012)*

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 *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.

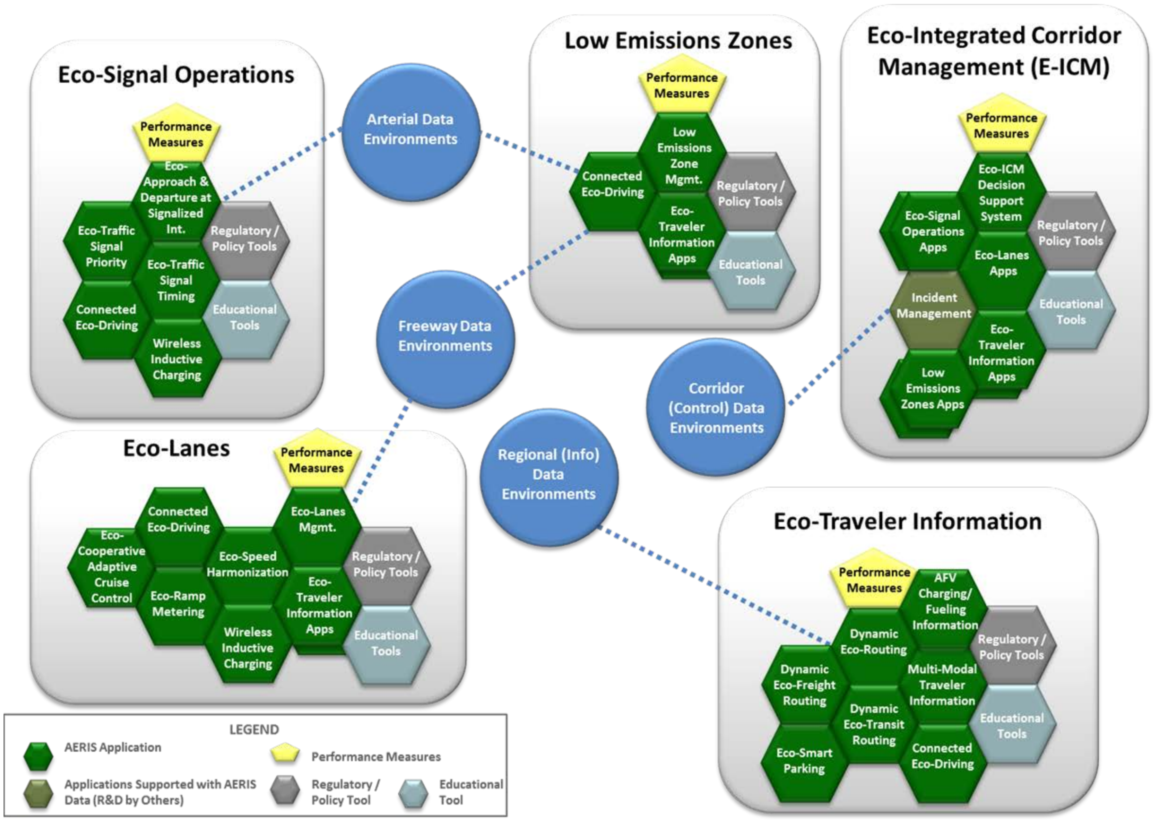


Figure 2-3: AERIS Transformative Concepts (*Source: Noblis, 2013)*

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

Before defining the Eco-Lanes Transformative Concept and its applications, it is important to understand existing ITS applications and the environmental benefits from these applications. This section describes existing ITS applications, similar to those included in the Eco-Lanes Transformative Concept. Many of these applications, however, do not use connected vehicle technologies and typically are not bundled together to achieve transformative change. Additionally, there has been some research in CACC and vehicle platooning applications, but those applications have not been deployed outside of the research community. Applications described in this section include:

- HOV Lanes
- High-Occupancy/Toll (HOT) Lanes and Express Toll Lanes (ETLs)
- Speed Management and Variable Speed Limits (VSL)
- Adaptive Cruise Control (ACC)
- Vehicle Platooning Research
- Ramp Metering

3.1 High-Occupancy Vehicle Lanes

HOV lanes are restricted traffic lanes, reserved at peak travel times or longer, for exclusive use of vehicles with a driver and one or more passengers, including carpools, vanpools and transit buses. The normal minimum occupancy level for HOV lanes is 2 or 3 occupants. These lanes are implemented to increase average vehicle occupancy and person throughput with the goal of reducing traffic congestion and air pollution. HOV lanes may be a single traffic lane within the main roadway with distinctive markings, or alternatively as a separate roadways with one of more traffic lanes either parallel to the general lanes or alternatively grade-separated, above or below, the general lanes. Many jurisdictions exempt other vehicles, including motorcycles, charter buses, emergency and law enforcement vehicles, and low emission and other green vehicles.

Because HOV lanes carry vehicles with a higher number of occupants, they move significantly more people during congested periods, even if the number of vehicles that use the HOV lane is lower than on the adjoining general purpose lanes. In general, carpoolers, vanpoolers, and bus patrons are the primary beneficiaries of HOV lanes by allowing them to move faster through congestion. HOV lanes provide the following benefits:

- **Efficiency.** HOV lanes increase freeway efficiency by moving more people in fewer vehicles than the non-HOV lanes.
- **Travel Time Reliability.** HOV lanes help express buses stick to their schedules. Carpools, vanpools, motorcycles, and emergency vehicles also receive a quicker trip.
- **Speed, Ease, and Money.** Users cite saving time and money, reduced stress, and convenience as the main reasons they use the HOV system.

- **Freeway Demand.** HOV lanes reduce competition for a limited amount of space on the freeway during rush hours.
- **Fewer Cars Area-Wide.** HOV lanes add fewer car trips to the transportation system than new general purpose lanes.
- **Greenhouse Gas Emissions.** By reducing the number of car trips, GHG emissions are reduced, resulting in less of a burden on the environment.
- **Sustainability.** HOV lanes play a crucial role in helping to support more sustainable transportation choices by providing an incentive to carpool, vanpool, or taking the bus.

3.2 High-Occupancy Toll and Express Toll Lanes

HOT lanes are an adaption of HOV lanes that use a road pricing scheme that gives motorists in single-occupant vehicles access to HOV lanes. In HOT lanes, tolls are collected either by manned toll booths, automatic license plate recognition (ALPR), or electronic toll collection (ETC) systems. Some systems use radio frequency identification (RFID) transmitters to monitor entry and exiting of the lane, and charge drivers depending on demand. Typically, these tolls increase as traffic density and congestion on the tolled lanes increase, a policy known as congestion pricing. The goal of this pricing scheme is to minimize traffic congestion on the lanes. ETLs are a similar concept. The main difference between HOT lanes and ETLs is that, in HOT lanes, HOVs are granted free access, whereas in ETLs all vehicles pay according to the same schedule.

The first practical implementation of HOT lanes was California's formerly private toll 91 Express Lanes, in Orange County in 1995. In these HOT lanes, solo drivers are allowed to use the HOV lanes upon payment of a fee that varied based on demand. The tolls changed throughout the day according to real-time traffic conditions, with the intent of managing the number of cars in the lanes to maintain good travel times in the HOT lanes. More recently, several states are undertaking projects to build new HOT lanes or convert existing HOV lanes into HOT lanes.

HOT lanes bring a wide variety of benefits to the driving public and transit users. When applied in conjunction with other management tools and the sensible, targeted provision of additional lane capacity, HOT lanes have the potential to afford significant improvements in congested travel corridors. The primary benefits of HOT lanes are that they provide the driving public with a new choice—premium and predictable travel conditions—on corridors where conditions would otherwise be congested. At the same time they maximize the use of managed lanes, including HOV lanes, without causing traffic service to fall below desired levels. These powerful dynamics also afford a wide range of related benefits, including:

- Superior, consistent, and dependable travel times, particularly during peak travel periods.
- Traffic service improvements on congested parallel general-purpose highway lanes by drawing vehicles off parallel local streets and improving corridor-wide mobility.
- Faster highway trips for transit vehicles that may encourage expanded express bus service.
- Environmental advantages by providing opportunities to encourage carpooling, improve transit service, and move more people in fewer vehicles at faster speeds.
- Increased efficiency of managed lane facilities, making HOT lanes attractive in regions that might not otherwise consider them, and eliminating potential pressure to convert underperforming HOV lanes to general-purpose use.

3.3 Speed Management and Variable Speed Limits

Speed management strategies focus on regulating vehicle speeds for mobility, safety, or environmental benefits. These strategies include reducing speed limits on freeways or more advanced strategies that change freeway speed limit based on real-time traffic conditions, and possibly energy consumption parameters, for smoother traffic flow. Variable speed limit (VSL) systems collect traffic data using traffic sensors and post speed limits on electronic speed limit signs that are used to harmonize traffic flow along the roadway. VSL systems account for real-time traffic conditions, weather conditions, time of day, traffic incidents, and lane closures. By adjusting vehicle speed, VSL systems can reduce congestion, provide more reliable journey times, reduce the frequency of accidents, reduce carbon emissions, and reduce driver stress.

The Center for Transportation Research at the University of Texas at Austin, investigated the environmental benefits of a VSL strategy. A Monte Carlo simulation method, which uses random numbers and probability statistics to investigate problems, was developed to evaluate the effectiveness of VSL. It was found that by reducing the speed limit from 65 mph to 55 mph on “ozone action” days, the average daily total NO_X emissions in a 24-hour period could be reduced by approximately 17 percent on the selected freeway segment. The study noted that for optimal results “the flow and speed patterns of the selected roadway should be carefully investigated.”[4]

Two European studies also investigated whether reducing speed limits reduces emissions levels. A study in Switzerland investigated the impacts on emissions when the maximum speed limit was changed from 120 kilometers per hour (kph) or 75 mph to 80 kph or 50 mph. The research found that if the speed limit was reduced, NO_X would be lowered by approximately four percent, but the peak ozone levels would remain relatively unchanged (less than one percent decrease). Volatile organic compounds (VOCs) were also not significantly affected. A second study in the Netherlands was conducted to examine whether a current speed limit reduction project that has demonstrated a decrease in nitrogen dioxide (NO_2) emissions could find additional emissions reductions if the speed limit was further reduced. The initial Overschie, Netherlands project reduced the speed limit from 120 kph (75 mph) to 100 kph (62 mph). The study investigated whether further reducing the speed limit to 80 kph (50 mph) would provide an additional reduction in NO_2 emissions during the study year (2002) and in 2010 and 2015. Using models, the study showed that an improvement in NO_2 emissions is possible, and that maximum benefits are found around the large cities of Amsterdam, Rotterdam, and Utrecht. NO_2 reductions averaged five percent.[5]

Graz, the second largest city in Austria, was the first European city to implement a reduction in speed limits from 50 kph (31 mph) to 30 kph (19 mph) for the entire city area.[6] During the initial two-year trial, NO_X emissions were reduced by 25 percent.[7] Graz is also a part of the CIVITAS Initiative (CIty-VITAlity-Sustainability). The main goals of the CIVITAS initiative are to:

- Promote and implement sustainable, clean and energy efficient urban transportation measures;
- Implement integrated technology and policy measures in the field of energy and transportation; and
- Build a critical mass and markets for innovation.

Through the CIVITAS initiative, Graz expanded the number of streets that are part of the 30 kph (19 mph) speed limit network. The city also implemented speed control devices to “inform drivers how fast they go without taking legal action against them in case they are too fast. It has proven a valuable and fairly simple outreach and speed reduction tool.” These additional CIVITAS initiatives have led to a reduction of 268 tons of CO_2 emissions per year, 1 ton of NO_x emissions per year, and 1.78 million kilowatt hours (kWh) of energy have been saved per year.[8]

For a speed harmonization system to manage traffic flow effectively, it must be able to achieve sufficiently high rates of speed limit compliance within the target zones. Review of the literature revealed many different approaches (including mandatory limits, advisory limits, strong enforcement, weak enforcement, and caps on the magnitude of speed limit changes) and decidedly mixed results. The following are some summary findings from studies that examined VSL implementation speed compliance:

- Analysis of the Netherlands’ A2 mandatory and automated enforced VSL showed high compliance, which was attributed to high public awareness of the automated enforcement.[9]
- Analysis of the United Kingdom’s M25 mandatory and photo radar enforced VSL showed high compliance, as well as high satisfaction rates among drivers and police.[10]
- Analysis of Finland’s E18 advisory weather-related VSL showed a 76 percent compliance rate, as well as a 95 percent satisfaction rating from drivers.[11]
- Analysis of Sweden’s speed harmonization pilot program, which utilized both advisory and mandatory signage, showed high compliance, especially during severe weather conditions.
- Analysis of Colorado’s I-70 pilot rolling speed harmonization program (mandatory and enforced) showed high compliance, attributed to the fact that a police vehicle with flashing lights managed the speed harmonization directly within the traffic stream.

3.4 Adaptive Cruise Control

ACC works like conventional cruise control, allowing the driver of a vehicle to set the desired speed, but it also automatically adjusts the vehicle speed to match the preceding vehicle to maintain a predefined following distance. ACC systems are typically radar-based systems installed in vehicles that can monitor the vehicle in front and adjust the speed of the vehicle to keep it at a preset distance behind the lead vehicle, even in most fog and rain conditions. These systems can determine how fast the vehicle is approaching the vehicle ahead. For example, when approaching a lead vehicle at a high rate of speed, the system will activate sooner than when approaching slower.

ACC is not a new concept. In fact, several vehicle manufacturers offer ACC systems in their vehicles today. A brief summary of ACC systems is provided below:

- In 1995, Mitsubishi was the first original equipment manufacturer (OEM) to offer a laser-based ACC system on the Japanese Diamante. The system used laser radar sensors installed on the front bumper to detect preceding vehicles in the lane allowing the system to “control the engine power and gear to follow behind the vehicle in front at a safe distance. The driver is alerted with sounds and lights if the two cars came too close. The vehicle returns to its initially set velocity when the forward vehicle moves out of the lane or increases its speed.”[12]
- Toyota offered its first "radar cruise control" system in 1997 on the Celsior, and in later years added brake control and a low speed tracking mode, which detects a stopped vehicle ahead.[13] Toyota’s "all-speed tracking function" system “monitors the preceding vehicle, maintaining the same distance behind it according to the other vehicle's speed, over a wide

range of speeds up to 100 kph [about 62 mph]." The system also ensures the driver maintains a safe distance when the preceding vehicle comes to a stop, which can lessen "driver burden when the vehicle is in a stop-and-go situation during traffic congestion."[14]

- Mercedes first introduced Distronic in 1998, and today offers Distronic Plus with Pre-Safe as an option. Distronic Plus is a radar-based cruise control that "monitors the vehicle ahead and adjusts speed to help maintain a chosen following distance." The system is able to slow down or stop the vehicle if traffic slows down or stops and then automatically accelerates when traffic does. The Pre-Safe Brake system "automatically engages up to 40% of available braking power and primes the brakes to deliver full power the moment you step on the brake pedal. If the brakes are not applied within 0.6 seconds of a calculated impact, Pre-Safe Brake will automatically engage them at 100% power. As an added safety precaution, a Proximity Warning System issues an audiovisual warning if the calculated closing speed indicates that insufficient braking power has been applied by the driver."[15]
- In 2005, Acura introduced ACC integrated with a Collision Mitigation Braking System (CMBS) as an option.[16] Today, the system is available on the Acura MDX and ZDX. The ACC system allows the driver to set a desired speed and time intervals (short, medium, and long) from the preceding vehicle car and provides cruise control even in light traffic conditions. ACC "will maintain the set distance, modulating the throttle, and applying moderate braking if necessary."[17] The CMBS uses a radar transmitter mounted in the front bumper to evaluate the distance and closing speed of the preceding vehicle. CMBS phases in a series of alerts and braking actions depending on a driver's reaction when the system detects a collision may occur. "When the system senses that a frontal collision is unavoidable, and even if no prior alerts have been given, the front seat belts tighten, and strong braking is automatically applied to help reduce the impact velocity and collision force."[18]
- BMW's Active Cruise Control with Stop & Go function is available on the 5 Series Sedan. The Active Cruise Control "automatically reduces your speed if a slower vehicle appears in the lane ahead and then accelerates back to cruise speed when the lane is free." The Stop & Go system "will brake to a standstill if required, then sets off again when the traffic ahead moves. If the standstill is longer than three seconds, a touch on the accelerator is needed to set the 5 Series off again."[19]
- Today, ACC is an available option on several vehicles.

ACC pilot projects have captured the environmental benefits of the application. Examples are summarized below:

- In Rotterdam, The Netherlands research indicated that ACC reduced CO_2 and NO_X by three percent.[20]
- In Southeast Michigan, ACC tests with 108 non-professional drivers reduced fuel consumption by 10 percent compared to manual driving.[21]
- In California, an ACC simulation between Palo Alto and San Jose reduced fuel consumption by five to seven percent.[22]

Additionally, the University of Southern California (USC) and Real-Time Innovations, Inc. conducted a research initiative in 2001 entitled *Evaluation of the Environmental Effects of Intelligent Cruise Control (ICC) Vehicles*. The research yielded promising results. Field tests were conducted using one ACC-enabled vehicle and two other manually operated vehicles in a single lane of freeway traffic. During the field trials, driver responses and vehicle dynamics were recorded as they followed a lead vehicle with a pre-programmed speed profile (aggressive-rapid-acceleration or smooth-acceleration). The ACC-enabled vehicle trailed the other vehicles at different positions and implemented a smoothing effect to decrease the variance between the acceleration and deceleration extremes exhibited by the manually operated vehicles. Information from each field test was then input into a simulation model to measure net changes in fuel consumption and emissions.[23] The Comprehensive Modal Emissions Model (CMEM) developed by the University of California – Riverside (UCR) was used to analyze and calculate pollution and fuel consumption estimates. The CMEM quantified tailpipe emissions based on second-by-second velocity, acceleration, and grade changes for each individual vehicle. Emissions measured included unburned HC, CO, CO_2, and NO_x. Results show that the smoothing of traffic flow by the ACC-enabled vehicle significantly reduced emissions and fuel consumption compared to manual traffic. Field studies demonstrated reductions of CO up to 19.2 percent, CO_2 up to 3.4 percent, and NO_x up to 25.7 percent.[24]

3.5 Vehicle Platooning

Grouping vehicles into platoons is a method of increasing the capacity of roads. Platoons decrease the distances between cars using wireless coupling. This capability would allow many cars to accelerate or brake simultaneously. A synchronized platoon would move as one, allowing for increased traffic throughput if spacing between vehicles is diminished. Vehicle platooning allows for a closer headway between vehicles by eliminating reacting distance needed for human reaction.

In 1997, the University of California’s Partners for Advanced Transportation TecHnology (PATH) program prototyped an automated highway system – or highway system with vehicle platooning. The project placed sensory technology in cars that can read passive road markings, and use radar and inter-car communications to make the cars organize themselves without the intervention of drivers. One area that PATH focused on during this initiative was platooning of trucks. This research placed an emphasis on platooning technologies rather than automated steering due to the significant energy savings that result from platooning.[25] According to research, platooning may yield a 10 to 20 percent fuel consumption savings.[26]

According to a PATH research report (2005), the necessary supporting attributes for developing automated truck platooning include those involving infrastructure, vehicles, wireless communications, and fault management systems. Truck automation coupled with platooning can decrease fuel usage and emissions and increase lane capacity.[27] Moreover, increased fuel economy and decreased operating costs will also favorably impact consumers.[28] In order to integrate automated technology into the freeway systems, however, creating designated truck lanes is essential because studies shows that automated truck driving should not be used when the truck is following a passenger vehicle. Researchers believe that both automated driving technologies and designated truck lanes are necessary and that implementing one will bring about the other. One legal complication with employing this system is that in some instances minimum distance requirements exist for spacing between trucks. In order to achieve fuel-reduction benefits, laws governing these regulations may have to change.[29]

When platooning two or more trucks behind the lead vehicle, benefits include increased fuel savings and increased roadway capacity. PATH found that platooning reduces aerodynamic drag, resulting in fuel and carbon emissions savings between 10 and 20 percent for trucks cruising at highway speeds. PATH has “demonstrated the drag savings in scale-model wind-tunnel tests of four trucks and full-scale track tests of two trucks.” With increased benefits comes increased complications and risk. For example, future systems must support lane changing and trucks attaching and detaching themselves to and from the platoon.[30]

More recently, the Safe Road Trains for the Environment (SARTRE) project, funded by the European Commission (EC) developed strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits. The overall concept for testing consisted of a lead vehicle driven normally by a trained professional driver with following vehicles having automated driving capabilities. In the demonstration, vehicle actuators built on existing technologies including ACC and Electric Power Assisted Steering (EPAS). V2V communications were also used allowing vehicles to travel at small headways and enabling coordinated control of road train vehicles with minimal delays. Fuel consumption results from the demonstrations indicated up to a 16 percent reduction for the following vehicles and up to an 8 percent reduction for the lead vehicle.

3.6 Ramp Metering

Ramp metering is the “use of a traffic signal(s) deployed on a freeway ramp to control the rate at which vehicles enter a freeway facility.” By controlling the rate at which vehicles are allowed to enter a freeway, the flow of traffic onto the freeway facility becomes more consistent, smoothing the flow of traffic on the mainline and allowing more efficient use of existing freeway capacity. Current ramp metering systems consist of traffic sensors, traffic signal controllers, and signal heads located at the end of the entrance ramp. Traffic sensors (generally inductive loops) are installed in the road, both on the ramp and on the main road which measure and calculate the traffic flow, speed and occupancy levels. These are then used to alter the number of vehicles that can leave the ramp. The more congested the mainline is, the fewer vehicles are allowed to leave the ramp. This is done by giving longer red times to the traffic signals at the ramp. Much research is currently being carried out into the most appropriate algorithms for controlling ramp meter signals. Some algorithms that are in use or have been evaluated are ALINEA, demand control and fuzzy algorithms.

Ramp metering can be an effective tool to address congestion and safety concerns that occur at a specific point or along a stretch of freeway. It can also improve overall system performance by increasing average freeway throughput and travel speed, and decreasing travel delay. An additional benefit of ramp metering is that it can lead to a reduction in fuel consumption and vehicle emissions.[31]

During 2002 and 2003, the Minneapolis-St. Paul DOT compared the use of a stratified metering strategy to the situation with no controls in place. Stratified metering maximizes freeway throughput but with an additional constraint to limit the waiting time on the ramps to a predetermined maximum. On a typical day, environmental benefits were apparent, with a decrease in fuel consumption by more than three percent to six percent, and emissions reductions of three to eight percent. Different results were found on high demand days. Fuel consumption increased 13 percent and emissions increased by 2 to 3 percent. The negative impacts of stratified metering on high demand days are due to the increase of queued vehicles idling at the ramp meters, which increases fuel consumption and emissions.[32]

Another study conducted by the Minnesota DOT in 2001 evaluated the “impacts of shutting down an extensive ramp metering system on Minneapolis-St. Paul area freeways for a 6-week evaluation period.” Four corridors that represent typical freeway configurations and conditions in the region were selected. Results showed:

- Without ramp metering, there was a net annual increase in emissions
- Ramp metering decreases freeway travel times by 22 percent

- Without ramp metering, there is a seven percent reduction in freeway speeds
- Without ramp metering, there is a decrease in fuel consumption of 5.5 million gallons; this is the “only category where ramp metering had a negative impact.” This result occurred because the reduction in freeway speed in the meters-off condition actually created fuel savings.[33]

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.

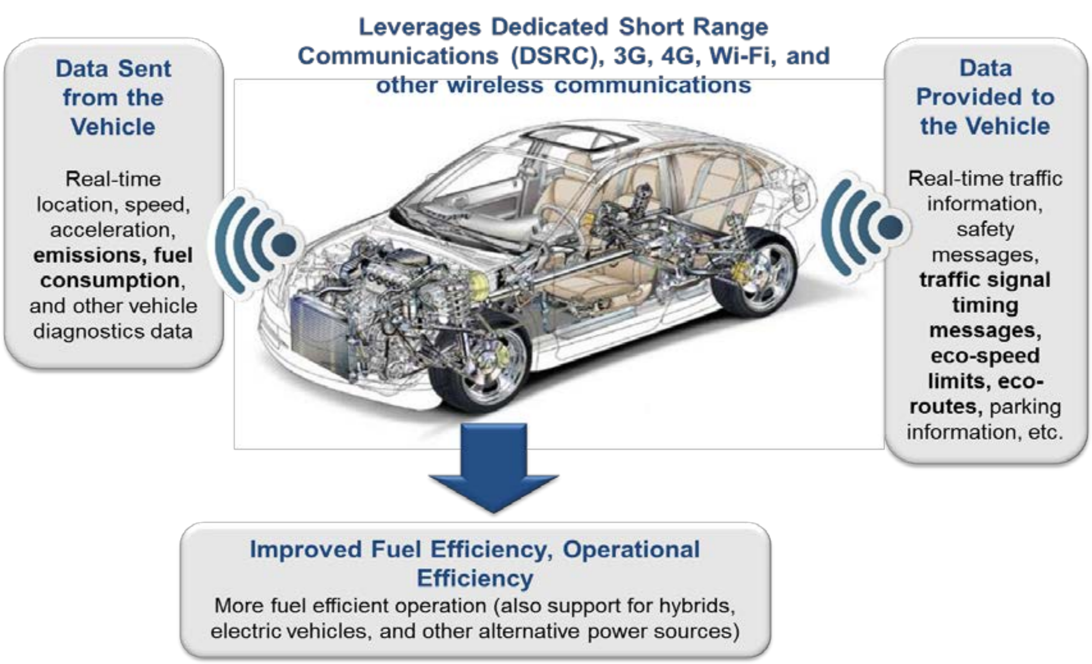


Figure 4-1: A Connected Vehicle (*Source*: *Noblis, 2013*)

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 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 HOV and HOT lanes are not optimized for the environment.** HOV and HOT lanes increase freeway efficiency by moving more people in fewer vehicles than the non-HOV lanes. As a result, these lanes help reduce single car trips to the transportation system. By reducing the number of car trips, GHG emissions are reduced, resulting in less of a burden on the environment. HOV and HOT lanes also play a crucial role in helping to support more sustainable transportation choices by providing an incentive to carpool, vanpool, or take the bus. While there are places in the United States that permit AFVs to use the lanes, operation of the current lanes are generally not optimized for the environment. Leveraging connected vehicle technology, the operation of these lanes can be improved to provide additional environmental benefits through eco-speed limits, vehicle platoons, and other operational strategies.
2. **Current HOV and HOT lane systems are limited geographically by roadside infrastructure.** Current systems boundaries are limited by the location of roadside infrastructure, especially HOT lanes which often require toll plazas or CCTV cameras

equipped with ALPR capabilities. As a result, the geographic limits of current lanes are static. Connected vehicle technologies allow for the geographic boundaries of an eco-lane to be responsive to traffic and environmental conditions (i.e., capable of expanding or contracting) through the use of geo-fencing capabilities. Leveraging the capabilities of connected vehicle technologies, Eco-Lanes Systems can geo-fence the boundaries of the lanes and provide information about the boundaries of the lanes and other parameters of the lanes directly to vehicles using wireless communications. This capability would allow the entity operating the lanes to be more responsive to real-time traffic conditions during incidents, special events, and code red air quality days. Operating entities would be able to change the location of the lanes, as well as increase or reduce the number of lanes assigned as dedicated eco-lanes, as needed. At its maturity, it is expected that vehicles would be able to receive data through wireless communications along the vast majority of the nation's transportation network, especially if vehicles are capable of receiving data through cellular communications. With these capabilities, eco-lanes would rely less on roadside infrastructure and could account for special events taking place within a metropolitan area.

3. **Current systems do not consider real-time traffic and environment data when establishing parameters for the HOV and HOT lanes.** Current systems do not consider real-time traffic and environmental conditions in determining the geographic limits or vehicles permitted to use the dedicated lanes. Instead these parameters are pre-determined thus limiting the responsive ability for these lanes. Collecting traffic and environmental data directly from vehicles allow the operating entity to collect better data about the transportation network. These data can be used by the operating entity to monitor the performance of the system in real-time. Using these data, the operating entity may decide to change the parameters of the eco-lanes to optimize performance of the system. For example, during a code red air quality day, real-time traffic and environmental data may be used to determine the number of lanes that should be dedicated as eco-lanes. Then once these lanes are dedicated as eco-lanes, their performance would be monitored to ensure that environmental performance metrics are met while minimizing mobility tradeoffs.

4. **Current VSL and ramp metering systems are limited by the data collected from infrastructure-based sensors.** Current VSL and ramp metering systems rely on infrastructure-based detection positioned along the roadway. Infrastructure-based detection provides information about the presence of a vehicle at the interchange or ramp, 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. Connected vehicle technologies enable data to be collected from vehicles along the entire freeway segment 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 VSL and ramp metering systems to be more robust and consider prevailing traffic conditions.

5. **Current VSL and ramp metering systems do not collect and use (or collect and use minimal) environmental data.** Current VSL and ramp metering systems do not collect (or collect minimal) environmental data. While environmental sensor stations allow these data to be collected, these sensors are not typically deployed as part of a VSL or ramp metering system. Connected vehicle technologies allow for environmental data (e.g., vehicle emissions data, average fuel consumption, and weather data) to be collected from vehicles, sent wirelessly to infrastructure, and used by the software to optimize the

operation of the roadway reducing emissions and fuel consumption at the freeway or ramp. Additionally, many of these systems also produce limited performance measures pertaining to the environment.

6. **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 entities to optimize the environmental performance of the transportation network.
7. **Current VSL and ramp metering systems are optimized for mobility, not the environment.** The objective of current VSL systems is focused on speed harmonization to adjust and coordinate appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions to maximize traffic throughput and reduce crashes. Environmental benefits are often a secondary benefit of these systems. Likewise, current ramp metering systems are often deployed for mobility purposes. Generally, algorithms used to optimize speed limits and ramp meters attempt to reduce delays (user time), travel times, or stops. Reduction in emissions is another measure of effectiveness (MOE) that some software systems use to optimize ramp meters, but emissions generally are secondary MOEs to mobility measures. Environmental benefits are usually presented as benefits of these systems after the fact instead of serving as the measure that the algorithm uses to optimize ramp meters. Since many 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 systems for optimization.
8. **Current VSL Systems, especially in the United States, have low levels of speed compliance.** Current practice of VSL shows limited levels of speed compliance, attributable to differing methods of deployment, speed recommendation selection, and speed limit enforcement. A connected vehicle-enabled speed harmonization system would be able to positively affect compliance by communicating speed recommendations directly to drivers using in-vehicle systems and could expand enforcement capabilities by collecting data directly from vehicles using V2I communications. However, it is important to keep in mind that automated enforcement presents many challenges, particularly in the U.S., relating to data privacy concerns, data ownership, legal authority questions, and user acceptance. Such issues must be well addressed prior to instituting any form of automated enforcement. Better compliance can be accomplished through educating drivers about the rationale and logic of the interventions, and most importantly reinforcing positive experiences with the system. Furthermore, experience shows that only limited compliance could accomplish the desired environmental objectives.
9. **ACC systems have a delay in sensing changes in the lead vehicle's motion, requiring longer minimum gaps between vehicles than CACC systems.** Current ACC systems function with information they sense about the lead vehicle using radar sensors, and need to sense a change in the lead vehicle's motion important enough to trigger a slowing down. Because of this delay in sensing a change in the vehicle following situation, there is a threshold for the minimum gap than can be technically achieved. This delay in communications can actually result in an accordion effect as vehicles are

constantly braking and accelerating to adapt to the lead vehicle. The result may be vehicles using more fuel. Leveraging V2V communications allows for data to be transmitted between vehicles at a rate of 10 times per second. CACC systems benefit from the communication of information regarding the speed and brake actuation of the lead vehicle, which allow them to have faster responses, and therefore allow a considerable reduction in the size of the gap that can be safely controlled by the system.

10. **In-Vehicle Systems do not provide travelers with parameters about HOV, HOT, and/or eco-lanes or alternative travel choices for entering the eco-lanes.** Conventional ITS devices such as DMS can be an effective means of information dissemination to the drivers; however messages on these devices are limited by the physical space of the message sign to three lines of text and often lack specific details. To achieve the benefits of an eco-lane, drivers must have highly accurate and detailed information on the parameters of the eco-lane including the fee structure, traffic conditions, environmental conditions, and multi-modal options. Connected vehicle-enabled communication is well suited to provide and disseminate this type of information directly to the driver. By providing this information directly to drivers, they will be more aware of real-time traffic and environmental conditions which would allow them to make better pre-trip and en-route decisions including the possibility of starting their trip later or switching their mode of travel.
11. **Electric vehicles are not capable of charging their batteries as they drive along the roadway.** Existing roadways do not include infrastructure or the capabilities to charge electric vehicle batteries while the vehicle is driving along the roadway. 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 along a roadway allowing electric vehicles to receive energy as the vehicle passes over the inductive charging pads. This transfer of energy would result in the electric vehicle's battery dynamically being 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 proposed Eco-Lanes Systems that addresses the limitations of current systems leveraging connected vehicle technologies.

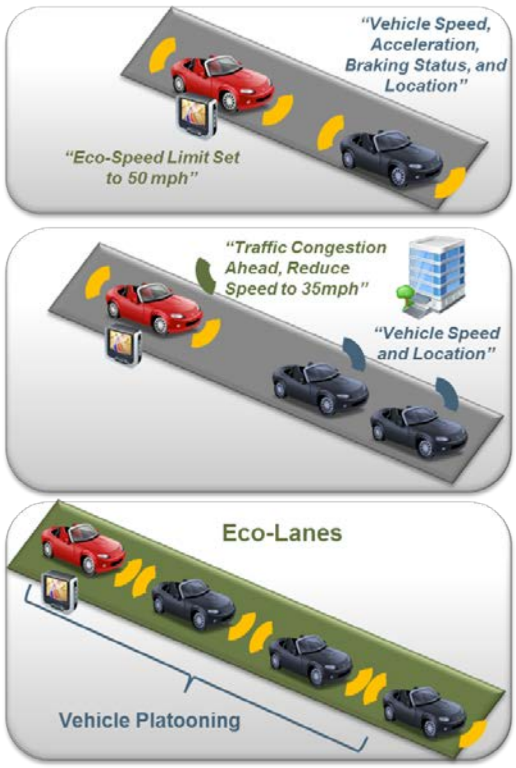
5 Eco-Lanes Transformative Concept

5.1 Eco-Lanes Transformative Concept Overview

The AERIS Program seeks to expand on the concept of applications described in Section 3. The Eco-Lanes Transformative Concept includes dedicated lanes optimized for the environment, referred to as Eco-Lanes. Eco-Lanes are similar to HOV and HOT lanes; however these lanes are optimized for the environment using connected vehicle data and can be responsive to real-time traffic and environmental conditions. Eco-Lanes allow an operating entity to change the location of the eco-lanes, the duration of the eco-lanes, the number of lanes dedicated as eco-lanes, the rules for vehicles entering the eco-lanes, and other parameters. These lanes would be targeted towards low emission, high occupancy, freight, transit, and alternative fuel vehicles. Drivers would be able to opt-in to these dedicated eco-lanes to take advantage of eco-friendly applications such as eco-cooperative adaptive cruise control, connected eco-driving, and wireless inductive charging applications.

At the heart of this Transformative Concept is an administrative application that supports the operation of eco-lanes, including establishing parameters for entering the lanes and defining or geo-fencing the Eco-Lanes boundaries. Eco-Lanes would use operational strategies implemented by the operating entity (e.g., Traffic Management Center) to reduce vehicle emissions in the lanes. These operational strategies include eco-speed harmonization and eco-ramp metering or dynamic merging. Once in the eco-lanes, drivers would be provided with speeds limits optimized for the environment. These eco-speed limits would be implemented to help reduce unnecessary vehicle stops and starts by maintaining consistent speeds, thus reducing GHG and other emissions. Eco-Ramp Metering applications determine the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of vehicles entering the freeway.

A major component of the Eco-Lanes Transformative Concept is the ability for drivers to utilize CACC applications. Eco-Cooperative Adaptive Cruise Control applications allow individual drivers to opt-in to applications that provide cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions. Figure 5-1depicts three levels of CACC. In the first level, drivers with CACC have 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 road grad as well as 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.



Cooperative Adaptive Cruise Control (CACC)

- Drivers have the convenience of setting their desired speed and having the vehicle safely maintain the speed.
- The CACC systems recognize the presence of a slower vehicle ahead and road grade and then automatically adjusts the speed to follow the other vehicle safely.

CACC and Eco-Speed Harmonization

- CACC systems may accept target speeds established by the traffic management centers (TMCs) that can optimize traffic performance for the environment.
- By having all CACC vehicles maintain the same speed that allows the best traffic/environmental performance, "speed harmonization" is achieved as the traffic stream moves smoothly and efficiently.

CACC and Eco-Lanes

- Eco-Lanes are specially managed targeted at optimizing performance for the environment.
- TMCs can set target speeds and recommend closer following (shorter gaps) between CACC vehicles for which drivers can agree to accept ("opt-in").
- Shorter gaps, combined with speed harmonization can help minimize congestion and reduce emissions.

Figure 5-1: Varying Levels of CACC (*Source*: Noblis, 2013)

For roadways that are monitored by traffic management centers and that support communication with vehicles, the CACC system can accept target speeds established by the traffic management centers that can optimize traffic performance. By having all CACC vehicles maintain the same speed that allows the best traffic performance, "speed harmonization" is achieved as the traffic stream moves smoothly and efficiently. This smoothness is more comfortable to the driver as speed changes normally experienced on congested roadways are avoided entirely or reduced. The CACC vehicles react more quickly and smoothly to any speed fluctuations, which improves traffic performance and improves the quality of the driving experience. In addition, the improved smoothness of traffic allows the roadway itself to operate at a higher level, and so congestion can often be avoided or reduced, and safety enhanced as there are fewer perturbations in traffic that can cause crashes.

For freeways that offer special managed lane operations that are monitored by traffic management centers and can support communication with vehicles, CACC vehicles that are allowed to use the managed lanes can be assured of even higher performance and driving quality. The traffic management center can set target speeds, as noted above, but can also recommend closer following (shorter gaps) between CACC vehicles for which drivers can agree to accept ("opt in"). Recent experiments found that drivers are comfortable with and generally prefer the shorter gaps between vehicles that are allowed by CACC. These shorter gaps, combined with the speed harmonization possible in managed lanes, can enable up to twice the number of CACC vehicles to efficiently use the roadways compared to today. This additional roadway capacity can be used to minimize congestion and to serve more drivers at a higher level of reliability, comfort, convenience, and safety that is possible through CACC.

Applications associated with the Eco-Lanes Transformative Concept are briefly described below.

- **Eco-Lanes Management.** The Eco-Lanes Management application establishes parameters and defines or geo-fences the eco-lanes boundaries. Eco-lanes parameters may include the types of vehicles allowed in the eco-lanes, emissions parameters for entering the eco-lanes, the number of lanes, and the start and end of the eco-lanes. The application also conveys pre-trip and en route traveler information about eco-lanes to travelers, including information about parameters for vehicles to enter the eco-lanes, current and predicted traffic conditions in the eco-lanes, and geographic boundaries of the eco-lanes.
- **Eco-Speed Harmonization.** The Eco-Speed Harmonization application determines eco-speed limits based on traffic conditions, weather information, and GHG and criteria pollutant information. The purpose of speed harmonization is to change speed limits on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds, thus reducing fuel consumption, GHG emissions, and other emissions on the roadway. Eco-speed limits can be broadcast by roadside equipment (RSE) units and received by on-board equipment (OBE) units or displayed on VSL signs located along the roadway. This application is similar to current VSL applications, although the speed recommendations seek to minimize emissions and fuel consumption along the roadway.
- **Eco-Cooperative Adaptive Cruise Control.** The Eco-Cooperative Adaptive Cruise Control application is an extension to the adaptive cruise control (ACC) concept. Eco-Cooperative Adaptive Cruise Control includes longitudinal automated vehicle control while considering eco-driving strategies. In addition to feedback loops used in ACC, which use radar and LIDAR measurements to derive to the vehicle in front, the preceding vehicle's speed, acceleration, and location are used. These data are transmitted from the lead vehicle to the following vehicle. This application allows following vehicles to use CACC aimed at relieving a driver from manually adjusting his or her speed to maintain a constant speed and a safe time gap from the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application incorporates other information, such as road grade, roadway geometry, and road weather information, to determine the most environmentally efficient trajectory for the following vehicle. In the long term, the application may also consider vehicle platooning, where two or more vehicles travel with small gaps, reducing aerodynamic drag. Platooning relies on V2V communication that allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction in drag results in reduced fuel consumption, greater fuel efficiency, and less pollution for vehicles. This application is applicable to all vehicle classes.
- **Eco-Ramp Metering.** The Eco-Ramp Metering application determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of entering vehicles. This application collects traffic and environmental data to allow on-ramp merge operations that minimize overall emissions, including traffic and environmental conditions on the ramp and on the freeway upstream and downstream of the ramp. Using this information, the application determines a timing plan for the ramp meter based on current and predicted traffic and environmental conditions. The objective for this application is to produce timing plans that reduce overall emissions, including reducing emissions from bottlenecks forming on the freeway as well as emissions from vehicles on the ramp.
- **Connected Eco-Driving.** The Connected Eco-Driving application provides customized real-time driving advice to drivers, allowing them to adjust behaviors to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration and deceleration profiles based on prevailing traffic conditions, and more local interactions with nearby vehicles. Finally, the application may also consider vehicle-assisted strategies, where

the vehicle automatically implements the eco-driving strategy (i.e., change gears, switch power sources, or use start-stop capabilities to turn off the vehicle's engine while it is sitting in congestion).

- **Eco-Traveler Information Applications.** Applications included in the Eco-Traveler Information Operational Scenario apply. Eco-Traveler Information Applications provides pre-trip and en route multimodal traveler information to encourage transportation choices with reduced environmental impacts. The application collects traffic and environmental data from connected vehicles and other sources and uses it to determine real-time or predicted traffic conditions. This information is provided to travelers so they can either plan to or adjust departure times or mode choices or select an alternate route. Traffic conditions include information about roadway speeds and travel times as well as predicted traffic conditions. Another key component of this application is providing travelers with transit options to encourage mode shift, including information about transit schedules and real-time transit vehicle arrival and departure times.
- **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 charging vehicles moving at highway speeds.

The Transformative Concept is described in more detail through the use of a storyboard described in Figure 5-2 and in Table 5-1.

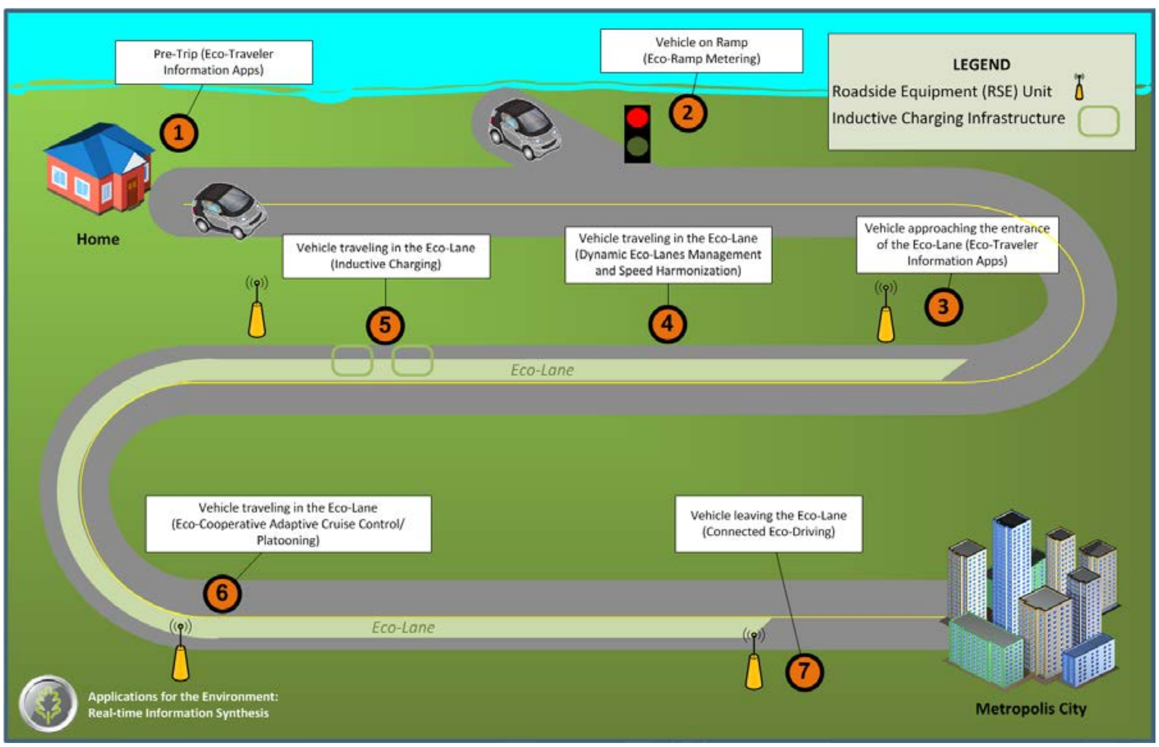


Figure 5-2: Eco-Lanes Storyboard (*Source*: Noblis, 2013)

Table 5-1: Eco-Lanes Storyboard

Step	Description
1	**Pre-Trip (Eco-Traveler Information Apps).** Prior to beginning a trip, the traveler enters his destination (Metropolis City) into the vehicle's OBE unit. An application on the vehicle's OBE provides travel options to the driver for getting to Metropolis City. The application informs the driver that there are eco-lanes currently in place along the driver's route to their destination. Several travel options are presented to the traveler, including multi-modal options where the traveler would use public transportation and routes where the traveler would travel to Metropolis City using their personal vehicle. For each option, the application informs the traveler of his travel time to Metropolis City using the eco-lanes versus the regular lanes, the cost for their trip using eco-lanes versus the regular lanes, and the traveler's environmental footprint for each option. The application also provides the driver with information on eco-lanes along the route. This information includes the entrance parameters, location, start time for the eco-lane, end time for the eco-lane, and other rules or parameters.
2	**Vehicle on Ramp (Eco-Ramp Metering).** At a nearby intersection, another vehicle is on the ramp to enter the freeway. The vehicle stops in accordance to a traffic signal at the bottom of the ramp (i.e., a ramp meter signal). The Eco-Ramp Metering application determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of entering vehicles. The application collects traffic and environmental data to allow on-ramp merge operations that minimize overall emissions, including traffic and environmental conditions on the ramp and on the freeway upstream and downstream of the ramp. Using this information, the application determines a timing plan for the ramp meter based on current and predicted traffic and environmental conditions. The ramp meter provides a red light to the vehicle waiting on the ramp. The traffic signal turns green once there is an acceptable gap for the vehicle to enter the freeway without interrupting traffic flow on the freeway.
3	**Vehicle Approaching the Entrance of the Eco-Lane (Eco-Traveler Information Apps).** The traveler chooses to drive and begins their trip. As their vehicle approaches the eco-lane, the vehicle receives traveler information being broadcasted from a nearby Roadside Equipment (RSE) unit. The vehicle's OBE unit receives this information and provides it to the driver. This information includes the geographic limits of the eco-lane as well as the parameters for using the eco-lane including the eco-speed limit and parameters for vehicle platooning. The OBE unit presents the driver with the parameters for using the eco-lanes. These parameters state that the eco-lanes consist of two lanes on the interstate. Only low emissions vehicles, buses, and motorcycles are permitted to use the eco-lanes for the next two hours. The eco-speed limit is 45 mph instead of 55 mph, but because of high traffic volumes in the regular lanes the travel time to Metropolis is 15 minutes faster in the eco-lanes than the regular lanes. This traveler is driving a hybrid electric vehicle and choses to drive into the city using the eco-lanes.

Step	Description
4	**Vehicle Traveling in the Eco-Lane (Dynamic Eco-Lanes Management and Speed Harmonization).** While in the eco-lanes, the vehicle's OBE collects emissions data from vehicle diagnostic systems and onboard sensors. This includes information about the vehicle's speed, acceleration, weather conditions, emissions, and the vehicle's average fuel economy while in the eco-lanes. These data are transmitted from the vehicle to nearby RSE units, which pass the information to the Traffic Management Center (TMC) responsible for operating the eco-lanes. The TMC uses these data to determine when to commission and decommission the eco-lanes. This includes determining the number of lanes along the freeway that should be eco-lanes versus regular lanes. The TMC's system for managing the eco-lanes may determine these parameters, including the number of lanes that may be designated as eco-lanes, based on real-time traffic and environmental conditions. The system allows for none or all of the lanes along the freeway to be set as eco-lanes and also allows the parameters for the eco-lanes to change (i.e., types of vehicles permitted to be in the eco-lanes). The TMC optimizes the speed limit on the freeway based on real-time traffic and emissions data collected from vehicles and roadside sensors. The goal is to smooth the traffic out along the entire eco-lane to reduce unnecessary slowdowns in traffic thus reducing overall emissions. So if the driver was approaching congestion, an accident, bad weather, or an event that may impact traffic, the speed would be decreased to help smooth the traffic flow approaching the incident. During times where there is not an incident, the speed limit is optimized for environmentally efficient travel speeds, which may be different than the posted speed limit in the regular lanes. The TMC communicates this information to drivers using messages broadcasted by RSE units or conventional ITS roadside equipment including dynamic message signs (DMS) and VSL signs.
5	**Vehicle Traveling in the Eco-Lane (Inductive Charging).** As the traveler continues their trip in the eco-lanes, their OBE unit alerts them that there is inductive charging infrastructure in the eco-lanes. The inductive charging infrastructure allows for transferring electric power from the electric grid (i.e., smart grid) to a vehicle. This allows electric vehicles and hybrid electric vehicles to charge their batteries while moving at highway speeds. The vehicle's OBE informs the driver that that the charge level for their vehicle's battery is low. The driver decides to opt-in to an inductive charging application so that the vehicle's battery is charged while driving in the eco-lanes. Payment for the charge is handled through communication between the vehicle and the grid via an electronic payment system.

Step	Description
6	**Vehicle Traveling in the Eco-Lanes (Eco-Cooperative Adaptive Cruise Control / Vehicle Platooning).** As the traveler continues the trip along their route in the eco-lane, they decide to use an eco-cooperative adaptive cruise control application. This application provides cruise control capabilities designed to minimize vehicle accelerations and decelerations for the benefit of reducing fuel consumption and vehicle emissions. The eco-cooperative adaptive cruise control application considers terrain, roadway geometry, surrounding vehicles and the eco-speed limit to determine a driving speed for a given vehicle that uses the momentum of the vehicle, when suitable, to avoid unnecessary accelerations, and reduce emissions. This may include vehicle assisted adjustments to travel speed. The traveler receives an alert from their OBE unit of a nearby vehicle platoon. The driver decides to enter the vehicle platoon since it is allowed in the eco-lane. The driver navigates his vehicle to the rear of the platoon and activates the platooning application. The vehicle control systems take over longitudinal control of the vehicle allowing the vehicle to safely travel in very close proximity to the other vehicles. This allows for reduced aerodynamic drag, reduced emissions, and increased fuel efficiency. The vehicles in the platoon will rely on V2V communications to navigate safely through the eco-lane, in close proximity to one another.
7	**Vehicle Leaving the Eco-Lane (Connected Eco-Driving).** As the traveler's vehicle approaches the end of the eco-lane, the vehicle platoon disperses to minimize traffic impacts at the merge with the regular lanes. Speed limits near the merge are reduced to facilitate a smooth transfer back into the regular lanes. This concept is similar to conventional ramp metering at freeway ramps. Additionally, the vehicle's OBE unit presents a report to the driver with their estimated savings of fuel, fuel costs, GHG, or other pollutants from using the eco-lanes compared to the regular lanes. The traveler is informed that the traveler saved ¼ gallon of fuel and reduced emissions by 3% by choosing to use the eco-lanes in their travels to Metropolis City instead of using the regular lanes. Once out of the eco-lanes, the driver opts into a Connected Eco-Driving application. The application provides customized real-time driving advice to drivers, allowing them to adjust behaviors to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration and deceleration profiles based on prevailing traffic conditions, and more local interactions with nearby vehicles.

5.2 Eco-Lanes 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-Lanes Transformative Concept; (1) Eco-Lanes System and (2) In-Vehicle System. Figure 5-3 depicts these systems. The Eco-Lanes 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.

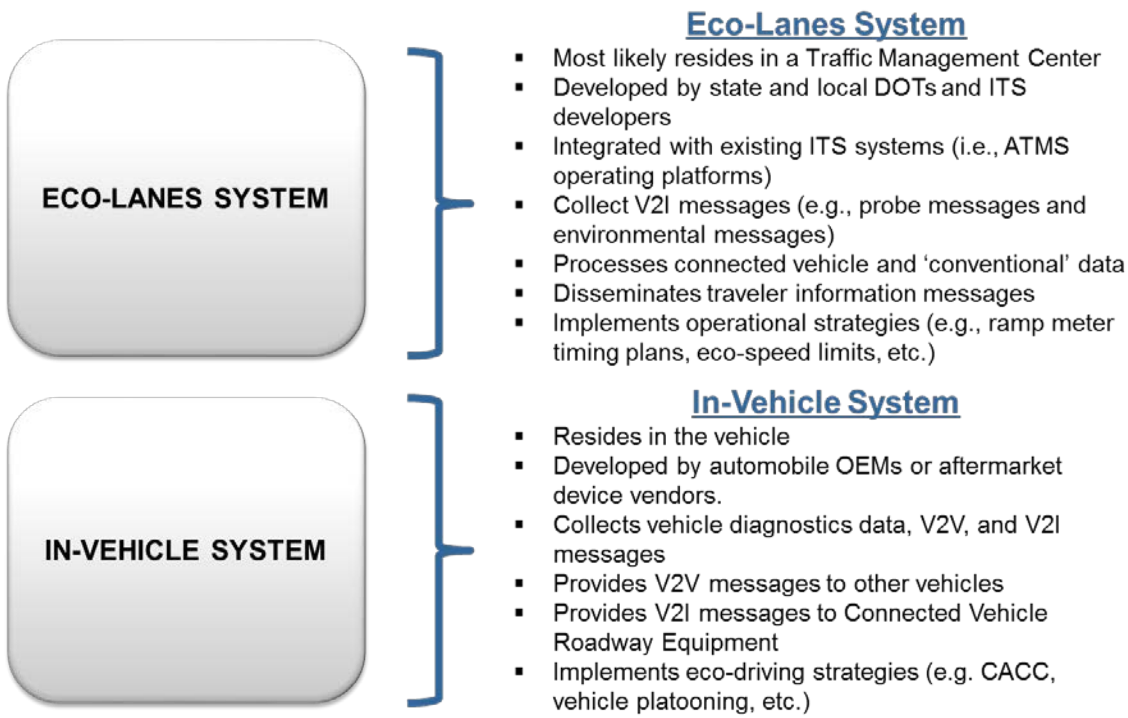


Figure 5-3: Eco-Lanes Systems (*Source*: Noblis, 2013)

The two systems do not exist in isolation; instead they interact with several actors or physical entities that communicate with the system. Figure 5-4 depicts the two 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-Lanes System resides in the ITS Environment. This environment consists of actors that one would typically associate with conventional ITS such as TMCs and their associated systems, closed circuit television (CCTV) cameras, traffic sensors, and DMSs. It is envisioned that the Eco-Lanes System will be deployed in a manner similar to today's current managed lanes systems (i.e., HOV and HOT lane systems) – most likely by a state or local DOT.

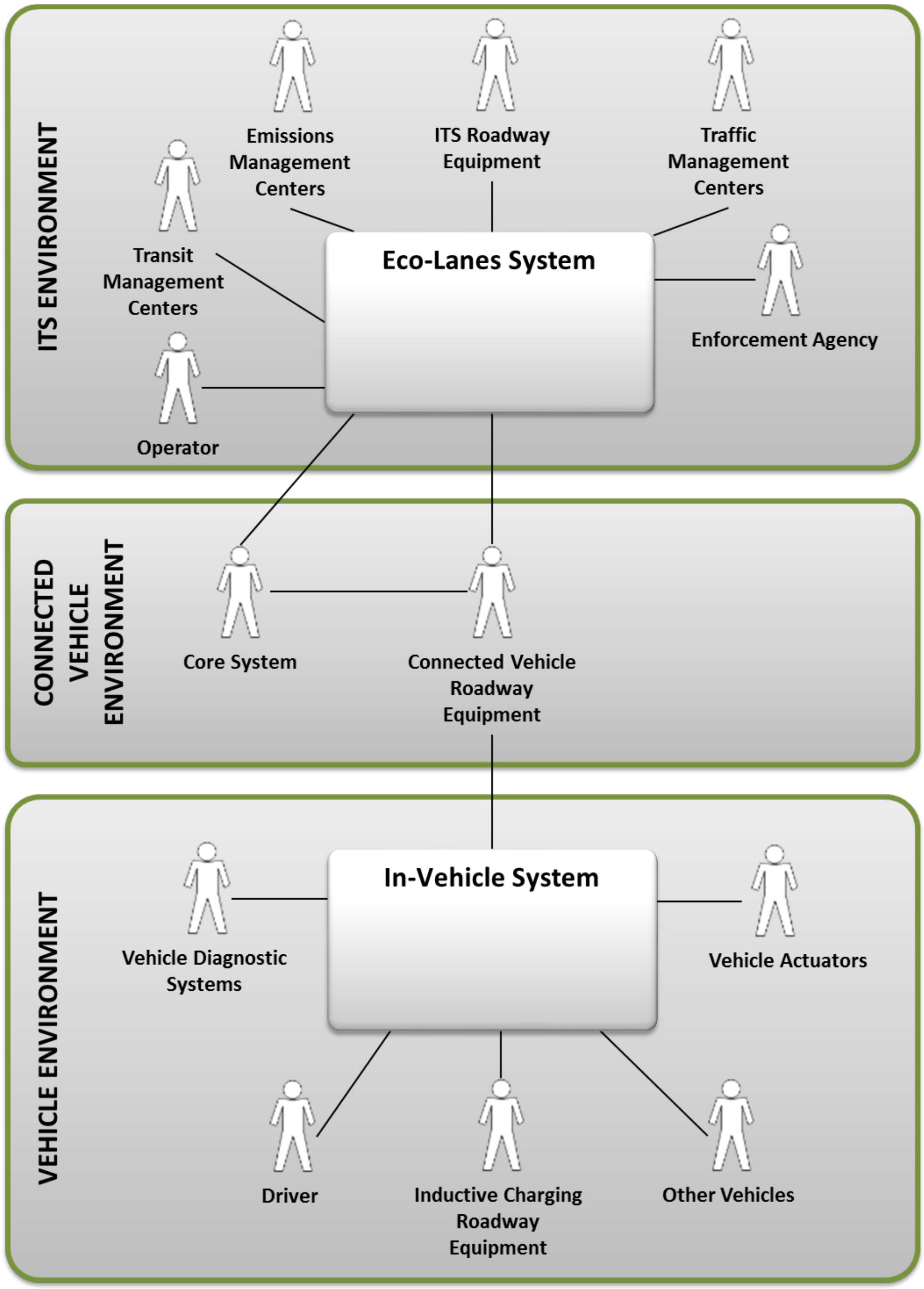


Figure 5-4: Eco-Lanes Environments (*Source*: Noblis, 2013)

The In-Vehicle System resides in the Vehicle Environment and is expected to be developed by automobile OEMs or aftermarket device vendors. It is unlikely that the public sector would deploy these systems; instead the public sector 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 define the eco-lanes to enable the functionality of In-Vehicle Systems located on the vehicle. For example, public agencies may provide parameters of the eco-lane including its location, start time and end time for the eco-lane, eco-speed limits, and parameters for vehicle platooning. This information, along with other traffic and environmental conditions information, would be disseminated to vehicles. The In-Vehicle System would provide this information to the driver, who would use the information to help make pre-trip and en-route traveler decisions prior to entering the eco-lanes. Additionally, In-Vehicle Systems would provide information to drivers allowing them to opt-in to applications such as vehicle platooning or eco-cooperative adaptive cruise control applications.

The Eco-Lanes System and the In-Vehicle System are linked 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 RSEs provide a V2I and I2V link between the two systems.

The boundaries of the two systems – Eco-Lanes System and In-Vehicle System – are shown by their rectangles. Entities outside of these boundaries represent external actors that may interface with the systems. Sections 6 and 7 describe the Eco-Lanes System and In-Vehicle System, respectively. These sections include system context diagrams, logic diagrams, subsystem diagrams, and user needs for each system.

6 Eco-Lanes System

The Eco-Lanes System is envisioned to be a computerized transportation operations 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. It is anticipated that this system would be a subsystem or module of an advanced traffic management system (ATMS) used by TMCs to operate ITS devices along a freeway.

After collecting data, the Eco-Lanes System processes these data and determines whether an eco-lane should be created or decommissioned along a roadway. These decisions would be in response to real-time traffic and environmental conditions. While the eco-lanes would have the capability to be flexible and more dynamic, it is envisioned that these parameters would change only as needed to ensure that travelers do not become confused by a system that is too dynamic in nature. Travelers would need to assume some level of consistency with their trip and should not be surprised by constant changing of the eco-lane's parameters.

The Eco-Lanes System is also responsible for managing operational strategies (e.g., eco-speed limits and vehicle platooning) in the eco-lanes with the objective of reducing fuel consumption and overall emissions along the roadway segment. Data considered in the creation or decommissioning of an eco-lane includes real-time and predicted traffic and environmental conditions, location and duration of special events, or other data.

Once an eco-lane is created, parameters would be established including the locations on the eco-lanes, the number of lanes of the roadway that will be dedicated as eco-lanes, start and end time for the eco-lanes, criteria for vehicles entering the eco-lanes (i.e., eco-lanes may be established solely for transit vehicle, freight vehicles, or alternative fuel vehicles), eco-speed limits, and parameters for vehicle platooning. The Eco-Lanes System evaluates traffic and environmental parameters for a roadway in real-time and adapts environmental applications to meet the real-time needs of the roadway. The system also predicts future traffic and environmental conditions using historical data and real-time data. This allows the system to predict future problem areas. Together, these features allow the system to readily adapt to actual and predicted traffic volumes and environmental conditions so that the traffic network operation is optimized to reduce emissions.

A major component of the Eco-Lanes System is speed harmonization. Using real-time and historic traffic and environmental data, the Eco-Lanes System establishes eco-speed limits for the eco-lanes. The purpose of speed harmonization is to change speed limits on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. Speed harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds, thus reducing fuel consumption, GHG emissions, and other emissions on the roadway. During times where there is not an incident, the speed limit is optimized for environmentally efficient travel speeds which may be different than the posted speed limit in the regular lanes. Eco-speed limits can be broadcast and received by OBE units or displayed on VSL signs located along the roadway. This application is similar to current VSL applications, although the speed recommendations seek to minimize emissions and fuel consumption along the roadway.

The Eco-Lanes System is also responsible for ramp metering in the eco-lanes. Eco-ramp meter timing plans can be determined based on real-time data collected from vehicles and infrastructure to minimize the overall emissions on a roadway segment, including the freeway mainline and ramp. The Eco-Lanes System includes the capability to determine and implement ramp metering timing plans.

Eco-Traveler information is another major component of the Eco-Lane System, especially considering the responsive nature of the lanes being proposed. This includes providing travelers with information about the geographic limits and parameters for the eco-lanes. The system allows this information to be disseminated to travelers using conventional ITS technologies such as DMS, traveler information websites, mobile phone applications, as well as connected vehicle technologies that would allow travelers to receive information about the eco-lanes through in-vehicle systems.

Finally, because the eco-lanes will have regional impacts on the transportation network, information sharing is critical. This includes sharing information about the eco-lanes with regional jurisdictions to support coordinated operations. For example, a neighboring jurisdiction responsible for operating eco-lanes may need to open or extend an eco-lane to match an eco-lane that needs to enter their jurisdiction. Additionally, agencies would need to share eco-lanes parameter information such as speed limits or platooning regulations to prevent parameters from changing drastically as a vehicle crosses jurisdictions in an eco-lane.

The remainder of this chapter 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-Lanes System – System Context Diagram

Figure 6-1 depicts the System Context Diagram for the Eco-Lanes System. This diagram represents the actors that interact 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, (5) Operator, and (6) Enforcement Agencies. 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. Arrows connecting the actors to the Eco-Lanes System illustrate relationships between the actors and the system.

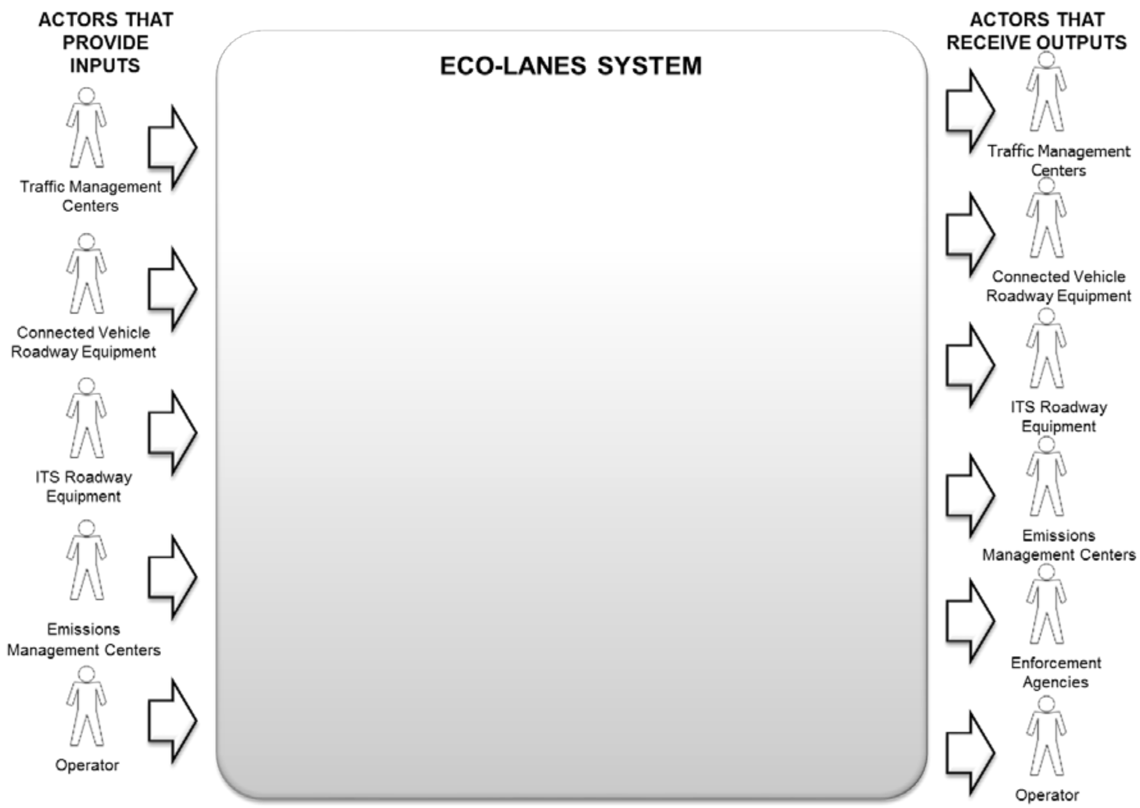


Figure 6-1: Eco-Lanes System – System Context Diagram (*Source*: Noblis, 2013)

6.2 Eco-Lanes System – Logic Diagram

Figure 6-2 is a Logic Diagram for the Eco-Lanes 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-Lanes 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.

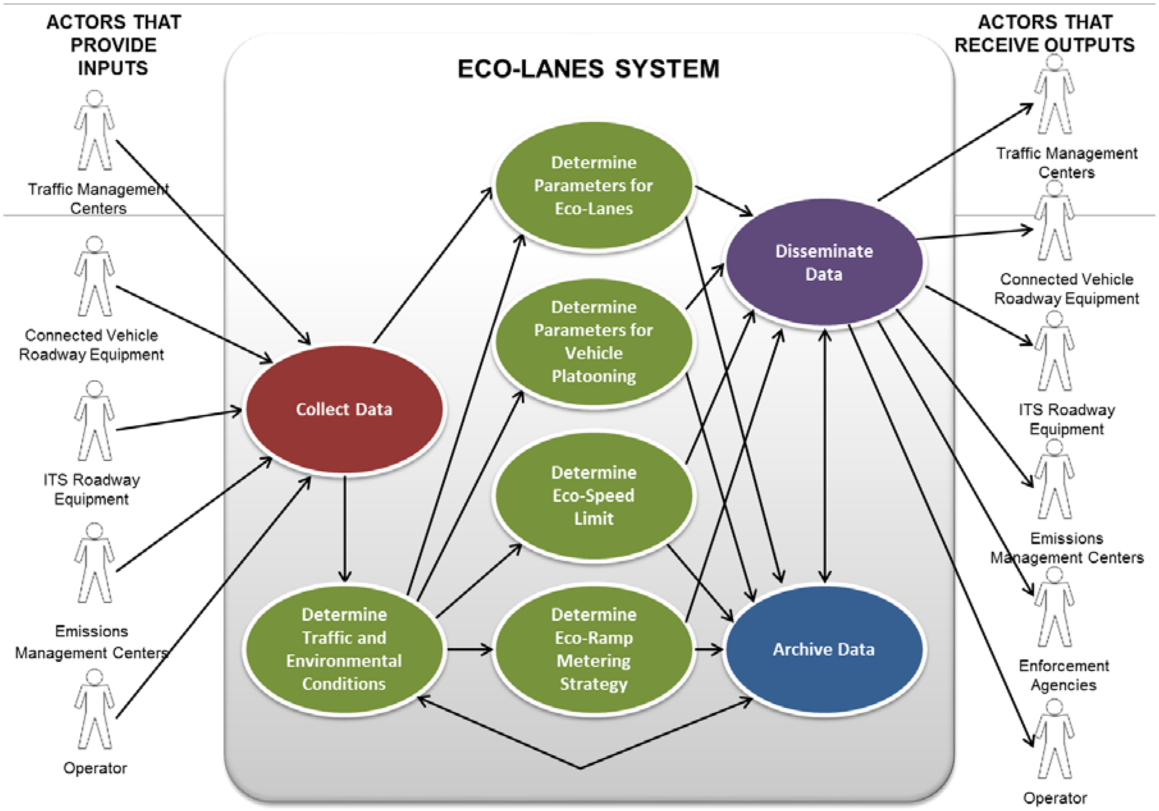


Figure 6-2: Eco-Lanes System – Logic Diagram (*Source*: Noblis, 2013)

6.3 Eco-Lanes System – Subsystem Diagram

Figure 6-3 depicts the subsystem diagram for Eco-Lanes System. Similar to previous diagrams, the left side of this diagram shows the actors that provide inputs to the Eco-Lanes 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-Lanes 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 Data Collection Subsystem, Environmental Data Collection Subsystem, Field Device Status Data Collection Subsystem, Vehicle Specific Data Collection Subsystem, and 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, Eco-Ramp Meter Timing Subsystem, Eco-Speed Limits Subsystem, Vehicle Platooning Parameters Subsystem, Eco-Lanes Parameters Subsystem, and Eco-Lanes Violations Subsystem.

- **Data Dissemination Element.** This element consists of the Eco-Ramp Meter Timing Dissemination Subsystem, Traffic and Environmental Conditions Dissemination Subsystem, Eco-Speed Limit Dissemination Subsystem, Parameters for Vehicle Platooning Dissemination Subsystem, Parameters for Eco-Lanes Dissemination Subsystem and Eco-Lanes Violations 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.

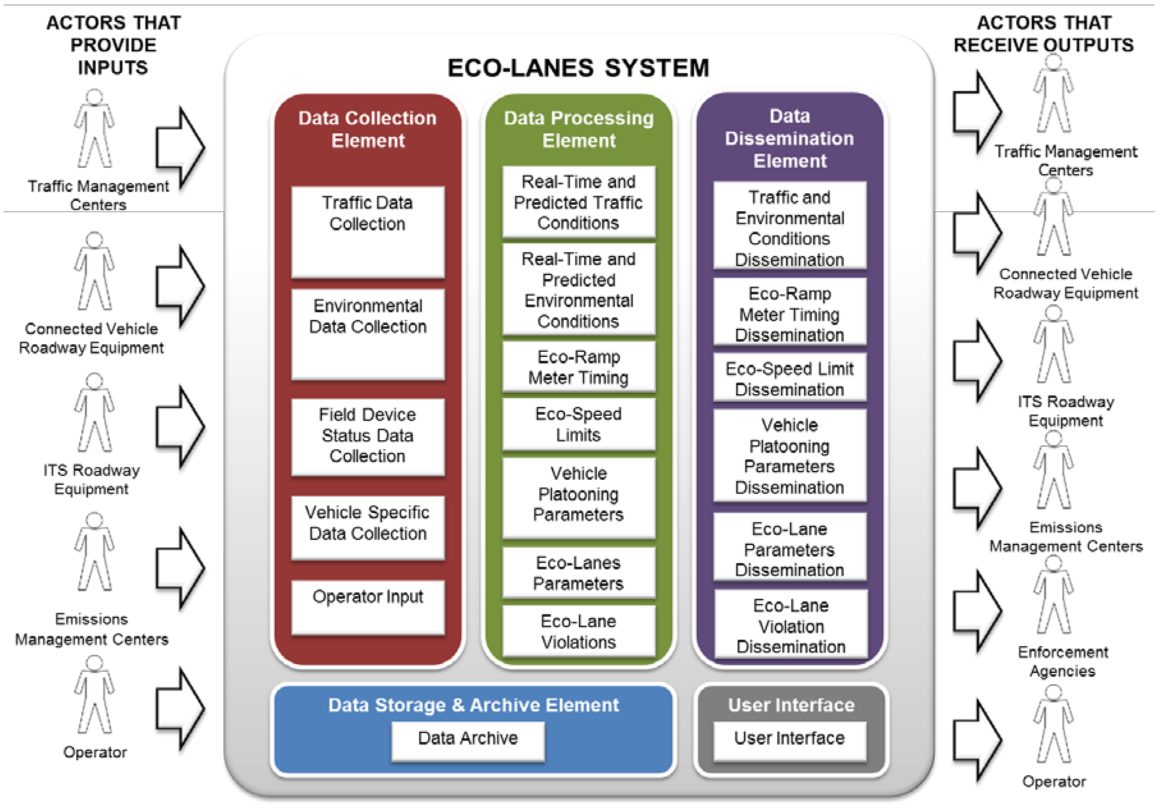


Figure 6-3: Eco-Lanes System – Subsystem Diagram (*Source*: Noblis, 2013)

6.4 Eco-Lanes System User Needs

This section identifies user needs, or desired capabilities, for the Eco-Lanes 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-Lanes System User Needs

Element	Subsystem	ID	Title	Description
Data Collection	Traffic Data Collection Subsystem	ELS-DC-01	Collect Traffic Data	**The Eco-Lanes System needs to collect traffic data (e.g., volume, speed, occupancy, vehicle classification, incidents) for eco-lanes and regular lanes.** Traffic data may be obtained from traffic sensors that detect the presence of vehicles at locations along the network (e.g. using vehicle detectors) or directly from messages collected from vehicles that measure a vehicle's speed, location, and other parameters. Finally, traffic data may be collected from other centers and Information Service Providers (ISPs). This information may also include lane closures due to construction or maintenance activities. Traffic data needs to be processed and then used as input to algorithms that determine whether traffic conditions support the imposition or cessation of an eco-lane. Traffic data also need to be processed and then used as input to algorithms that determine operational strategies for eco-speed limits and ramp metering. Traffic data may also be processed for dissemination of current or predicted traffic conditions to travelers.
Data Collection	Environmental Data Collection Subsystem	ELS-DC-02	Collect Environmental Data	**The Eco-Lanes System needs to collect environmental data (e.g. ambient air quality, vehicle 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 or directly from messages collected from vehicles. Finally, environmental data may be collected from other centers. Environmental data will be key variables for determining the geographic area of the eco-lanes. It will also be used to monitor the environmental conditions in and around the eco-lanes. Environmental data also needs to be processed and then used as input to algorithms that determine operational strategies for eco-speed limits and ramp metering. Environmental data may also be collected to enable dissemination of environmental conditions to travelers.

Element	Subsystem	ID	Title	Description
Data Collection	Field Device Status Data Collection Subsystem	ELS-DC-03	Collect Field Device Status Data	**The Eco-Lanes System needs to collect data on the operational status of Connected Vehicle and ITS Roadway Equipment.** These data include the operational status of RSE units and ITS field devices such as controllers at ramp meters and VSL signs. This information is used to determine the state of the field devices and whether the equipment is operating correctly or a repair is needed. Additionally, these data may include the current timing plan of a ramp meter or the speed limit posted on a VSL sign. Finally, the Eco-Lanes System needs to collect traffic signal timing plans of arterials near ramps so that the ramp metering operations are coordinated with arterials traffic signal timing plans.
Data Collection	Vehicle Specific Data Collection Subsystem	ELS-DC-04	Collect Vehicle Specific Data	**The Eco-Lanes System needs to collect vehicle-specific data about individual vehicles' parameters.** Vehicle specific data may include the vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, and unique identifier (e.g., license plate number or vehicle registration data). These data may be used to determine if a vehicle meets the criteria to enter an eco-lane if parameters restrict certain types of vehicles from entering the lanes. The Eco-Lanes System shall ensure that measures for security and privacy are taken in collecting and using vehicle-specific data.
Data Collection	Operator Input Data Collection Subsystem	ELS-DC-05	Collect Operator Input	**The Eco-Lanes System needs to collect data entered by personnel operating the system.** This allows the operator to manually enter parameters for the eco-lanes. For example, the operator may commission an eco-lane, decommission the eco-lane, and set parameters for the eco-speed limit, vehicle types allowed to enter the eco-lanes, and vehicle platooning. Also, this allows the operator to enter and modify the eco-lanes criteria (i.e., the threshold for emissions that must be exceeded or predicted to exceed before imposition of a lane is justified). Additionally, the operator may enter and modify input to algorithms used to calculate eco-lane criteria or modify algorithms for ramp metering applications.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	ELS-DP-01	Process Traffic Data	**The Eco-Lanes 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., corridor and regional levels).** Traffic data should also be synthesized for differing time categories (e.g., times of day, day of week, holidays). Once the data are processed, they support the Eco-Lane System Operator in determining when and where to establish an eco-lane. These data may also be used to monitor the performance of the eco-lanes. These data will support several applications in optimizing for the environment. For example, traffic data may be aggregated from various sources and used as input to algorithms to determine eco-ramp meter timing plans and eco-speed limits.
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	ELS-DP-02	Generate Predicted Traffic Conditions and Forecast Demand	**The Eco-Lanes System needs to use historical and current traffic data to predict traffic conditions aggregated at different levels (e.g., corridor, and regional levels).** The Eco-Lanes 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 be used as input into determining whether the criteria for an eco-lane are met. The predictive model of traffic flow would support applications in determining eco-ramp meter timing plans and eco-speed limits for predicted traffic conditions. For example, timing plans may be adjusted to account for predicted traffic volumes upstream of the ramp. The prediction may be based on current surveillance, historic traffic data and surveillance, current incidents, planned events, current traffic control strategy, and current environmental conditions. The predictive model should also support forecasting of travel demand in the geographic area served by the system. The model needs to predict the effect of the changes that the imposition of an eco-lane would cause. Finally, the Eco-Lanes System may need to generate estimated travel times for roadway segments of the eco-lanes and regular lanes so that this information can be presented to drivers to assist them in making an informed decision about whether to use the eco-lanes or regular lanes.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	ELS-DP-03	Process Environmental Data	**The Eco-Lanes System needs to synthesize environmental data from multiple sources (e.g., fixed sensors, connected vehicle roadside equipment, other centers) to provide emissions analyses aggregated at different levels (e.g., corridor and regional levels).** The Eco-Lanes System needs to process the environmental data being collected from sensors in the geographic area and from probe vehicles. Once collected, these environmental data may be transmitted to environmental agencies that may produce environmental and air quality forecasts. These data will support several eco-lanes applications in optimizing for the environment. For example, data may be aggregated from various sources and serve as input to algorithms that determine eco-ramp meter timing plans and eco-speed limits.
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	ELS-DP-04	Generate Predicted Emissions Profile	**The Eco-Lanes System needs to synthesize environmental data from multiple sources (e.g., fixed sensors, connected vehicle roadside equipment, other centers) to generate predicted emissions aggregated at different levels (e.g., freeway segment, corridor, and regional levels).** This includes producing and continually updating a predictive model of the environmental conditions. The prediction may be based on historic data and current environmental conditions. This prediction may be used as input into determining whether the criteria for an eco-lane are met. For example, eco-lanes may be established around environmental hot spots (i.e., high emission area) to help reduce transportation's impact on the environment in the area. The predictive model of environmental conditions may support eco-lanes applications that determine eco-ramp meter timing plans and eco-speed limits. Finally, the Eco-Lanes System may need to generate estimated fuel consumption for roadway segments of the eco-lanes and regular lanes so that this information can be presented to drivers to assist them in making an informed decision about whether to use the eco-lanes or regular lanes.

Element	Subsystem	ID	Title	Description
Data Processing	Eco-Ramp Meter Timing Subsystem	ELS-DP-05	Generate Ramp Meter Timing Strategy	**The Eco-Lanes System needs to generate ramp meter timing plans using processed traffic data, predicted traffic data, processed environmental data, and predicted emissions data.** The Eco-Lanes System needs to consider traffic and environmental conditions on the ramp, on the freeway upstream of the ramp, and on the freeway downstream of the ramp in determining ramp metering timing plans. The timing plans must also consider traffic signal timing plans on nearby arterials, as well as queue lengths on the ramp. Generating ramp meter timing plans may be similar to current adaptive ramp control systems; however the objective should be to generate timing plans to reduce overall emissions from bottlenecks forming on the freeway as well as emissions from vehicles on the ramp.
Data Processing	Eco-Speed Limits Subsystem	ELS-DP-06	Generate Eco-Speed Limits	**The Eco-Lanes System needs to generate eco-speed limits using processed traffic data, predicted traffic data, road weather information, and GHG and criteria pollutant information.** The purpose of eco-speed limits are to change speed limits approaching areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that impact flow or in response to predicted poor air quality conditions. Eco-speed limits assist in maintaining flow, reducing unnecessary stops and starts and maintaining consistent speeds, thus reducing fuel consumption, GHGs, and other emissions on the roadway. Eco-speed limits may be posted to VSL signs or sent directly to in-vehicle systems for display to drivers.
Data Processing	Vehicle Platooning Parameters Subsystem	ELS-DP-07	Generate Vehicle Platooning Parameters	**The Eco-Lanes System needs to generate parameters for vehicle platooning**. These parameters need to include geographic limits (start and end locations) for vehicle platooning capabilities as well as speed and gap strategies for the platoon. If security or credentialing are required for a vehicle to enter a platoon, the Eco-Lane System may also support the management of the check-in or check-out capabilities of a vehicle in a platoon to ensure that only registered or safe vehicles are permitted to enter a platoon.

Element	Subsystem	ID	Title	Description
Data Processing	Eco-Lanes Parameters Subsystem	ELS-DP-08	Create and Decommission Eco-Lanes	**The Eco-Lanes System needs to create and decommission Eco-Lanes.** The system needs to use data collected from multiple sources (e.g., sensors, connected vehicle roadside equipment, and other centers) to determine whether current or predicted conditions meet the criteria for the eco-lane. Information from models that produce real-time and predicted traffic, environmental, and demand forecasts would be used to determine the geographic limits of the eco-lane, the number of lanes included in the eco-lane, as well as the criteria for vehicles entering the eco-lane. For example, eco-lanes may be available to all vehicles or limited to certain vehicle types (i.e., transit vehicles, freight vehicles, low emissions vehicles, and/or vehicles capable of following platooning instructions). In determining a low emissions vehicle, the criteria may include vehicle type, engine type, average emissions, or average fuel consumption. This information would be collected by the Eco-Lanes Systems directly from vehicles. Dedicated lanes for transit vehicles and low emissions vehicles would be established to encourage mode shift to transit as well as to discourage the use of high emissions vehicles.
Data Processing	Eco-Lane Violations Subsystem	ELS-DP-09	Detect Violations for Individual Vehicles	**The Eco-Lanes System needs to determine violations for individual vehicles in the Eco-Lanes.** Violations include vehicles entering the eco-lanes that do not meet the parameters established for the eco-lanes. These parameters may include the vehicle type or emissions standards. Additionally, a vehicle may be in violation if the vehicle is exceeding the eco-speed limit in the eco-lanes. Vehicle specific data would be collected from individual vehicles as they enter the eco-lanes to determine if the vehicle was allowed to use the lanes. If the vehicle enters the eco-lane, and is in violation, data about the vehicle could be collected directly from the vehicle including the vehicle's license plate number or registration number. Alternatively, a picture may be taken of the vehicle and its license plate. Traditional ITS technologies would be required if the vehicle is not equipped for V2I communication or can't transmit the required type of information. Enforcement of the eco-lanes would be performed by police on the roadway.

Element	Subsystem	ID	Title	Description
Data Dissemination	Eco-Ramp Meter Timing Dissemination Subsystem	ELS-D-01	Provide Ramp Meter Timing Plans to Roadway Equipment	**The Eco-Lanes System needs to provide ramp meter timing plans to the ramp meter controller.** These timing plans will be used by the ramp meter controller to implement ramp meter timing plans on freeway ramps. Ramp metering systems meter freeway entry lanes to restrict the flow of traffic onto the freeway. The ramp metering field controller has a metering plan that is either locally stored or can be loaded from the traffic management center. The metering plan can be adjusted manually or automatically based upon traffic sensor data gathered from the mainline lanes or metered lanes.
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ELS-D-02	Disseminate Traffic Conditions to Other Centers and Travelers	**The Eco-Lanes System needs to disseminate traffic conditions to: (1) other centers to enable coordination of operational strategies for a corridor or a region and (2) travelers.** Other centers may be adjacent geographically, under control of a different jurisdiction, or part of a more complex hierarchy. They may include TMCs, Transit Management Centers, or private entities responsible for disseminating traveler information. An example of a benefit from these exchanges is sharing information about congestion or incidents that have an impact on traffic conditions in the network served by other Traffic Management Centers. Similarly, a Transit Management Center may use this information to adjust its transit operations. Finally, traffic conditions may be disseminated to travelers in the form of traveler information. Travelers may access traffic conditions using personal computers, smartphones, or other devices.
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ELS-D-03	Disseminate Traffic Conditions for the Eco-Lanes and Regular Lanes to Vehicles	**The Eco-Lanes System needs to provide traffic condition messages to vehicles for the eco-lanes and regular lanes.** These messages need to be formatted for use by in-vehicle systems and should include information that would typically be displayed on a dynamic message sign (e.g., current traffic conditions, predicted traffic conditions, incidents, construction, and travel times). This information, along with information about the eco-lane, will help travelers make informed en-route decisions about their trips. For example, as a vehicle approaches an eco-lane, the driver of the vehicle may be presented with information about traffic delays, travel times, or incidents for both the eco-lanes and regular lanes. The driver may use this information to decide whether to use the eco-lanes or regular lanes or to take an alternate route around the congestion or incident or switch to another mode (e.g., transit).

Element	Subsystem	ID	Title	Description
Data Dissemination	Traffic and Environmental Conditions Dissemination Subsystem	ELS-D-04	Disseminate Environmental Conditions to Other Centers and Travelers	**The Eco-Lanes System needs to disseminate environmental data (e.g., regional and/or local air quality, temperature, precipitation) to other centers and travelers.** 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-applications on arterials and freeways. 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	ELS-D-05	Disseminate Environmental Conditions to Vehicles	**The Eco-Lanes System needs to provide environmental conditions messages to vehicles.** These messages may include real-time and predicted environmental and air quality conditions. These messages need to be formatted for use by in-vehicle systems. Environmental conditions in the eco-lanes and regular lanes need to be provided to drivers. This may include weather conditions in the eco-lanes or regular lanes as well as the estimated average fuel consumption for each lane. These messages would be presented to drivers to help them make informed travel decisions about their trips based on weather and environmental conditions, including information that would typically be displayed on a dynamic message sign (e.g., code red day alerts and road weather conditions).
Data Dissemination	Eco-Speed Limit Dissemination Subsystem	ELS-D-06	Disseminate Eco-Speed Limits to Vehicles	**The Eco-Lanes System needs to provide eco-speed limits to vehicles.** The Eco-Lanes System need to disseminate speed limits directly to vehicles traveling in eco-lanes as well as to VSL signs along an eco-lane. Eco-speed limits will provide drivers with an environmentally efficient speed to follow. These speed limits may be based on real-time and predicted traffic and environmental conditions. Based on these data, eco-speed limits need to be displayed on ITS Roadway Equipment or formatted for use by in-vehicle systems where it would be displayed to the driver. Eco-speed limits would be used to create more uniform speeds, to promote safer driving during adverse conditions (such as fog), and/or to reduce air pollution.

Element	Subsystem	ID	Title	Description
Data Dissemination	Parameters for Vehicle Platooning Dissemination Subsystem	ELS-D-07	Disseminate Vehicle Platooning Parameters	**The Eco-Lanes System needs to provide parameters about vehicle platooning to vehicles.** Vehicle platooning parameters include the geographic limits (start and end locations) for vehicle platooning capabilities as well as speed and gap strategies for the platoon. If security or credentialing are required for a vehicle to enter a platoon, the Eco-Lane System may disseminate the check-in or check-out data for vehicles in a platoon to ensure that only registered or safe vehicles are permitted to enter a platoon.
Data Dissemination	Parameters for Eco-Lanes Dissemination Subsystem	ELS-D-08	Disseminate Eco-Lanes Parameters to Vehicles	**The Eco-Lanes System needs to provide parameters about the eco-lanes to vehicles.** These messages need to be formatted for use by in-vehicle systems. This information may also be provided to drivers using conventional ITS devices, such as DMS. This should include parameters of the eco-lanes to ensure that drivers receive necessary information about the eco-lanes. This information may include the location of the eco-lanes, start and end times for the eco-lanes, number of lanes on the freeway included in the eco-lanes, inductive charging capabilities in the eco-lanes, and types of vehicles permitted in the eco-lanes (i.e., eco-lanes may be dedicated for transit vehicles, freight vehicles, or low emitting vehicles). This information allows drivers to make informed pre-trip and en-route decisions as they approach the eco-lane.
Data Dissemination	Parameters for Eco-Lanes Dissemination Subsystem	ELS-D-09	Disseminate Eco-Lanes Parameters to Other Centers and Travelers	**The Eco-Lanes System needs to provide parameters about the eco-lanes to Other Centers and Travelers.** The Eco-Lanes System should provide information to Other Centers and the traveling public. This information may include the location of the eco-lanes, start and end times for the eco-lanes, number of lanes on the freeway included in the eco-lanes, inductive charging capabilities in the eco-lanes, and types of vehicles permitted in the eco-lanes (i.e., eco-lanes may be dedicated for transit vehicles, freight vehicles, or low emitting vehicles). This information allows Other Centers to make operational decisions that support the eco-lanes and allows travelers to receive information allowing them to make informed pre-trip and en-route decisions as they approach the eco-lane.

Element	Subsystem	ID	Title	Description
Data Dissemination	Eco-Lane Violations Dissemination Subsystem	ELS-D-10	Provide Notice of Violation to Vehicles	**The Eco-Lanes System needs to provide individual vehicles notice of a violation.** This notification may be sent as a message to in-vehicle systems or sent to roadway signage. This notification of a violation allows the Eco-Lanes System to inform a driver that he or she violated the rules of the eco-lanes. Rules violations may include not abiding by the eco-speed limit or not meeting the criteria to enter the eco-lanes. For example, if parameters are established permitting only transit vehicles to use the eco-lanes, a passenger vehicle driving in the lanes would be in violation.
Data Dissemination	Eco-Lanes Violations Dissemination Subsystem	ELS-D-11	Notify Enforcement Agencies of Violations	**The Eco-Lanes System needs to notify enforcement agencies of a violation.** This capabilitiy allows the Eco-Lanes System to inform an enforcement agency that a vehicle violated the rules of the eco-lanes.

Element	Subsystem	ID	Title	Description
Data Storage and Archive	Data Archive Subsystem	ELS-DA-01	Archive Data	**The Eco-Lanes System needs to archive traffic data, environmental data, operations data (e.g., status of ramp meter or variable speed limit signs), and event logs (e.g., when the eco-lanes were commissioned or decommissioned, parameters of the eco-lanes, and vehicle platooning parameters).** This capability allows the Eco-Lanes 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-ramp meter timing plans, eco-speed limits, and other eco-lanes parameters. The center shall maintain a log of all automated vehicle check-in and check-out transactions received from the field elements regardless of whether they are successful or not.
Data Storage and Archive	Data Archive Subsystem	ELS-DA-02	Determine Performance Measures	**The Eco-Lanes 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	ELS-UI-01	User Interface	**The Eco-Lanes System needs to provide a user interface.** This allows an operator to interact with the Eco-Lanes System with minimal keyboarding.

7 In-Vehicle System

The In-Vehicle System resides in the vehicle and is used to collect, process, and disseminate data to various actors including the driver of the vehicle. A major function of the In-Vehicle System is to collect information about the eco-lanes, as well as traffic and environmental conditions, and present this information to the driver to assist him or her in making informed pre-trip and en-route travel choices. This information may include the location of the eco-lanes, start and end time for the eco-lanes, criteria for entering the eco-lanes, eco-speed limits while traveling in the eco-lanes, and parameters for vehicle platooning. Additionally, the In-Vehicle System may present drivers with information about traffic conditions and environmental conditions in both the eco-lanes and adjacent regular lanes. This information may include real-time travel times, incident information, or estimated fuel consumption for both the eco-lanes and regular lanes. This information would be provided to the driver allowing him/her to make informed decisions about using the eco-lanes.

The In-Vehicle System provides real-time driving advice to drivers so that they can adjust driving behavior to save fuel and reduce emissions. The advice includes recommended driving speeds, optimal acceleration, and optimal deceleration profiles on freeways. These recommendations would be a part of eco-cooperative adaptive cruise control functions. Eco-cooperative adaptive cruise control may also consider vehicle-assisted strategies where the vehicle automatically implements the eco-driving strategy, for example platooning. Additional details on eco-driving strategies for arterials are described in the Eco-Signal Operations Operational Concept document.

Another key function of the In-Vehicle System is to collect emissions data from vehicle diagnostic systems or other on-board sensors and to disseminate these data to Connected Vehicle Roadway Equipment. These data would be used by the Eco-Lanes System – located at a center – to determine when an eco-lane should be established or decommissioned based on real-time environmental conditions data. They would also be used to help determine eco-speed limits, ramp metering plans, and other traffic control strategies on the freeway that help reduce environmental impacts caused by vehicles.

The In-Vehicle System uses traffic data, environmental data, vehicle status data from other vehicles, and terrain information to determine optimal eco-driving strategies which in turn are disseminated to the driver through a driver interface. Eco-Cooperative Adaptive Cruise Control applications, as well as, Vehicle Platooning applications would use these data. For example, the system would provide optimal speed recommendations – or eco-driving recommendations – to the driver accounting for variables such as terrain and the locations, speeds, and accelerations of surrounding vehicles. After receiving the alert from an eco-driving application, the driver may adjust his or her speed to increase fuel efficiency on the freeway. A driver may also opt in to a vehicle platoon, where the vehicle control systems would take longitudinal and/or lateral control of the vehicle. The system would consider potential interactions with other vehicles, traffic conditions downstream, and eco-lanes parameters to travel in very close proximity to a vehicle in front of it. A platoon of vehicles would reduce their aerodynamic drag because of the small distance between the vehicles, thus increasing fuel efficiency and reducing emissions.

The remainder of this chapter 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 square 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 Onboard Sensors, (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. Arrows connecting the actors to the In-Vehicle System illustrate relationships between the actors and the system.

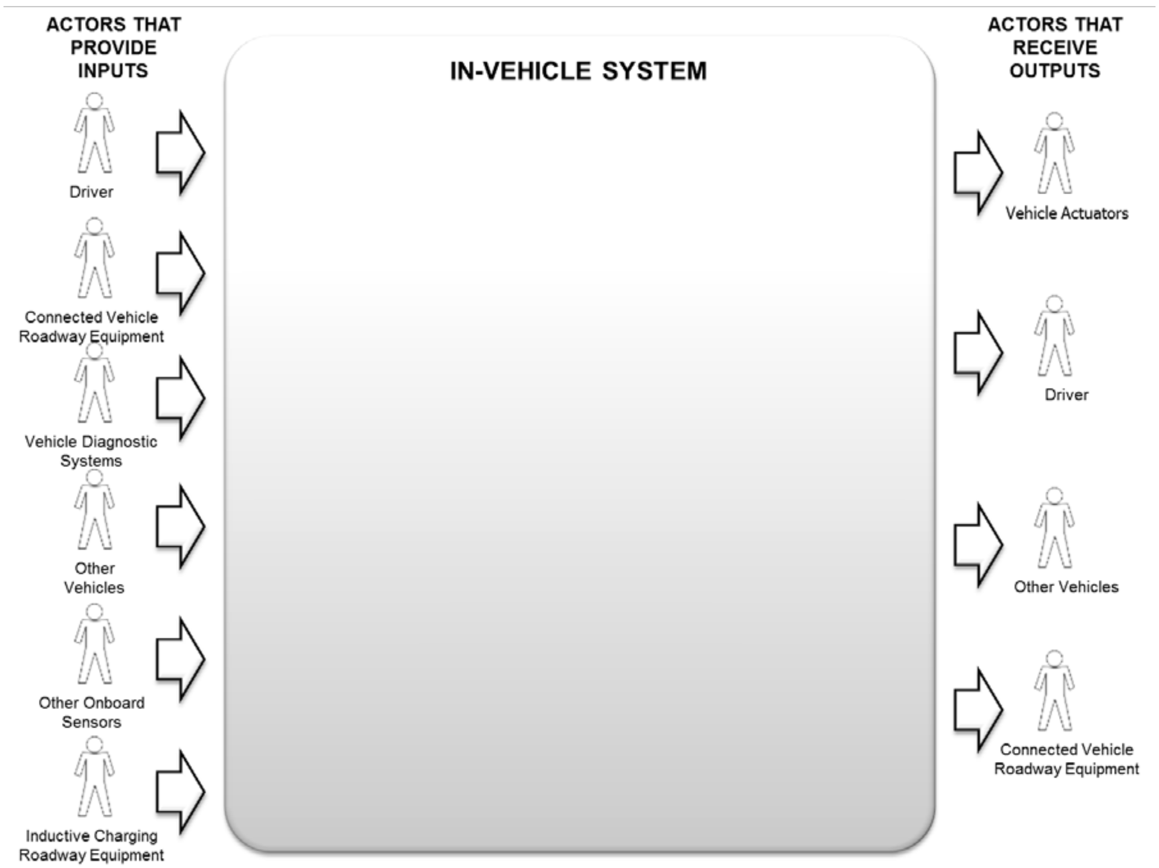


Figure 7-1: In-Vehicle System – System Context Diagram (*Source*: Noblis, 2013)

7.2 In-Vehicle System – Logic Diagram

Figure 7-2 is 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 including (1) data collection depicted as red ovals, (2) data processing which are depicted as green ovals, (3) vehicle assisted control depicted as orange ovals, and (4) dissemination which are depicted as purple ovals.

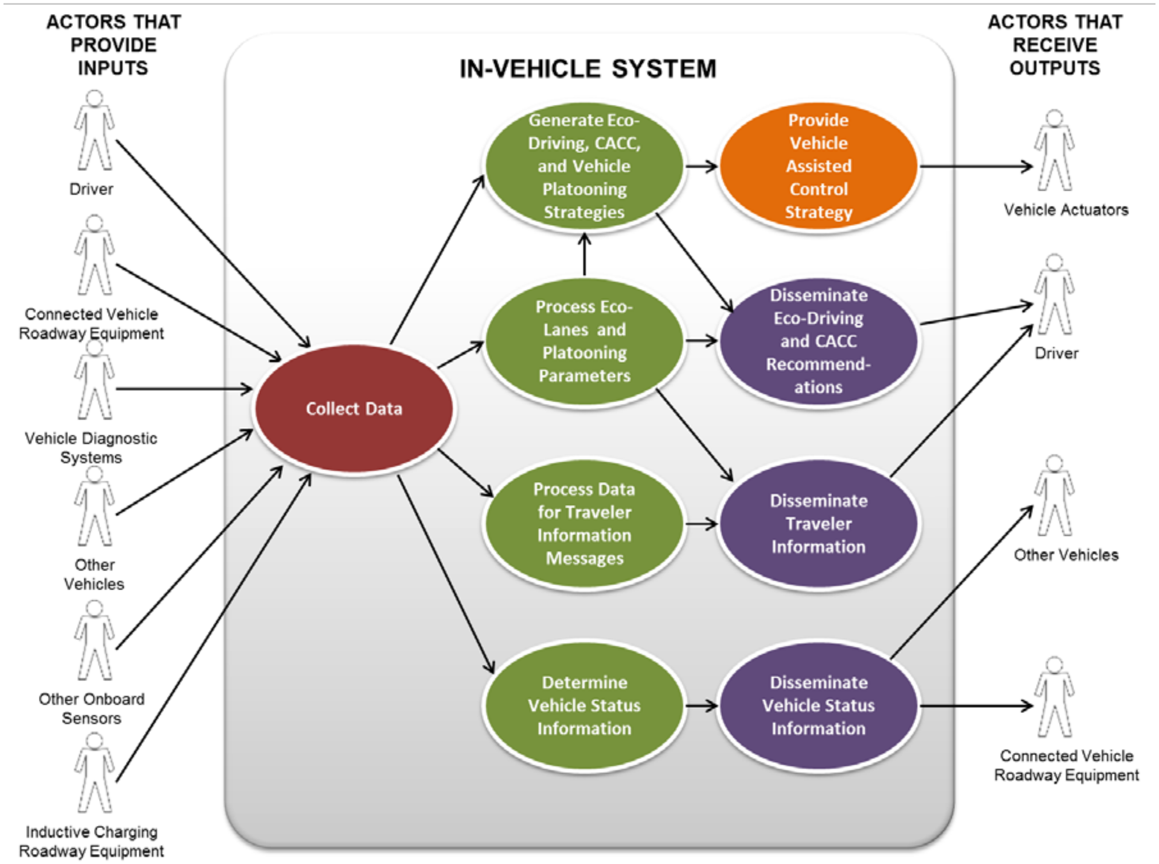


Figure 7-2: In-Vehicle System – Logic Diagram (*Source*: Noblis, 2013)

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, Vehicle Platooning Parameters Data Collection Subsystem, Eco-Lanes Parameters Data Collection Subsystem, Eco-Speed Limits Data Collection Subsystem, 'Other Vehicle' Vehicle Status Data Collection Subsystem, and Diagnostics Data Collection Subsystem.
- **Data Processing Element.** This element consists of the Eco-Driving, Eco-Cooperative Adaptive Cruise Control, and Vehicle Platooning Subsystem, Eco-Lanes Criteria Determination Subsystem, Traveler Information Processing Subsystem, and Vehicle Status Data Processing Subsystem.
- **Vehicle Assisted Control Element.** This element consists of the Vehicle Assisted Control Strategy Subsystem.
- **Data Dissemination Element.** This element consists of the Driver Information Dissemination Subsystem and Vehicle Status Dissemination Subsystem.
- **Driver Interface Element.** This elements consists of the Driver Interface Subsystem.

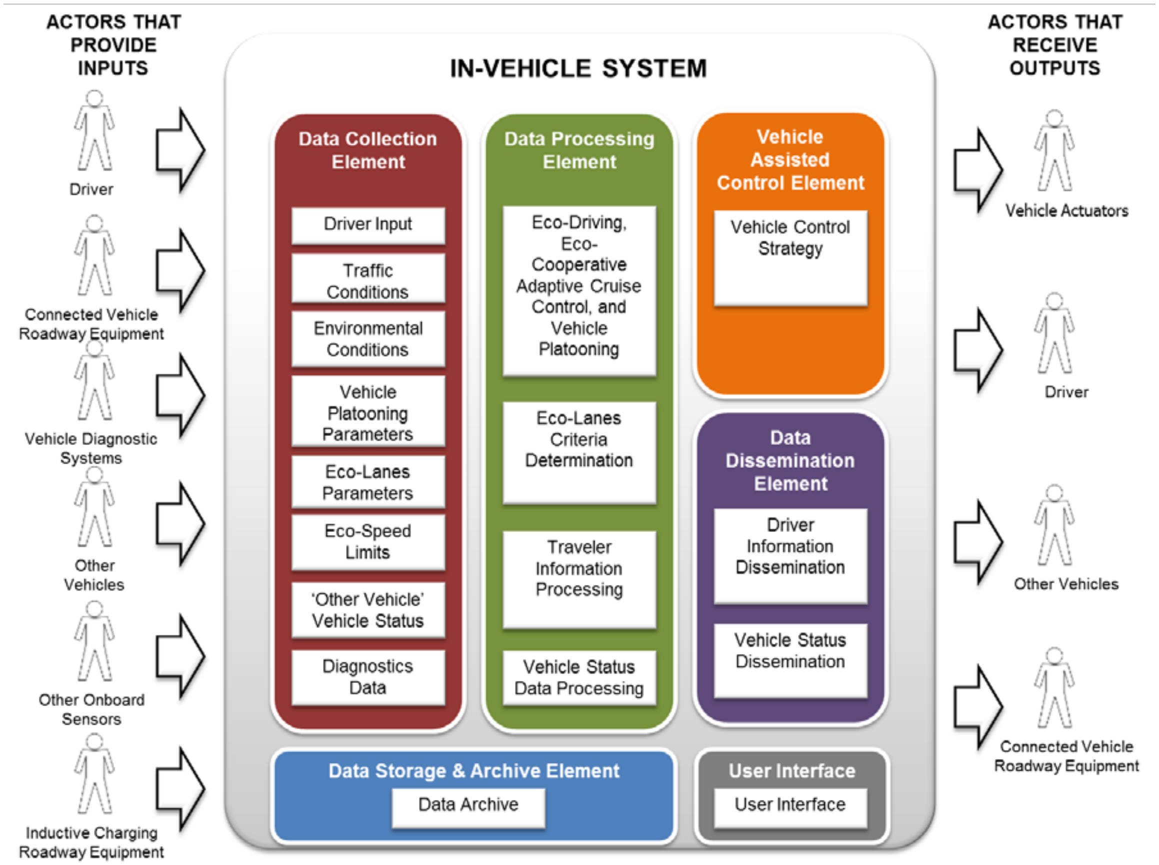


Figure 7-3: In-Vehicle System – Subsystem Diagram (*Source*: Noblis, 2013)

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 vehicle characteristics.** The system should include an interface that supports inputs from the driver in manual or audio form. This capability allows the system to establish 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, etc. The In-Vehicle system also needs to support inputs from the driver allowing the driver to enable eco-driving, inductive charging, and CACC and vehicle platooning capabilities on the vehicle.
Data Collection	Traffic Conditions Data Collection Subsystem	IVS-DC-02	Receive Traffic Conditions Data	**The In-Vehicle System needs to receive traffic conditions data.** These data should include information that would typically be displayed on a dynamic message sign (e.g., information about current traffic conditions, incidents, and posted speed limits). This information may include travel times for the eco-lanes and regular lanes. This information would be provided to the driver of the vehicle allowing him or her to make pre-trip and en-route travel choices based on the traffic conditions including when to use the eco-lanes. Additionally, these data need to be used as inputs to eco-cooperative adaptive cruise control and eco-driving strategies.
Data Collection	Traffic Conditions Data Collection Subsystem	IVS-DC-03	Collect Geographic Information Description Data	**The In-Vehicle System needs to collect 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. It also needs to include road grade information which would be used by the in-vehicle system to support eco-CACC applications.

Element	Subsystem	ID	Title	Description
Data Collection	Environmental Conditions Data Collection Subsystem	IVS-DC-04	Receive Environmental Conditions Data	**The In-Vehicle System needs to receive environmental conditions data.** These data may include real-time and predicted environmental and air quality conditions that would typically be displayed on a dynamic message sign (e.g., code red day alerts). This information may also include estimated fuel consumption along a roadway segment comparing the eco-lanes to the regular lanes. The In-Vehicle System needs to provide this information to drivers allowing them to make pre-trip and en-route travel choices based on the environmental conditions. Road weather information may also be used as input to eco-CACC and eco-driving strategies.
Data Collection	Vehicle Platooning Parameters Data Collection Subsystem	IVS-DC-05	Receive Vehicle Platooning Parameters	**The In-Vehicle System needs to receive vehicle platooning parameters from the Eco-Lanes System and from vehicle platoons.** Vehicle platooning parameters allow an individual vehicle to enter a platoon based on data received from the entity operating the roadway, other vehicles, and vehicle platoons. These parameters may include the geographic limits (start and end locations) for vehicle platooning capabilities, location of the platoon, and speed and gap strategies for the platoon. If security or credentialing are required for a vehicle to enter a platoon, the Eco-Lane System may also support the management of the check-in or check-out capabilities of a vehicle in a platoon to ensure that only registered or safe vehicles are permitted to enter a platoon.
Data Collection	Eco-Lanes Parameters Data Collection Subsystem	IVS-DC-06	Receive Eco-Lanes Parameter Information	**The In-Vehicle System needs to receive parameters about Eco-Lanes that have been created and decommissioned.** This information should include parameters to ensure that drivers receive necessary information about the eco-lanes, including the location of the eco-lanes, start and end times for the eco-lanes, number of lanes, location of inductive charging infrastructure, as well as the criteria for vehicles entering the eco-lane. For example, eco-lanes may be available to all vehicles or limited to certain vehicle types (i.e., transit vehicles, freight vehicles, or low emissions vehicles). This information allows drivers to make informed pre-trip and en-route decisions as they approach the eco-lanes. This information may be used by drivers to assist them in making decisions about whether to enter the eco-lanes based on the location, fees, and other parameters.

Element	Subsystem	ID	Title	Description
Data Collection	Eco-Speed Limits Data Collection Subsystem	IVS-DC-07	Receive Eco-Speed Limits	**The In-Vehicle System needs to receive lane specific eco-speed limits broadcasted from Connected Vehicle Roadway Equipment.** Eco-speed limits will provide drivers with an environmentally efficient speed to follow. These speed limits may be based on real-time and predicted traffic and environmental conditions. Eco-speed limits need to be received by the in-vehicle system and presented to the driver. Eco-speed limits would be used to create more uniform speeds on freeways, to promote safer driving during adverse conditions (such as fog), and/or to reduce air pollution.
Data Collection	'Other Vehicle' Vehicle Status Data Collection Subsystem	IVS-DC-08	Receive Vehicle Status Data from Other Vehicles	**The In-Vehicle System needs to receive 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 for eco-CACC and vehicle platooning to couple vehicles together and avoid a collision between two vehicles.
Data Collection	Diagnostics Data Collection Subsystem	IVS-DC-09	Collect Vehicle Diagnostics Data	**The In-Vehicle System needs to collect diagnostics data from onboard systems and onboard 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. The diagnostics data may be sent to the Eco-Lanes System as input for determining traffic and environmental conditions for a roadway segment, corridor, or region. These data may also be used as input to eco-speed limit and eco-ramp metering algorithms. Finally, these data may also be sent to the Eco-Lanes System as a vehicle enters the eco-lane to determine if the vehicle is permitted to use the eco-lanes if parameters are in place restricting to certain types of vehicles from using the eco-lanes.

Element	Subsystem	ID	Title	Description
Data Collection	Diagnostics Data Collection Subsystem	IVS-DC-10	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 need supports inductive charging of electric vehicles. Inductive charging infrastructure could be installed in the eco-lanes, so while an electric vehicle is driving over inductive charging pads the driver of an electric vehicle could opt-in to an application allowing his/her vehicle's electric battery to be dynamically charged.

Element	Subsystem	ID	Title	Description
Data Processing	Eco-Driving, Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Subsystem	IVS-DP-01	Generate Eco-Driving Strategies	**The In-Vehicle System needs to determine driving recommendations with the objective of promoting a driving style that lowers vehicle emissions.** These driving recommendations may include advice about recommended 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 traffic congestion).
Data Processing	Eco-Driving, Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Subsystem	IVS-DP-02	Determine if Vehicle Meets Criteria for Vehicle Platooning	**The In-Vehicle System needs to determine if the vehicle meets the criteria for entering a vehicle platoon.** Upon receiving parameters for vehicle platooning, the In-Vehicle System needs to determine if the vehicle meets the requirements to join a vehicle platoon. Criteria that the In-Vehicle System may consider include the vehicle type, vehicle credentials are met, vehicle sensors are working properly, or other parameters established by the entity responsible for operating the eco-lane.
Data Processing	Eco-Driving, Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Subsystem	IVS-DP-03	Generate Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Strategies	**The In-Vehicle System needs to generate eco-cooperative adaptive cruise control and vehicle platooning strategies that may include vehicle control of accelerations and declarations based on traffic and environmental conditions, eco-speed limits, and interactions with surrounding vehicles.** The system needs to quickly and reliably generate speed and gap decisions by interpreting internal vehicle data with data received from other vehicles. This would enable the vehicle to follow a lead vehicle very closely (inches apart) in a platoon, responding to changes in speed and direction of the lead vehicle. This control may consider traffic and environmental conditions, eco-speed limits, eco-lane parameters (e.g. is platooning allowed), and entrance and exit point into the platoon. Additionally, when a driver decides to enter or leave a platoon, he or she must be able to give away or regain manual throttle control and change lanes safely. A vehicle may be allowed to join or continue running in a platoon only if the vehicle and/or the driver are considered to be in a safe condition, using data received from other vehicles and the driver, and the eco-lane currently allows platooning.

Element	Subsystem	ID	Title	Description
Data Processing	Eco-Lanes Criteria Determination Subsystem	IVS-DP-04	Determine if the Vehicle Meets Criteria to Enter the Eco-Lanes	**The In-Vehicle System needs to determine if the vehicle meets the criteria for entering the Eco-Lanes.** Upon receiving parameters for the Eco-Lanes, the In-Vehicle System needs to use vehicle diagnostics data and other data collected from vehicle systems to determine if the vehicle is permitted to use the eco-lanes. Criteria that the In-Vehicle System may consider include the vehicle type, average fuel consumption, average vehicle emissions, capability of receiving onboard VSL messages, or other parameters established by the entity responsible for operating the eco-lane.
Data Processing	Traveler Information Processing Subsystem	IVS-DP-05	Process Traffic and Environmental Data for Traveler Information Messages	**The In-Vehicle System needs to process traffic and environmental data and develop traveler information messages to be provided to the driver.** Traffic data may include information on traffic conditions including travel times, incidents, and construction activities. Environmental data may include information about weather conditions or air quality conditions that may be of value to the driver. These data need to be synthesized and packaged for traveler information messages that would be provided to the driver.
Data Processing	Vehicle Status Data Processing Subsystem	IVS-DP-06	Determine Vehicle Emissions Data	**The In-Vehicle System needs to calculate estimates of tailpipe emissions and fuel consumption if this data cannot be collected directly from the vehicle.** These 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., use of the 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. 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-Lanes applications. For example, eco-ramp metering algorithms may need to collect emissions data from vehicles as input to signal timing plans that have an objective of reducing emissions for a ramp. 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
Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-01	Disseminate Vehicle Status Data	**The In-Vehicle System needs to transmit 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).** This information needs to be sent to the connected vehicle infrastructure prior to entering and when a vehicle is in the eco-lane. Data about the vehicle's speed, accelerations, make and model, as well as other data that may also be used to estimate vehicle emissions may be disseminated. Additionally, vehicles need to provide vehicle status data to other vehicles to enable cooperative adaptive cruise control and vehicle platooning capabilities. This information may include information about joining or leaving a vehicle platoon.
Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-02	Disseminate Vehicle Status 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.** The environmental data message includes data such as the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption. These data are needed to determine if a vehicle is permitted to enter the eco-lanes. Additionally, this information may be disseminated to the Eco-Lanes System as input for determining when an eco-lane should be established or decommissioned.
Dissemination	Driver Information Dissemination Subsystem	IVS-D-03	Provide Traffic Conditions to the Driver	**The In-Vehicle System needs to provide traffic conditions to drivers so they can make informed decisions during their trips.** These data should include information that would typically be displayed on a dynamic message sign (e.g., information about current traffic conditions, incidents, and posted speed limits). This information may include travel times for the eco-lanes and regular lanes. This information would be provided to drivers of the vehicles allowing them to make pre-trip and en-route travel choices based on the traffic conditions. These data may assist travelers in determining whether to enter the eco-lanes.

Element	Subsystem	ID	Title	Description
Dissemination	Driver Information Dissemination Subsystem	IVS-D-04	Provide Environmental Conditions to the Driver	**The In-Vehicle System needs to provide environmental conditions to the driver so they can make informed decisions during their trip.** These data may include real-time and predicted environmental and air quality conditions that would typically be displayed on a dynamic message sign (e.g., code red day alerts). This information may also include estimated fuel consumption along a roadway segment comparing the eco-lanes to the regular lanes. The In-Vehicle System needs to provide this information to drivers allowing them to make pre-trip and en-route travel choices based on the environmental conditions.
Dissemination	Driver Information Dissemination Subsystem	IVS-D-05	Provide Eco-Lanes Parameters to the Driver	**The In-Vehicle System needs to provide eco-lane parameters to the driver and inform the driver if his/her vehicle meets the criteria for entering the eco-lanes.** These parameters may include entrance parameters for the eco-lanes (e.g. vehicle type or fuel type), location (start and end), start and end time, or other rules that may be implemented by the eco-lanes operating entity. If there are restrictions to using the eco-lanes, the In-Vehicle System needs to inform the driver if his/her vehicle is permitted to use the lanes. This information will help inform drivers if they are allowed to enter eco-lanes and what they must do when they enter the lane.
Dissemination	Driver Information Dissemination Subsystem	IVS-D-06	Provide Vehicle Platooning Parameters to the Driver	**The In-Vehicle System needs to provide vehicle platooning parameters to the driver and inform the driver if his/her vehicle meets the criteria for entering a vehicle platoon.** The In-Vehicle System needs to inform the driver of vehicle platooning parameters prior to entering the platoon. This may include the geographic limits (start and end locations) for vehicle platooning capabilities, speed and gap strategies for the platoon, and information about whether the vehicle is permitted to enter the platoon. The driver must be made aware of how, when, and where to safely join a platoon. Once a driver has joined a platoon, the driver must be provided information to accept or reject a recommended speed and gap policy for his/her vehicle. Additionally, when a driver decides to enter or leave a platoon, they must be provided with information stating that they are giving away or regaining manual throttle control to change lanes safely.

Element	Subsystem	ID	Title	Description
Dissemination	Driver Information Dissemination Subsystem	IVS-D-07	Provide Eco-Driving Information to the Driver	**The In-Vehicle System needs to provide eco-driving information to drivers that encourage them to drive in a more environmentally efficient manner.** This information may be provided via the driver interface and include recommended speeds, accelerations, and changing of gears.

Element	Subsystem	ID	Title	Description
Vehicle Control	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 autonomous driving vehicle controls.** This allows for vehicle assisted or automated control of the vehicle based on outputs from applications (e.g., eco-cooperative adaptive cruise control or vehicle platooning), vehicle sensors, and vehicle status messages received from other vehicles.

Element	Subsystem	ID	Title	Description
Driver Interface	Driver Interface Subsystem	IVS-DI-01	Provide Driver Interface	**The In-Vehicle System needs to provide a user interface through which traffic conditions, environmental conditions, driving recommendations, eco-lanes parameters, and vehicle platooning parameters, battery charge, and feedback on driving behavior can be displayed to the driver**. The interface also needs to allow the user to opt-in to applications. The interface needs to allow the driver to enter information for route guidance capabilities. User-configurable traffic and environmental condition alert subscriptions need to be supported and resultant alerts may be output to the driver. In-vehicle signage needs to be output to the driver; including eco-speed limits, traffic conditions, and environmental conditions such as that typically displayed on a dynamic message sign (DMS). The interface also needs to provide drivers with speed recommendations that support eco-driving. 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.

8 Eco-Lanes Interfaces and Data Exchanges

To better understand how the Eco-Lanes 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-Lanes 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. In this diagram three options are shown for data exchanges between the Eco-Lanes System and the In-Vehicle System. The first option includes data exchanges through the Connected Vehicle Roadway Equipment or an 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.

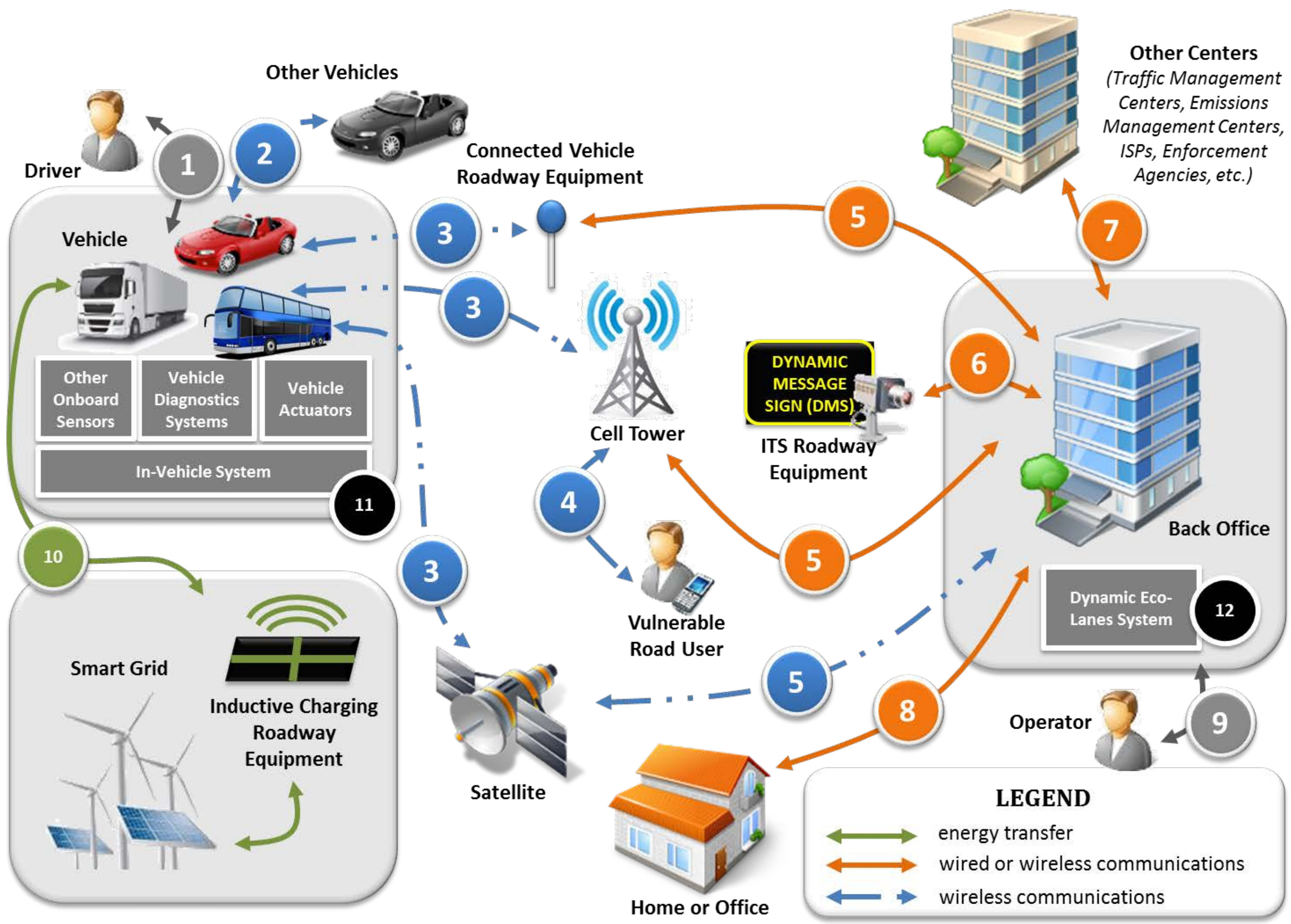


Figure 8-1: Eco-Lanes Interface and Data Exchange Diagram (*Source*: Noblis, 2013)

Table 8-1: Eco-Lanes Interfaces and Data Exchanges

Item	Actors	Data Exchange / Action	Related User Needs
1	In-Vehicle System and Driver	<u>In-Vehicle System sends to Driver</u> • Eco-Lanes Parameter Information (e.g., location, entrance criteria, eco-speed limits, etc.) • Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, etc.) • Eco-driving Information • 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-cooperative adaptive cruise control) • Updates to configurable parameters	• IVS-DC-01: Collect Driver Input • IVS-D-03: Provide Traffic Conditions to the Driver • IVS-D-04: Provide Environmental Conditions to the Driver • IVS-D-05: Provide Eco-Lanes Parameters to the Driver • IVS-D-06: Provide Vehicle Platooning Parameters to the Driver • IVS-D-07: Provide Eco-Driving Information to the Driver • IVS-DI-01: Provide Driver Interface
2	In-Vehicle System and Other Vehicles	<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.)	• IVS-DC-08: Receive Vehicle Status Data from Other Vehicles • IVS-D-01: Disseminate Vehicle Status Information

3	In-Vehicle System and Connected Vehicle Roadway Equipment In-Vehicle System and Cell Tower In-Vehicle System and Satellite	In-Vehicle System sends to Connected Vehicle Roadway Equipment, Cell Tower, and Satellite • Vehicle status data (e.g., BSM data including vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Vehicle status environmental data including the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption) Connected Vehicle Roadway Equipment, Cell Tower, and Satellite sends to the In-Vehicle System • 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) • Eco-Lanes Parameter Information (e.g., location, entrance criteria, etc.) • Eco-Speed Limits • Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, etc.) • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.)	• IVS-DC-02: Receive Traffic Conditions • IVS-DC-03: Collect Geographic Information Description Data • IVS-DC-04: Receive Environmental Conditions Data • IVS-DC-05: Receive Vehicle Platooning Parameters • IVS-DC-06: Receive Eco-Lanes Parameter Information • IVS-DC-07: Receive Eco-Speed Limits • IVS-D-01: Disseminate Vehicle Status Data • IVS-D-02: Disseminate Vehicle Status Environmental Data • ELS-D-10: Provide Notice of Violation to Vehicles
4	Cell Tower and Vulnerable Road User	Vulnerable Road User receives from Cell Tower • Eco-Lanes Parameter Information (e.g., location, entrance criteria, etc.) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality information, code red air quality alerts)	• ELS-D-02: Disseminate Traffic Conditions to Other Centers and Travelers • ELS-D-04: Disseminate Environmental Conditions to Other Centers and Travelers • ELS-D-09: Disseminate Eco-Lanes Parameters to Other Centers and Travelers

5	Connected Vehicle Roadway Equipment and Eco-Lanes System Cell Tower and Eco-Lanes System Satellite and Eco-Lanes System	<u>Connected Vehicle Roadway Equipment, Cell Tower, and Satellite sends to Eco-Lanes System</u> • Vehicle status data (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>Eco-Lanes 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) • Eco-Lanes Parameter Information (e.g., Location, entrance criteria, etc.) • Eco-Speed Limits • Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, etc.)	• ELS-DC-01: Collect Traffic Data • ELS-DC-02: Collected Environmental Data • ELS-D-03: Disseminate Traffic Conditions for the Eco-Lanes and Regular Lanes to Vehicles • ELS-D-05: Disseminate Environmental Conditions to Vehicles • ELS-D-06: Disseminate Eco-Speed Limits to Vehicles • ELS-D-07: Disseminate Vehicle Platooning Parameters • ELS-D-08: Disseminate Eco-Lanes Parameters to Vehicles

6	ITS Roadway Equipment and Eco-Lanes System	ITS Roadway Equipment sends to Eco-Lanes System • Traffic data (e.g., speed, volume, occupancy, pedestrian calls, etc.) • Environmental data (e.g., air quality data, etc.) • Road weather data (e.g., pavement friction, precipitation, air temperature, etc.) • Field Device operational status • Potential Vehicle Violations Eco-Lanes System sends to ITS Roadway Equipment • Geographic Information Description Data (e.g., lane geometries, lane configurations, posted speed limits, etc.) • Eco-Speed Limits • Eco-Lanes Parameter Information (e.g., Location, entrance criteria, etc.) • Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, etc.) • Ramp Meter Timing Plans	• ELS-DC-01: Collect Traffic Data • ELS-DC-02: Collected Environmental Data • ELS-D-06: Disseminate Eco-Speed Limits to Vehicles • ELS-D-07: Disseminate Vehicle Platooning Parameters • ELS-D-08: Disseminate Eco-Lanes Parameters to Vehicles • ELS-DP-09: Detect Violations for Individual Vehicles • ELS-D-01: Provide Ramp Meter Timing Plans to Roadway Equipment

7	Eco-Lanes System and Other Centers	Eco-Lanes System sends to other Traffic Management Centers • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality data, code red air quality alerts) • Ramp Meter timing plans in operation • Eco-Lanes and Vehicle Platooning Parameters • Road weather conditions (e.g., pavement conditions) Eco-Lanes System sends to Emissions Management Centers • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality data, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) Eco-Lanes System sends to Travelers (via ISPs) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality data, code red air quality alerts) • Eco-Lanes and Vehicle Platooning Parameters • Road weather conditions (e.g., pavement conditions) Eco-Lanes System sends to Enforcement Agencies • Notice of Violation • Eco-Lanes and Vehicle Platooning Parameters Other Centers sends to Eco-Lanes System • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Ramp meter timing plans in operations • Eco-Lanes and Vehicle Platooning Parameters in operation • Environmental conditions (e.g., air quality data, code red air quality alerts) • Road weather conditions (e.g., pavement conditions)	• ELS-DC-01: Collect Traffic Data • ELS-DC-02: Collect Environmental Data • ELS-D-02: Disseminate Traffic Conditions to Other Centers and Travelers • ELS-D-04: Disseminate Environmental Conditions to Other Centers and Travelers • ELS-D-11: Notify Enforcement Agencies of Violations

8	Eco-Lanes System and Home or Office	<u>Eco-Lanes System sends to Homes or Offices</u> • Eco-Lanes Parameter Information (e.g., Location, entrance criteria, etc.) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality information, code red air quality alerts)	• ELS-D-02: Disseminate Traffic Conditions to Other Centers and Travelers • ELS-D-04: Disseminate Environmental Conditions to Other Centers and Travelers • ELS-D-09: Disseminate Eco-Lanes Parameters to Other Centers and Travelers
9	Eco-Lanes System and Operator	<u>Eco-Lanes System sends to Operator</u> • Traffic conditions • Environmental conditions • Road weather conditions • Performance measures • Eco-Lanes System operational status • Archive data <u>Operator sends to Eco-Lanes System</u> • Operator inputs (e.g., create eco-lane parameters, implement new platooning plan, or add new equipment (e.g., new ramp meters) to the system)	• ELS-DC-05: Collect Operator Input • ELS-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-10: 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) • Geographic Information Description data (e.g., lane geometries, lane configurations, posted speed limits, etc.) • Eco-Lanes Parameter Information (e.g., location, entrance criteria, etc.) • Eco-Speed Limits • Vehicle Platooning Parameters (e.g., locations, number of vehicles, speeds, 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 if Vehicle meets Eco-Lane Parameters and / or Platooning Parameters • Determine Eco-CACC and Platooning Strategies • Determine vehicle emissions data (e.g., determine BEM for dissemination) <u>Disseminate Data</u> • Eco-driving recommendations to driver and driver feedback • Traffic and Environmental Conditions to the driver • Eco-Lanes and Vehicle Platooning Parameters to the driver • 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>Vehicle Control</u> • Vehicle assisted control (e.g., control of vehicle acceleration and speed) <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.) • 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	• IVS-DC-01: Collect Driver Input • IVS-DC-02: Receive Traffic Conditions Data • IVS-DC-03: Collect Geographic Information Description Data • IVS-DC-04: Receive Environmental Conditions Data • IVS-DC-05: Receive Vehicle Platooning Parameters • IVS-DC-06: Receive Eco-Lanes Parameter Information • IVS-DC-07: Receive Eco-Speed Limits • IVS-DC-08: Receive Vehicle Status Data from Other Vehicles • IVS-DC-09: Collect Vehicle Diagnostics Data • IVS-DC-10: Receive Inductive Charge • IVS-DP-01: Generate Eco-Driving Strategies • IVS-DP-02: Determine if Vehicle Meets Criteria for Vehicle Platooning • IVS-DP-03: Generate Eco-Cooperative Adaptive Cruise Control and Vehicle Platooning Strategies • IVS-DP-04: Determine if the Vehicle Meets Criteria to Enter the Eco-Lanes • IVS-DP-05: Process Traffic and Environmental Data for Traveler Information Messages • IVS-DP-06: Determine

12	Eco-Lanes System	Collect Data • Traffic data (e.g., speeds, volumes, occupancy, vehicle types, turning movements, CCTV images, incidents, etc.) • Environmental data (e.g., vehicle emissions, local air conditions, etc.) • Road weather conditions (e.g., pavement friction, precipitation, air temperature, etc.) • Operational status of dynamic eco-lanes system and other devices • Operator input (i.e., new device installation, new timing plans, eco-lanes parameters, etc.) Process Data • Process traffic data • Generate predicted traffic conditions • Process environmental data • Generate predicted environmental data • Generate Eco-Speed Limits • Generate Vehicle Platooning Parameters • Create and Decommission Eco-Lanes • Detect Violations • Generate ramp meter timing strategy (e.g., determine eco-timing strategy) Disseminate Data • Ramp Meter 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) • Eco-Speed Limits • Vehicle Platooning Parameters • Eco-Lanes Parameters • Notice of Violation User Interface • Traffic conditions • Environmental conditions • Road weather conditions • Performance measures • Dynamic eco-lanes system operational status • Archive data • Operator inputs (e.g., creating new ramp meter timing plans, implementing timing plans, creating eco-lane parameters or adding new equipment to the system)	• ELS-DC-01: Collect Traffic Data • ELS-DC-02: Collect Environmental Data • ELS-DC-03: Collect Field Device Status Data • ELS-DC-04: Collect Vehicle Specific Data • ELS-DC-05: Collect Operator Input • ELS-DP-01: Process Traffic Data • ELS-DP-02: Generate Predicted Traffic Conditions and Forecast Demand • ELS-DP-03: Process Environmental Data • ELS-DP-04: Generate Predicted Emissions Profile • ELS-DP-05: Generate Ramp Meter Timing Strategy • ELS-DP-06: Generate Eco-Speed Limits • ELS-DP-07: Generate Vehicle Platooning Parameters • ELS-DP-08: Create and Decommission Eco-Lanes • ELS-DP-09: Detect Violations for Individual Vehicles • ELS-D-01: Provide Ramp Meter Timing Plans to Roadway Equipment • ELS-D-02: Disseminate Traffic Conditions to Other Centers and Travelers • ELS-D-03: Disseminate Traffic Conditions for the Eco-Lanes and Regular Lanes to Vehicles

9 Scenarios

This section describes scenarios for the Eco-Lanes 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: Establishing an Eco-Lane

Actors. Eco-Lanes System, In-Vehicle System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Traffic Management Centers, Emissions Management Centers, Transit Management Centers, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. Metropolis City is one of the more congested and polluted cities in the country. To help reduce emissions in the city, the Metropolis City Department of Transportation (MCDOT) along with elected officials decided to implement traffic responsive eco-lanes along the freeways entering the city. The eco-lanes are flexible in that the system allows MCDOT to commission the eco-lane(s) based on real-time traffic and environmental conditions. It also allows MCDOT to establish parameters for entering the eco-lanes in accordance with regulations or policies established by state legislation. The purpose of the eco-lanes is to get people to make "greener" transportation decisions. This may include using public transportation or changing their departure times to avoid congestion. Additionally, the city also wants to promote the use of alternative fuel vehicles, which produce fewer emissions than petroleum fuel vehicles.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes moderate penetration rates of vehicles equipped with connected vehicle technologies. Since penetration rates are less than 100%, some vehicles are not equipped.
- The scenario assumes high penetration rates of Connected Vehicle Roadway Equipment deployed throughout and around Metropolis City.

- The Connected Vehicle Roadway Equipment is located at the entrance of eco-lanes and connected to the Eco-Lanes System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and vehicle detectors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

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

Table 9-1: Establishing an Eco-Lane: Scenario Steps

Step	Description
1	In-Vehicle Systems collect data from vehicle diagnostic systems and other onboard systems about the vehicle's emissions and vehicle's status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, cellular, or other wireless communications. Vehicle emissions data may be collected directly from vehicle diagnostic systems or estimated from other data collected from the vehicle. Estimates for emissions may be based on the vehicle's speed, acceleration, and engine characteristics. If emissions data cannot be collected or estimated on the vehicle, vehicle status data (e.g., speed, acceleration, engine type, etc.) may be sent to Connected Vehicle Roadway Equipment and then to the Eco-Lanes System, which would estimate vehicle emissions at a center.
2	Other Centers provide traffic, environmental, and road weather data to the Eco-Lanes System. Traffic data includes volumes, speeds, occupancy, travel times, incidents, or other traffic and road weather data collected by a Traffic Management Center. These data may be collected using ITS Roadway Equipment such as traffic sensors, probe vehicles, or other ITS technologies. Environmental data includes air quality data and/or weather data collected by Emissions Management Centers.
3	The Eco-Lanes System uses the data collected from Connected Vehicle Roadway Equipment, ITS Roadway Equipment, and Other Centers to determine whether an eco-lane should be established, and if so, the parameters of the eco-lane. These parameters include the geographic limits of the eco-lane, the duration of the eco-lane, and types of vehicle permitted to use the eco-lanes (i.e., high emitting vehicles may be restricted from using the lanes).
4	The eco-lane is established by the Eco-Lanes System and is approved by the operator. The Eco-Lanes System geo-fences the geographic limits of the eco-lane and assigns parameters including the types of vehicles permitted to use the eco-lanes.

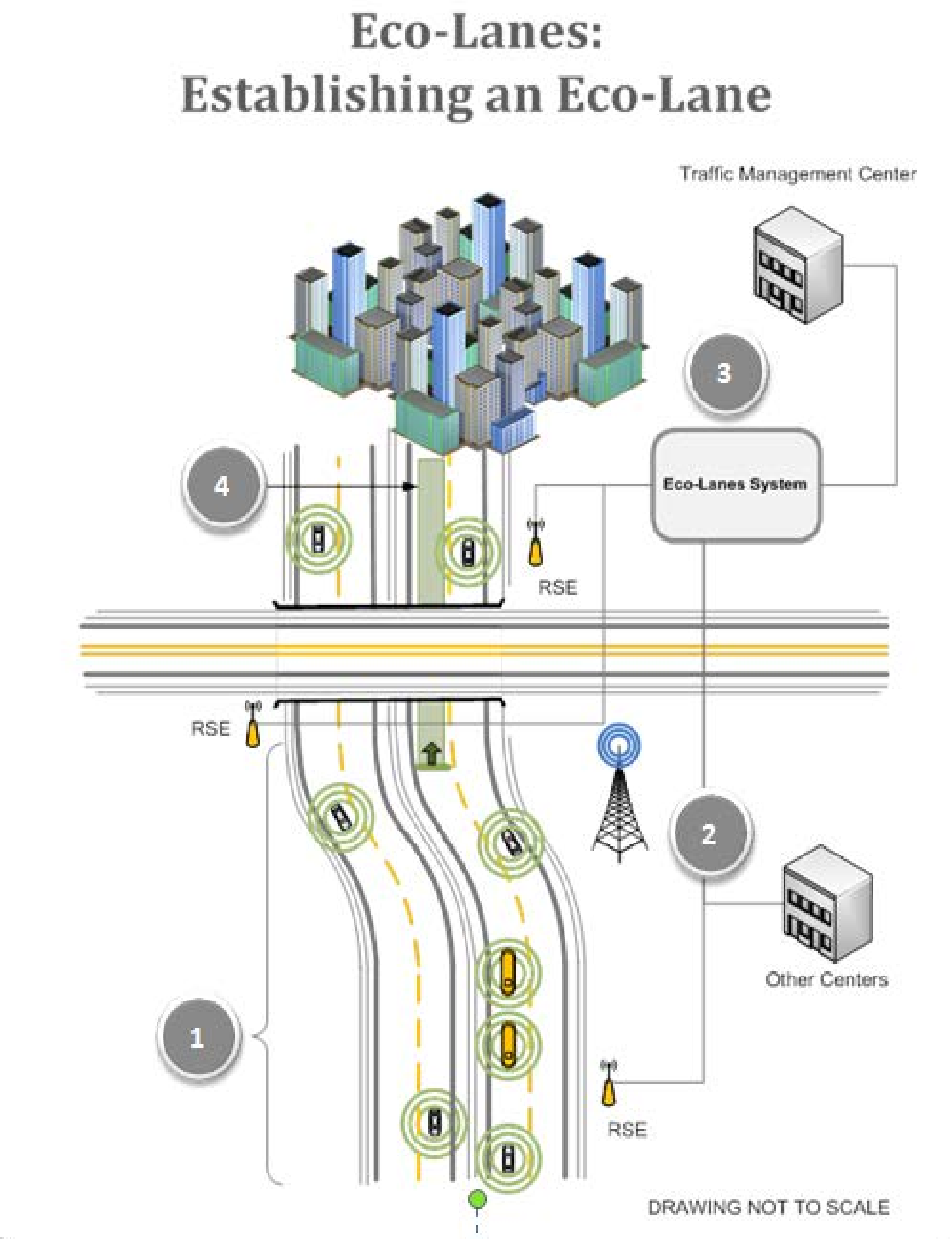


Figure 9-1: Establishing an Eco-Lane Scenario (*Source*: Noblis, 2013)

9.2 Scenario: Disseminate Eco-Lanes Traveler Information

Actors. Eco-Lanes System, In-Vehicle System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Traffic Management Centers, Emissions Management Centers, Transit Management Centers, Information Service Providers, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. Based on traffic and environmental data collected, the Eco-Lanes System determines that an eco-lane should be placed on the freeway going into Metropolis City. The decision to establish the eco-lane is in response to a code red day air quality report. The rules for the eco-lanes change from routine, everyday rules. Travelers must be alerted about these changes to parameters. Parameters for the eco-lane are established defining the geographic limits, the time the lane will be established, and the types of vehicle allowed to use the eco-lanes. Information about the parameters of the eco-lanes needs to be shared with the traveling public and other centers operating the transportation network in nearby jurisdictions.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle “knows” its current location.
- The scenario assumes moderate penetration rates of vehicles equipped with connected vehicle technologies. Since penetration rates are less than 100%, some vehicles are not equipped.
- The scenario assumes high penetration rates of Connected Vehicle Roadway Equipment deployed throughout and around Metropolis City. Additionally, cellular communications are used to convey traveler information to vehicles.
- The Connected Vehicle Roadway Equipment is located at the entrance of eco-lanes and connected to the Eco-Lanes System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and vehicle detectors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

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

Table 9-2: Disseminate Eco-Lanes Traveler Information: Scenario Steps

Step	Description
1A	The Eco-Lanes System determines the parameters for the eco-lanes.
1B	The Eco-Lanes System sends parameters about the eco-lanes to Other Centers such as Traffic Management Centers and Transit Management Centers. These centers use information about the eco-lanes to support their traffic and transit operations in the vicinity of the eco-lanes. For example, transit operators may inform their transit drivers to use the eco-lanes. Information is also sent to Information Service Providers, including the media, allowing them to disseminate information to travelers via television, radio, websites, or other sources.
1C	Using information from the Eco-Lanes System, the Connected Vehicle Roadside Equipment broadcasts traveler information messages about the parameters of the eco-lanes. Messages may be broadcast using DSRC communications or other wireless communications (e.g., 4G). This includes information such as the geographic limits of the eco-lanes, the time the lanes will be established and decommissioned, the types of vehicles permitted to use the eco-lanes, and estimated travel times and emissions for the eco-lanes versus the regular lanes.
1D	ITS Roadway Equipment including Dynamic Message Signs and 511 Traveler Information Telephone Systems provide information about the parameters of the eco-lanes. This includes information such as the geographic limits of the eco-lanes, the time the lanes will be established and decommissioned, the types of vehicles permitted to use the eco-lanes, and estimated travel times and emissions for the eco-lanes versus the regular lanes. Note: ITS Roadway Equipment will be needed to disseminate information to motorists in vehcles that are not equipped with Connected Vehicle technologies.
2	In-Vehicle Systems receive information about the parameters of the eco-lanes. This information is presented to drivers to assist them in making informed en-route travel choices as they approach the eco-lane. Prior to entering the eco-lane, drivers would be presented with comparisons of travel times and estimated fuel consumption for the eco-lanes versus the regular lanes. The traveler information would also inform the driver if his or her vehicle is permitted to use the eco-lane.
3	Travelers receive pre-trip traveler information about the parameters of the eco-lanes and other traveler information. This information may be received by travelers from MCDOT or other Information Service Providers on their personal computers, tablets, television, radio, or 511 traveler information telephone systems. Travelers use this information to plan their trips accordingly. For example, upon receiving information about the eco-lanes, travelers may to use their alternative fuel vehicle to drive into Metropolis City.

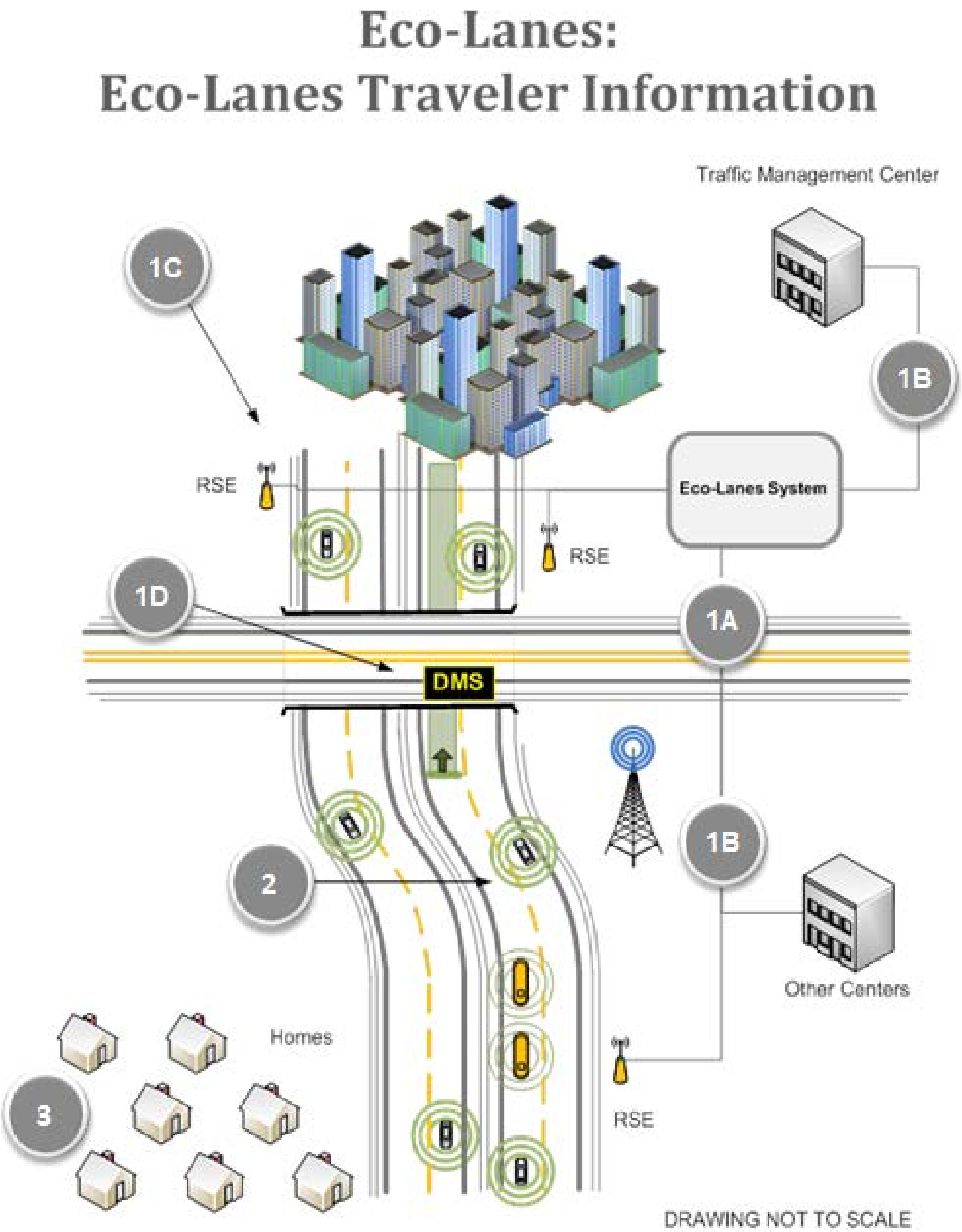


Figure 9-2: Eco-Lanes Traveler Information Scenario (*Source*: Noblis, 2013)

9.3 Scenario: Eco-Speed Harmonization

Actors. Eco-Lanes System, In-Vehicle System, ITS Roadway Equipment, Connected Vehicle Roadway Equipment, Enforcement Agencies, Transit Vehicles, Commercial Vehicles, and Passenger Vehicles

Description. The Eco-Lanes System collects vehicle status, traffic, and environmental data and uses this data to determine eco-speed limits. The Eco-Lanes System interacts with variable speed limit signs to change the speed limit based on traffic, vehicle emissions, and other environmental conditions such as road weather. The application is similar to other speed harmonization applications; however, the application's objective is to optimize eco-lanes and freeways for the environment using connected vehicle data. The application collects data such as vehicle location, traffic and incidents, speed, GHGs, and other emissions from vehicles using connected vehicle technologies and determines the optimal operation of the eco-lane 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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of vehicles equipped with connected vehicle technologies. While the penetration rate is high, it is less than 100%, meaning that some vehicles are not equipped.
- The scenario assumes high penetration rates of Connected Vehicle Roadway Equipment deployed throughout and around Metropolis City.
- The Connected Vehicle Roadway Equipment is located at the entrance of eco-lanes and connected to the Eco-Lanes System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., variable speed limit signs) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation. Legislation is also in place for automatic speed enforcement.
- Eco-speed limits are enforced by the Metropolis City Police.

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

Table 9-3: Eco-Speed Harmonization: Scenario Steps

Step	Description
1	In-Vehicle Systems collect data from vehicle diagnostic systems and other onboard systems about the vehicle's emissions and vehicle's status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, cellular, or other wireless communications. Vehicle emissions data may be collected directly from vehicle diagnostic systems or estimated from other data collected from the vehicle. Estimates for emissions may be based on the vehicle's speed, acceleration, and engine characteristics. If emissions data cannot be collected or estimated on the vehicle, vehicle status data (e.g., speed, acceleration, engine type, etc.) may be sent to a Connected Vehicle Roadway Equipment and then to the Eco-Lanes System, which would estimate vehicle emissions at a center.
2	The Eco-Lanes System collects vehicle status data from vehicles traveling in an eco-lane, via Connected Vehicle Roadway Equipment. This information along with historical traffic conditions, and data collected from roadway sensors, via ITS Roadway Equipment, are used to calculate environmentally optimized speed limits for the eco-lane(s). The speed limits also consider congestion and incidents to slow the speed of vehicles approaching the back of a queue. Eco-speed limits are determined for each roadway segment and are specific to a travel lane. Lane specific eco-speed limits need to be determined to differentiate speeds for eco-lanes versus regular lanes running adjacent to the eco-lanes. The system updates the eco-speed limit every 5 minutes based on real-time and predicted traffic conditions.
3	The Eco-Lanes System sends eco-speed limit information to VSL signs and to Connected Vehicle Roadway Equipment. Connected Vehicle Equipment disseminates the eco-speed limits using DSRC or other wireless communications. Eco-speed limits are also sent to other centers, in particular enforcement agencies that are responsible for enforcing the speed limits in the eco-lanes.
4	In-Vehicle Systems receive eco-speed limits disseminated by Connected Vehicle Roadway Equipment and present this information to the driver. The eco-speed limits are lane specific, so the speed limits can be different in the eco-lanes and the regular lanes. Additionally, if there are dedicated eco-lanes for transit, those lanes could receive an eco-speed limit specific to transit vehicles. Upon receiving the eco-speed limits, drivers adjust their vehicle's speed accordingly. In the future, if automated systems are incorporated into vehicles, the vehicle may automatically adjust its speed according to the eco-speed limit.

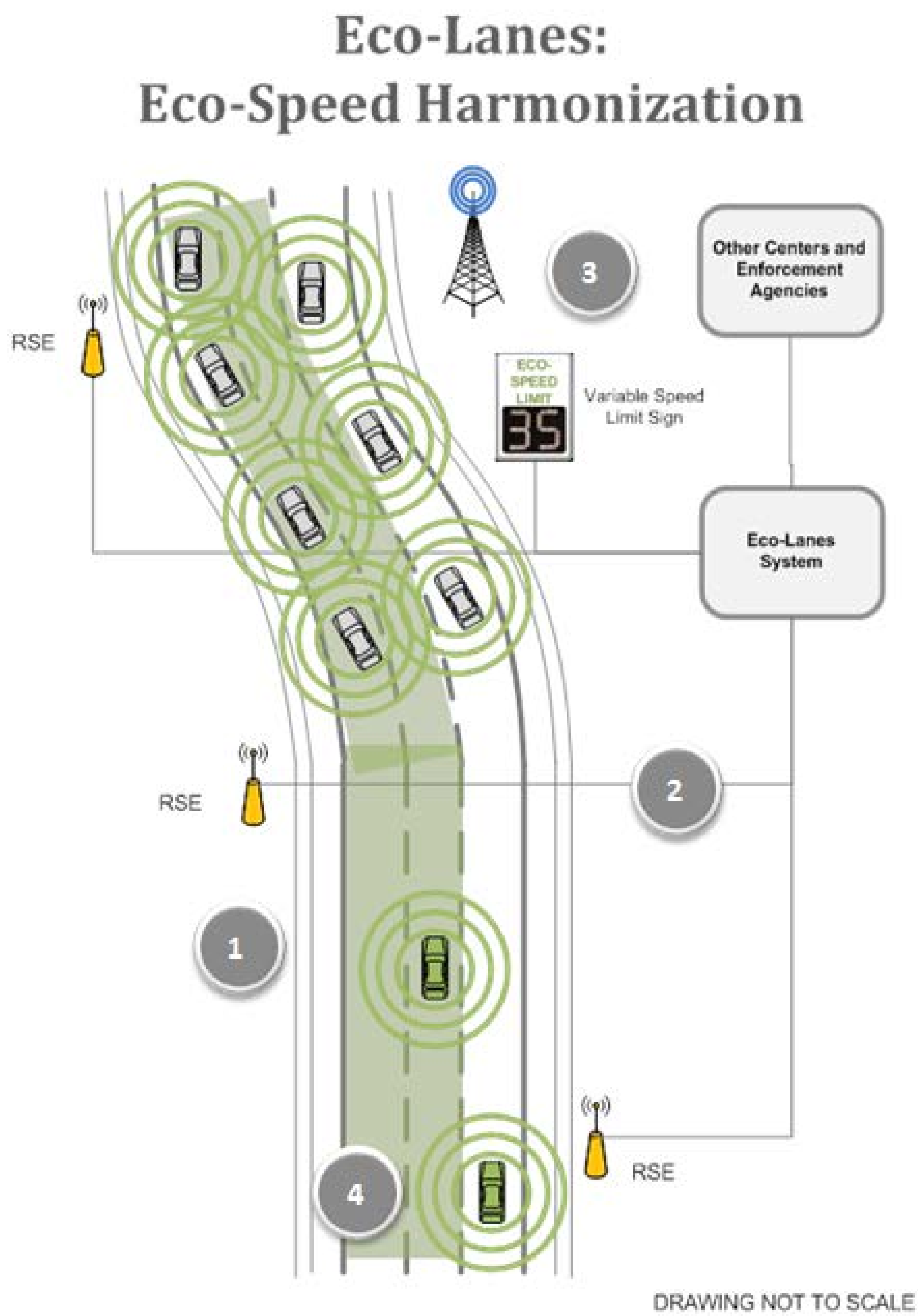


Figure 9-3: Eco-Speed Harmonization Scenario (*Source*: Noblis, 2013)

9.4 Scenario: Eco-Ramp Metering

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

Description. The Eco-Lanes System determines the most environmentally efficient operation of traffic signals at freeway on-ramps to manage the rate of vehicles entering the freeway. The Eco-Lanes System collects traffic and environmental data from vehicles and roadside equipment. These data include traffic and environmental conditions on ramps, and on the freeway upstream and downstream of ramps. The objective is to produce ramp meter timing plans that reduce overall emissions. This includes reducing emissions from bottlenecks forming on the freeway as well as emissions from vehicles on ramps.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes moderate penetration rates of vehicles equipped with connected vehicle technologies. The penetration rate is less than 100%, meaning that some vehicles are not equipped.
- The Connected Vehicle Roadway Equipment is located on freeway ramps and along the eco-lanes and regular lanes.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and vehicle detectors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

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

Table 9-4: Eco-Ramp Metering: Scenario Steps

Step	Description
1	In-Vehicle Systems collect data from vehicle diagnostic systems and other onboard systems about the vehicle's emissions and vehicle's status (e.g., current speed, acceleration, location, etc.). These data are sent to Connected Vehicle Roadway Equipment using DSRC, cellular, or other wireless communications. Vehicle emissions data may be collected directly from vehicle diagnostic systems or estimated from other data collected from the vehicle. Estimates for emissions may be based on the vehicle's speed, acceleration, and engine characteristics. If emissions data cannot be collected or estimated on the vehicle, vehicle status data (e.g., speed, acceleration, engine type, etc.) may be sent to a Connected Vehicle Roadway Equipment and then to the Eco-Lanes System, which would estimate vehicle emissions at a center.
2	The Eco-Lanes System collects vehicle status data, data from roadway sensors (e.g., vehicle detectors and weather sensors), and uses historical traffic and environmental data to determine ramp meter timing plans. These plans consider real-time and predicted traffic and environmental conditions and optimize the ramp metering system to reduce emissions on the freeway and the ramp. Ramp metering plans may include times for activating the ramp meter and the cycle length of the timing plan (e.g., red times and green times). Additionally, the Eco-Lanes System needs to monitor the queues on the ramp to ensure that vehicles waiting to enter the freeway do not impact traffic flow on the arterial.
3	The Eco-Lanes System sends the eco-ramp metering timing plans to the ramp meter controllers in the field which implement the timing plan.
4	As a vehicle approaches the ramp meter, its presence is detected. A vehicle may be detected from a vehicle detector (e.g., inductive loop or microwave sensor) or a nearby Connected Vehicle Roadway Equipment unit may receive a message about the vehicle's presence. Once the vehicle is detected, the ramp metering signal will issue a short green light (e.g., 2 seconds) allowing one vehicle to merge onto the freeway. The green light will be followed by a short red light creating a gap between vehicles merging onto the highway. By creating these gaps, vehicles can merge onto the freeway smoothly without causing vehicles to slow down on the freeway.

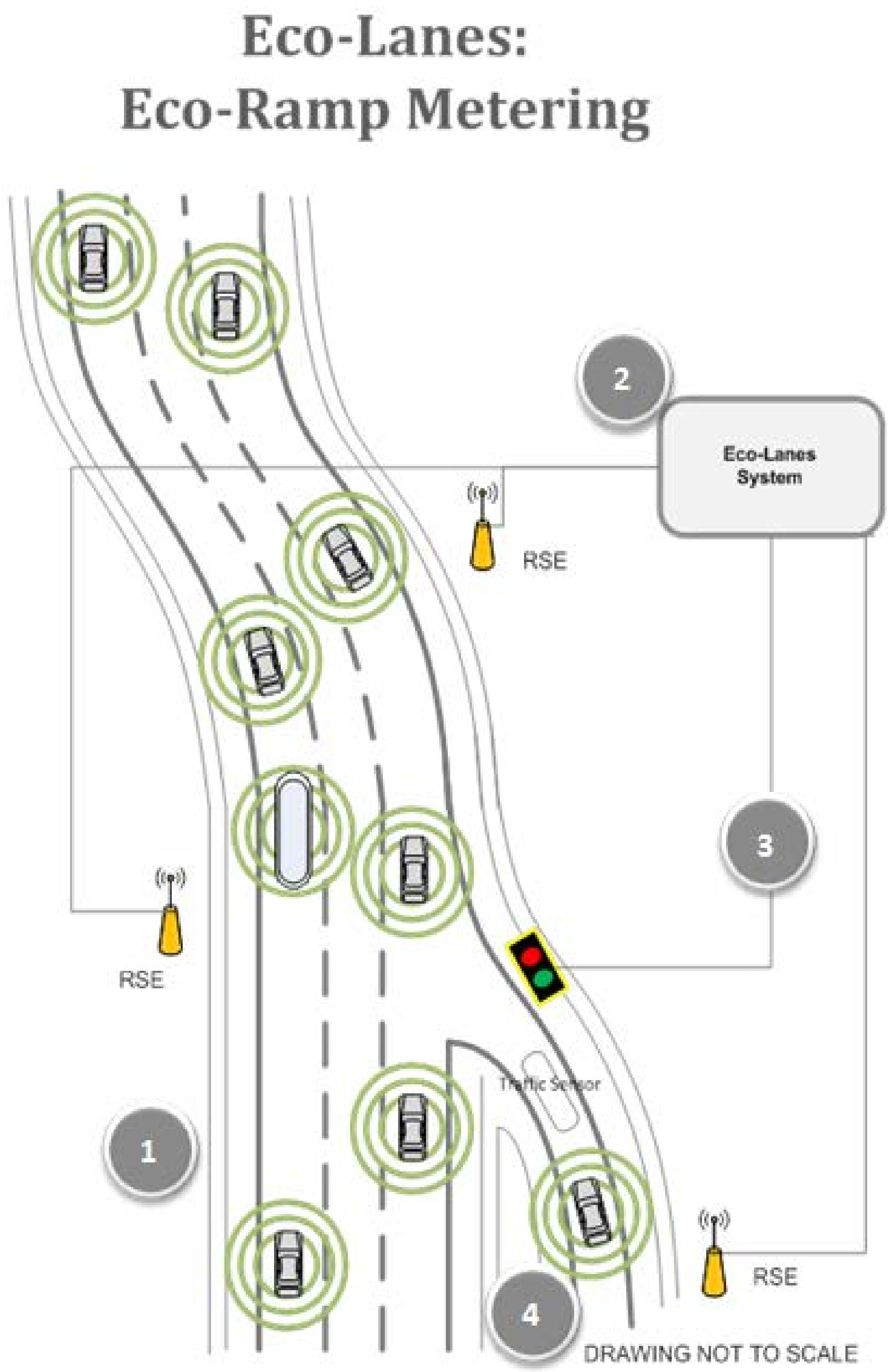


Figure 9-4: Eco-Ramp Metering Scenario (*Source*: Noblis, 2013)

9.5 Scenario: Eco-Cooperative Adaptive Cruise Control (Non-Platooning)

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

Description. The In-Vehicle System uses V2V communications to transmit a vehicle's current speed and acceleration to surrounding vehicles. This allows the following vehicle to use an eco-cooperative adaptive cruise control application that allows the driver of the following vehicle to maintain a constant speed and a safe distance from the lead vehicle without having to manually touch his/her vehicle's accelerator or brake. The application also considers other information such as road grade, roadway geometry, traffic conditions, and road weather information to determine the most environmentally efficient trajectory for the following vehicle. This information is collected from Connected Vehicle Roadway Equipment using V2I communications.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes moderate penetration rates of vehicles equipped with connected vehicle technologies. Since penetration rates are less than 100%, some vehicles are not equipped.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

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

Table 9-5: Eco-Cooperative Adaptive Cruise Control (Non-Platooning): Scenario Steps

Step	Description
1	The Eco-Lanes System determines traffic and weather conditions for the eco-lanes and regular lanes. This information includes average speeds for roadway segments, incidents, lane closures, construction and maintenance activities, and road weather conditions. Messages are disseminated to vehicles using Connected Vehicle Roadway Equipment that uses DSRC and other wireless communications (e.g., 4G).
2	The lead vehicle's In-Vehicle System collects data from its diagnostic systems about the vehicle's status (e.g., current speed, acceleration, location, etc.). These data are broadcasted to surrounding vehicles by the In-Vehicle Systems using DSRC.
3	The following vehicle is equipped with an Eco-Cooperative Adaptive Cruise Control Application. Its In-Vehicle System receives traffic conditions from Connected Vehicle Roadway Equipment and vehicle status messages from surrounding vehicles using V2V communications. V2V messages from the lead vehicle are received at a rate of ten times per second. The Driver activates the Eco-Cooperative Adaptive Cruise Control application setting a desired or acceptable gap between his/her vehicle and the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application automatically controls the speed of a vehicle adjusting the vehicle's speed to maintain a safe time gap from the lead vehicle. The Eco-Cooperative Adaptive Cruise Control application incorporates information, such as road grade, roadway geometry, and road weather information, to determine the most environmentally efficient trajectory for the following vehicle. *Note: The In-Vehicle System collects Geographic Information Description data (e.g., road grade, road geometry) from Connected Vehicle Roadway Equipment broadcasts in order to update the on-board, map database."*

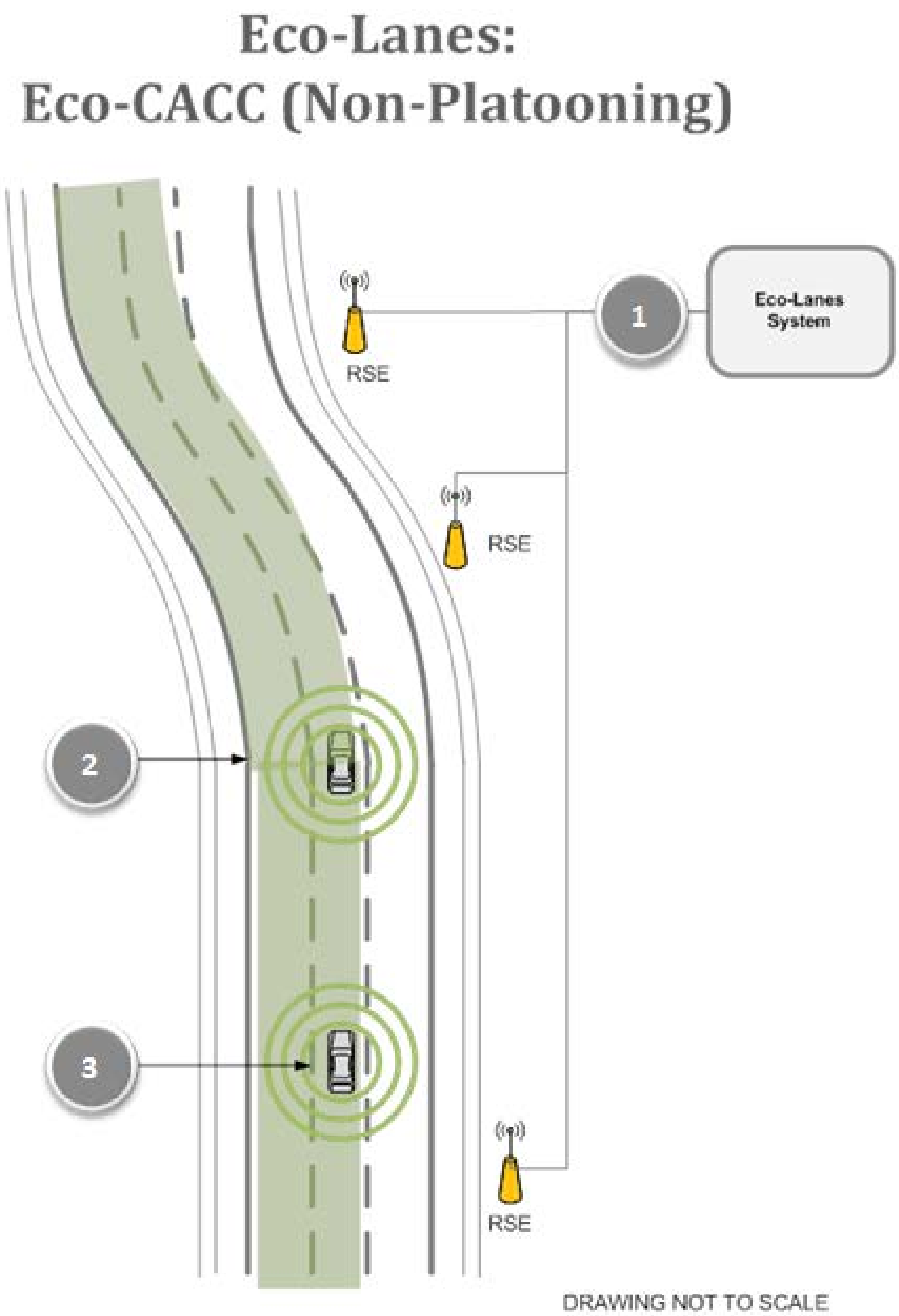


Figure 9-5: Eco-Cooperative Adaptive Cruise Control (Non-Platooning) Scenario
(*Source*: Noblis, 2013)

9.6 Scenario: Eco-Cooperative Adaptive Cruise Control (Vehicle Entering a Platoon)

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

Description. In-Vehicle Systems have the capabilities to support vehicle platooning. Policies are in place allowing MCDOT to establishing vehicle platooning in eco-lanes. Vehicles must be pre-registered with MCDOT to be able to join a vehicle platoon. Registering vehicles for platooning ensures that only vehicles with platooning capabilities can enter a platoon. Vehicle platoons allow two or more vehicles to travel with small gaps, reducing aerodynamic drag. Platooning relies on V2V communication that allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction in drag results in reduced fuel consumption, greater fuel efficiency, and less pollution. This scenario describes a vehicle with platooning capabilities joining a vehicle platoon.

Note: The concept of vehicle platoons is larger than the AERIS Program. This scenario describes vehicle platooning at a high level. It is assumed that more details describing how a vehicle platoon will work will be captured in other connected vehicle program documentation.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of vehicles equipped with connected vehicle technologies. While the penetration rate is high, it is less than 100%, meaning that some vehicles are not equipped.
- The scenario assumes high penetration rates of Connected Vehicle Roadway Equipment deployed throughout and around Metropolis City.
- The Connected Vehicle Roadway Equipment is located at the entrance of eco-lanes and connected to the Eco-Lanes System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and vehicle detectors) are deployed throughout and around the city.
- Policies ae in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

Steps. The following table describes the steps for the scenario depicted in Figure 9-6.

Table 9-6: Eco-Cooperative Adaptive Cruise Control (Vehicle Entering a Platoon): Scenario Steps

Step	Description
1	Using Connected Vehicle Roadway Equipment, the Eco-Lanes System disseminates vehicle platooning parameters including the geographic limits (start and end locations) for vehicle platooning capabilities, as well as, speed, and gap strategies for the platoon. If security or credentialing are required for a vehicle to enter a platoon, the Eco-Lane System may disseminate the check-in or check-out data for vehicles in a platoon to ensure that only registered or safe vehicles are permitted to enter a platoon.
2	Vehicles in a vehicle platoon disseminate parameters about the platoon including the speed of the platoon, number of vehicles in the platoon, location of the platoon, and type of vehicles in the platoon (e.g., platoons may be limited to trucks or transit vehicles). This information is broadcast using V2V DSRC.
3	A vehicle approaching the back of the platoon meets the security requirements to enter the platoon and has been approved by the operating entity to join the platoon. The vehicle's In-Vehicle System receives information about the nearby platoon and its parameters. As the vehicle approaches the end of the vehicle platoon, the driver confirms through the In-Vehicle System that he wants to join the platoon. The vehicle's In-Vehicle System sends a message to the last vehicle in the platoon requesting the vehicle to join the platoon. The last vehicle in the platoon accepts the request. The vehicle "attaches" itself to the platoon. The driver is notified that he has joined the platoon and has been released from lateral and longitudinal movement of the vehicle while his vehicle is in the platoon..

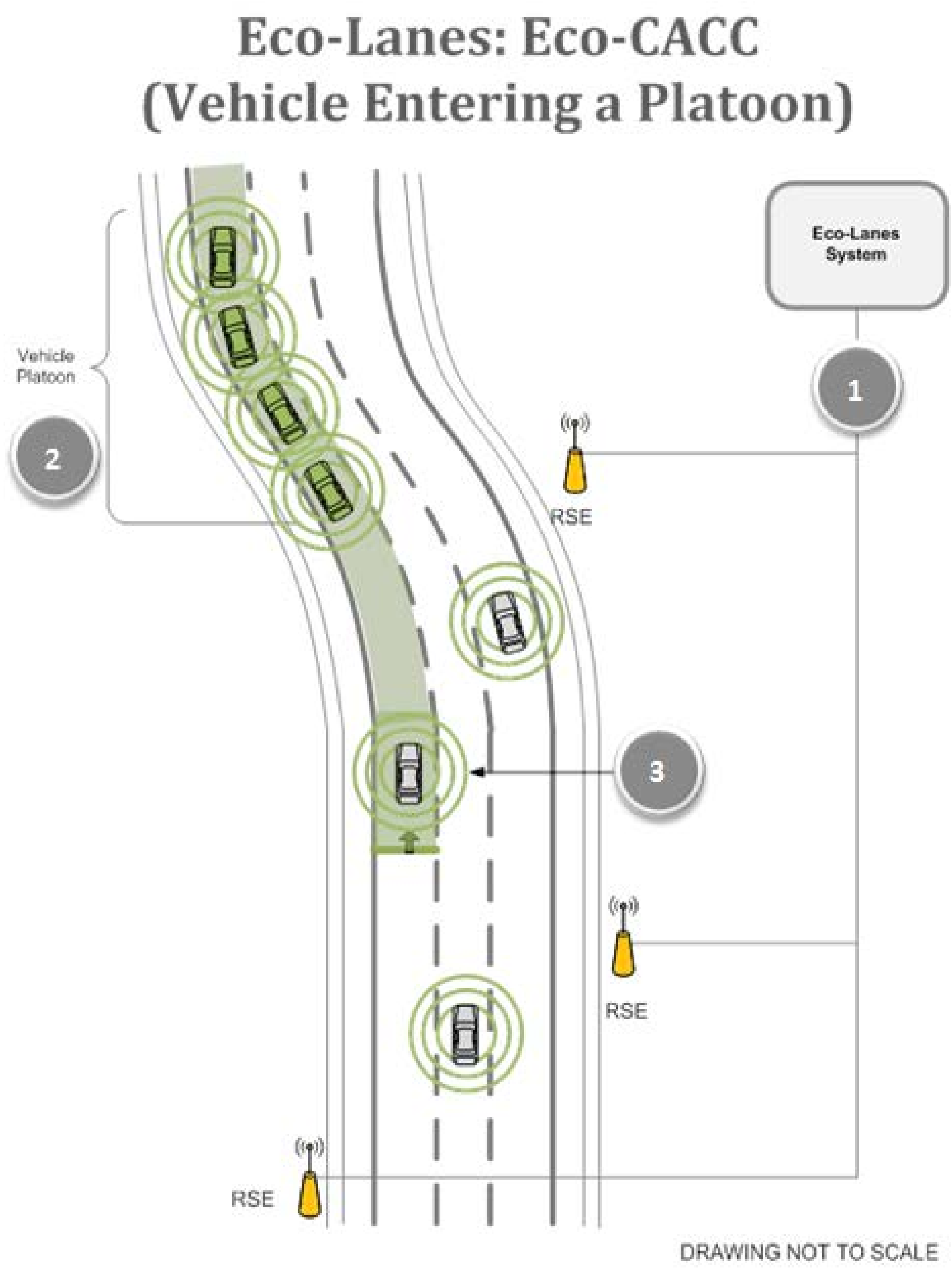


Figure 9-6: Eco-Cooperative Adaptive Cruise Control (Vehicle Entering a Platoon)
(*Source*: Noblis, 2013)

9.7 Scenario: Eco-Cooperative Adaptive Cruise Control (Vehicle Leaving a Platoon)

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

Description. In-Vehicle Systems have the capabilities to support vehicle platooning. Policies are in place allowing MCDOT to establishing vehicle platooning in eco-lanes. Vehicles must be pre-registered with MCDOT to be able to join a vehicle platoon. Registering vehicles for platooning ensures that only vehicles with platooning capabilities can enter a platoon. Vehicle platoons allow two or more vehicles travel with small gaps, reducing aerodynamic drag. Platooning relies on V2V communication that allows vehicles to accelerate or brake with minimal lag to maintain the platoon with the lead vehicle. The reduction in drag results in reduced fuel consumption, greater fuel efficiency, and less pollution. This scenario describes a vehicle leaving a platoon and merging with traffic in the regular lanes.

Note: The concept of vehicle platoons is larger than the AERIS Program. This scenario describes vehicle platooning at a high level. It is assumed that more details describing how a vehicle platoon will work will be captured in other connected vehicle program documentation.

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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- The scenario assumes high penetration rates of Connected Vehicle Roadway Equipment deployed throughout and around Metropolis City.
- The Connected Vehicle Roadway Equipment is located at the exit of eco-lanes and connected to the Eco-Lanes System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and vehicle detectors) are deployed throughout the city.
- Policies are in place allowing MCDOT to implement eco-lanes in accordance with state legislation.

Steps. The following table describes the steps for the scenario depicted in Figure 9-7.

Table 9-7: Eco-Cooperative Adaptive Cruise Control (Vehicle Leaving a Platoon): Scenario Steps

Step	Description
1	The Eco-Lanes System disseminates a message containing the location for the end of the vehicle platooning lane. The message also includes information to assist the vehicles in the vehicle platoon in merging with the regular lanes. The information includes recommended gaps and speeds for the vehicles as they leave the platoon. These recommended speeds and gaps are based on real-time traffic conditions in the eco-lanes and regular lanes. The message is broadcasted by Connected Vehicle Roadway Equipment using DSRC or other wireless communications (e.g., 4G).
2	Vehicles in the platoon receive the message about the end of the platooning lane and information about recommended speeds and gaps as the vehicles merge with the regular lanes. Prior to the end of the vehicle platooning lanes, the gaps between vehicles increase and the vehicle speeds decrease. The larger gaps between vehicles continue to increase until a threshold is met and the driver is alerted that control of the vehicle will be given back to the driver.
3	Vehicles in the regular lanes receive messages that the vehicle platooning lanes are ending. The vehicles also receive messages with recommended speeds specific to the regular lanes to assist with upcoming merging. This information is provided to drivers who manually adjust their vehicle's speed.

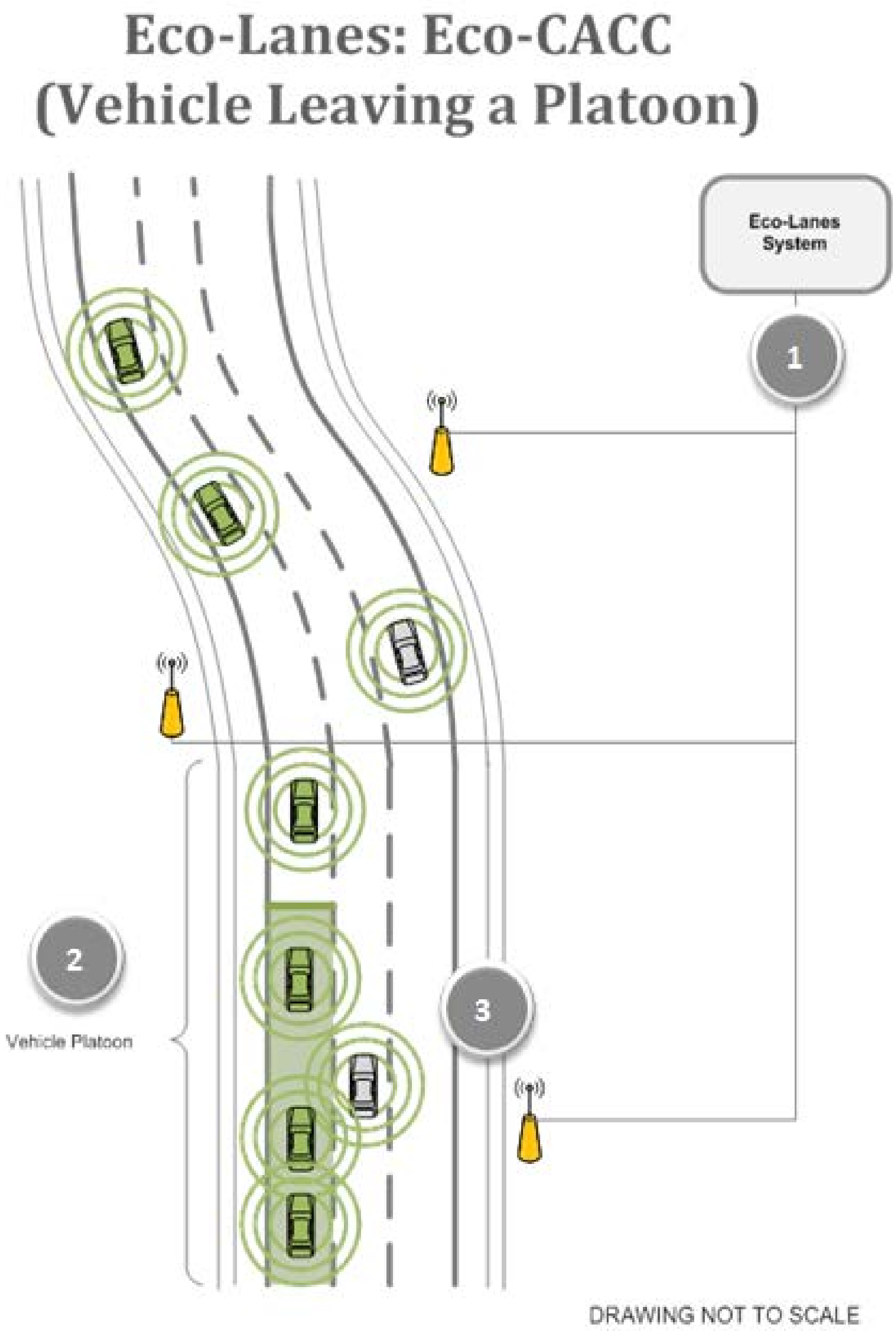


Figure 9-7: Eco-Cooperative Adaptive Cruise Control (Vehicle Leaving a Platoon)
(*Source*: Noblis, 2013)

9.8 Scenario: Dynamic Inductive Charging

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 is driving in an eco-lane. Connected Vehicle Roadway Equipment broadcasts information about the eco-lanes parameters including inductive charging capabilities. Once the vehicle enters the eco-lane, the driver of the electric vehicle opts-in to an application so his/her vehicle can begin receiving inductive charges from charging pads embedded in the roadway. If the vehicle is positioned over the wireless charging pads in the roadway and the driver of the electric vehicle activates the application, energy is sent from the wireless inductive charging pads to the vehicle. Each time a vehicle passes over a charging pad, energy is transferred to the vehicle's battery. Charging occurs when the vehicle is stopped in traffic over a charging pad, or while a vehicle is in motion and passes over a series of pads. 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 roadway network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchange ramps along the route such that the vehicle "knows" its current location.
- A series of wireless inductive charging pads are installed on freeway segments where eco-lanes can be established.
- The Connected Vehicle Roadway Equipment is located the entrance of eco-lanes and connected to the Eco-Lanes System.
- The vehicle in the eco-lane is an electric vehicle capable of receiving an inductive charge. The vehicle may be a transit vehicle, commercial vehicle, or a passenger vehicle.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with an In-Vehicle System.
- Connected Vehicle Roadway Equipment broadcasts information about the locations of inductive charging infrastructure.

Steps. The following table describes the steps for the scenario depicted in Figure 9-8.

Table 9-8: Dynamic Inductive Charging: Scenario Steps

Step	Description
1	The Connected Vehicle Roadway Equipment broadcasts parameters about the eco-lanes. These parameters, obtained from the Eco-Lanes System, include information about the presence of inductive charging infrastructure in the eco-lanes.
2	The In-Vehicle System receives messages about the parameters for the eco-lanes. The driver of the electric vehicle opts into an inductive charging application. The application informs the driver of the exact locations of inductive charging infrastructure.
3	As the vehicle approaches the first inductive charging pad, 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.
4	As the vehicle drives in the eco-lanes, it passes over wireless inductive charging pads. Each time the vehicle is positioned over the pad and the vehicle's application is activated, the vehicle receives energy from the pads. A series of inductive charging pads embedded in the roadway enable 'dynamic charging' which allows charging of vehicles in motion.
5	The vehicle stops receiving energy from the inductive charging pads when one of the following criteria is met: (1) the vehicle's battery is fully charged, (2) the driver opts out of the inductive charging application, or (3) the vehicle passes over the last charging pad. Upon termination, transfer of payment is made for the energy consumed. The In-Vehicle System notifies the driver of the battery's charge level and any payments transferred to the Inductive Charging Roadway Equipment.

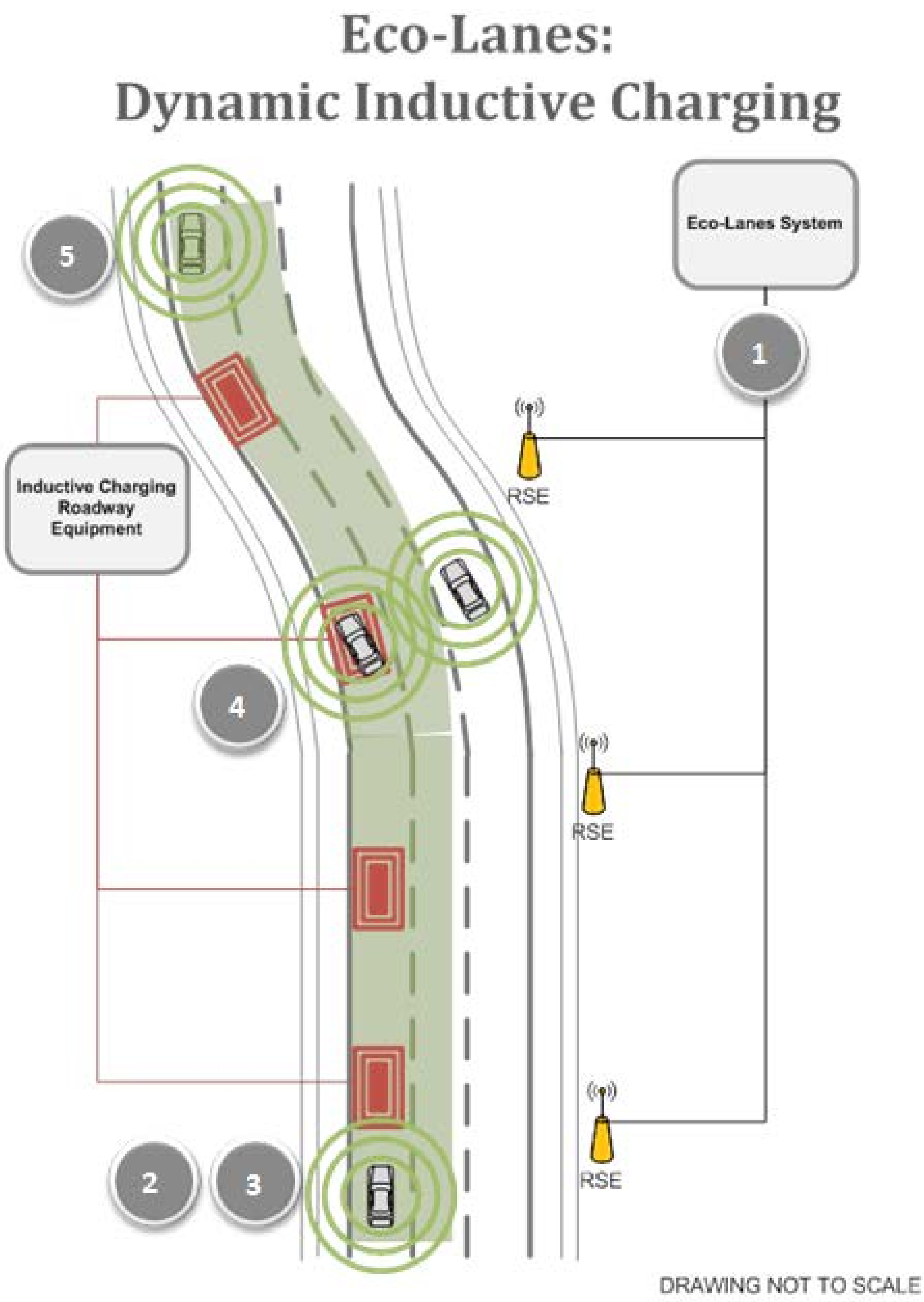


Figure 9-8: Dynamic Inductive Charging Scenario (*Source*: Noblis, 2013)

10 Goals, Objectives, and Performance Measures

This section presents an analysis of the goals, objectives, and potential performance measures for the Eco-Lanes 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 Eco-Lanes may want to measure. Objectives include "X's" and "Y's" for performance measures. 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-Lanes 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 to 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 speeds in accordance to eco-speed limits or simply switching travelers 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 by X percent by Y.
- Reduce total energy consumption per capita by X percent by Y.

Goal #2: Support "Green Transportation Decisions" by Travelers and Operating Entities

- Increase Modal Shifts to Transit, Carpooling, and Vanpooling
  - Increase alternative (non-SOV) mode share for all trips by X percent by Y.
  - Increase transit mode share by X percent by Y.
- Increase average transit load factor by X percent by Y. (Load factor is the ratio of revenue passenger miles to available seat miles of a particular transportation operation).
  - Increase passenger miles traveled per capita on transit by X percent by Y.
  - Increase the number of carpools by X percent by Y.
  - Increase use of vanpools by X percent by Y.
  - Reduce per capita single-occupancy vehicle (SOV) commute trip rate by X percent by Y.
- Increase Purchases of Alternative Fuel Vehicles (AFVs)
  - Increase purchases of personal AFVs by X percent by Y.
  - Increase purchases of transit AFVs by X percent by Y.
  - Increase purchases of freight AFVs by X percent by Y.
- Increase Vehicle Miles Traveled (VMT) of Alternative Fuel Vehicles
  - Increase VMT of personal AFVs by X percent by Y.
  - Increase VMT of transit AFVs by X percent by Y.
  - Increase VMT of freight AFVs by X percent by Y.
- 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 Goals and Objectives)*

- Improve the Efficiency of the Transportation System
  - Reduce the annual monetary cost of congestion per capita by X percent 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 Freeways
  - Reduce the number of person hours (or vehicle hours) of delay experienced by travelers on the freeway system by X by Y.
  - Reduce the share of freeway miles at Level of Service (LOS) X by Y by Z.
- Improve Transit Operating Efficiency
  - Improve average transit travel time compared to auto in major corridors by X minutes by Y.
  - Maintain or reduce a travel time differential between transit and auto during peak periods of X percent by Y.
- Improve 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 Goals and Objectives)*

- Reduce Crashes, Injuries, and Fatalities
  - Reduce the total number of crashes on the freeway by X percent by Y.
    - Reduce crashes, injuries, and fatalities on the freeway due to adverse road weather conditions by X percent by Y.
    - Reduce crashes, injuries, and fatalities on the freeway due to unexpected congestion by X percent by Y.
    - Reduce secondary, injuries, and fatalities crashes on the freeway by X percent by Y.
  - Reduce the total number of injuries on the freeway by X percent by Y.
  - Reduce the total number of fatalities on the freeway 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
ACC	Adaptive Cruise Control
AERIS	Applications for the Environment: Real-Time Information Synthesis
AFV	Alternative Fuel Vehicle
ALPR	Automatic License Plate Recognition
ANSI	American National Standards Institute
BRT	Bus Rapid Transit
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CAN	Controller Area Network
CCTV	Closed Circuit Television
CMBS	Collision Mitigation Braking System
CMEM	Comprehensive Modal Emissions Model
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DCM	Data Capture and Management
ELS	Eco-Lanes System
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSRC	Dedication Short Range Communications

Acronym	Meaning
DVI	Driver Vehicle Interface
EPA	Environmental Protection Agency
ETC	Electronic Toll Collection
ETL	Express Toll Lanes
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
GHG	Greenhouse Gas
GHz	Gigahertz
GID	Geographic Information Description
GPS	Global Positioning System
HAR	Highway Advisory Radio
HC	Hydrocarbon
HMI	Human Machine Interface
HOT	High Occupancy/Toll
HOV	High-Occupancy Vehicle
ICM	Integrated Corridor Management
IEEE	Intitue of Electrical and Electronic Engineers
ISP	Information Service provider
IVS	In-Vehicle Ssystem
ITS	Intelligent Transportation Systems

Acronym	Meaning
JPO	Joint Program Office
kph	Kilometers per Hour
kWh	Kilowatt Hours
LOS	Level of Service
MCDOT	Metropolis City Department of Transportation
MOE	Measure of Effectiveness
mpg	Miles per Gallon
NHTSA	National Highway Traffic Safety Administration
NO_X	Nitric Oxide
NO_2	Nitrogen Dioxide
NTCIP	National Transportation Communications for ITS Protocol
OBE	Onboard Equipment
OEM	Original Equipment Manufacturer
PATH	Partners for Advanced Transportation Technology
PM	Particulate Matter
RFID	Radio Frequency Identification
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SARTRE	Safe Road Trains for the Environment
SOV	Single-Occupancy Vehicle
TCIP	Transit Communications Interface Profiles
TMC	Traffic Management Center
TMDD	Traffic Management Data Dictionary

Acronym	Meaning
UCR	University of California – Riverside
U.S.	United States
USDOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VSL	Variable Speed Limit
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Wi-Fi	Wireless Fidelity
X2D	Vehicle or Infrastructure-to-Device
3G	Third Generation
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.

- **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 Institute of Electrical and Electronics Engineers (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.

- **Enforcement Agencies.** The Enforcement Agencies actor represents the systems that receive reports of violations detected by various ITS facilities including individual vehicle emissions, toll violations, excessive speed in work zones, etc.
- **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.
- **Information Service Provider.** The Information Service Provider actor collects, processes, stores, and disseminates transportation information to system operators and the traveling public. The actor can play several different roles in an integrated ITS. In one role, the ISP provides a data collection, fusing, and repackaging function, collecting information from transportation system operators and redistributing this information to other system operators in the region and other ISPs. In this information redistribution role, the ISP provides a bridge between the various transportation systems that produce the information and the other ISPs and their subscribers that use the information. The second role of an Information Service Provider is focused on delivery of traveler information to subscribers and the public at large. Information provided includes basic advisories, traffic and road conditions, transit schedule information, yellow pages information, ride-matching information, and parking information. The subsystem also provides the capability to provide specific directions to travelers by receiving origin and destination requests from travelers, generating route plans, and returning the calculated plans to the users. In addition to general route planning for travelers, the Information Service Provider also supports specialized route planning for vehicle fleets. In this third role, the ISP function may be dedicated to, or even embedded within, the dispatch system. Reservation services are also provided in advanced implementations. Both basic one-way (broadcast) and personalized two-way information provision are supported. The ISP is most commonly implemented as an Internet web site, but it represents any traveler information distribution service including systems that broadcast digital transportation data (e.g., satellite radio networks) and systems that support distribution through I2V communications networks. The ISP accomplishes these roles using constantly evolving technologies like the Internet (World Wide Web pages), direct broadcast communications (email alerts, pagers, satellite radio network data broadcasts), communications through I2V communications networks, etc.
- **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 (HARs), 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-Lanes 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.
- **Remote Traveler Support.** The Remote Traveler Support actor provides access to traveler information at transit stations, transit stops, other fixed sites along travel routes (e.g., rest stops, merchant locations), and major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theaters. Traveler information access points include kiosks and informational displays supporting varied levels of interaction and information access. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. This basic information may be extended to include multi-modal information including traffic conditions and transit schedules along with yellow pages information to support mode and route selection at major trip generation sites. Personalized route planning and route guidance information can also be provided based on criteria supplied by the traveler. The subsystem also supports electronic payment of transit fares.
- **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.
- **Transit Management Center.** The Transit Management Center actor manages transit vehicle fleets and coordinates with other modes and transportation services. It provides operations, maintenance, customer information, planning, and management functions for the transit property. It spans distinct central dispatch and garage management systems and supports the spectrum of fixed route, flexible route, paratransit services, transit rail, and bus rapid transit (BRT) service. The actor receives special event and real-time incident data from the traffic management subsystem. It provides current transit operations data to other center subsystems. Transit Management Centers collect and store accurate ridership levels and implement fare structures for use in electronic fare collection. They also collect operational and maintenance data from transit vehicles, manages vehicle service histories, and assigns vehicle operators and maintenance personnel to vehicles and routes. The Transit Management actor also provides the capability for automated planning and scheduling of public transit operations. The actor also furnishes travelers with real-time travel information, continuously updated schedules, schedule adherence information, transfer options, and transit routes and fares.
- **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-Lanes Transformative Concept. The columns of the table are documented as follows:

- **Subsystem.** The subsystems for the Eco-Lanes Transformative Concept as portrayed in Figure 6-3 and Figure 7-3.
- **Need.** The system needs are listed in this 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 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 less than 5 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.

Table C-1: Eco-Lanes System Communication Needs and Standards

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use
Traffic Data Collection Subsystem	Collect Traffic Data (ELS-DC-01)	Vehicle stats, e.g. speed, acceleration, heading,	Vehicles	RSEs, the Eco-Lanes System	V2I, then backhaul	Medium	J2735	Characterize traffic conditions
Traffic Data Collection Subsystem	Collect Traffic Data (ELS-DC-01)	Traffic conditions	Roadside Sensors	Eco-Lanes System	Backhaul	Medium	TMDD	Characterize traffic conditions
Traffic Data Collection Subsystem	Collect Traffic Data (ELS-DC-01)	Traffic conditions	Other Centers	Eco-Lanes System	Backhaul	Medium	TMDD	Characterize traffic conditions
Environmental Data Collection Subsystem	Collect Environmental Data (ELS-DC-02)	Road weather observations	Vehicles	RSEs, then Eco-Lanes System	V2I, then backhaul	Medium	J2735	Characterize weather conditions
Environmental Data Collection Subsystem	Collect Environmental Data (ELS-DC-02)	Environmental conditions	Roadside Sensors	Eco-Lanes System	Backhaul	Medium	TMDD	Characterize weather conditions
Environmental Data Collection Subsystem	Collect Environmental Data (ELS-DC-02)	Environmental conditions	Other Centers	Eco-Lanes System	Backhaul	Medium	TMDD	Characterize weather conditions
Field Device Status Data Collection Subsystem	Collect Field Device Status Data (ELS-DC-03)	Device status	Roadside Sensors, VSL signs, and Other ITS Devices	Eco-Lanes System	Backhaul	Medium	NTCIP	Characterize device status
Vehicle Specific Data Collection Subsystem	Collect Vehicle Specific Data (ELS-DC-04)	Vehicle operating parameters	Vehicles	RSEs	V2I	Low	J2735	Determine eligibility for eco-lane
Operator Input Data Collection Subsystem	Collect Operator Input (ELS-DC-05)	Operating parameters	Operators	Eco-Lanes System	Backhaul	Low	TBD	Configure the system
Eco-Ramp Meter Timing Dissemination Subsystem	Provide Ramp Meter Timing Plans to Roadway Equipment (ELS-D-01)	Ramp meter plans	Eco-Lanes System	Ramp meters	Backhaul	Medium	NTCIP	Send update ramp meter plans to controller

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Conditions to Other Centers and Travelers (ELS-D-02)	Traffic conditions	Eco-Lanes System	Other Centers, ISPs, Travelers	Backhaul	Medium	TMDD	Characterize traffic conditions
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Conditions for the Eco-Lanes and Regular Lanes to Vehicles (ELS-D-03)	Traffic conditions	Eco-Lanes System	DMS	Backhaul	Medium	NTCIP	Info for display on DMS
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Traffic Conditions for the Eco-Lanes and Regular Lanes to Vehicles (ELS-D-03)	Traffic conditions	Eco-Lanes System	Vehicles	I2V	Medium	J2735	Eco-lane parameters
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Other Centers and Travelers (ELS-D-04)	Environmental data	Eco-Lanes System	Other Centers, ISPs, Travelers	Backhaul	Medium	TMDD	Characterize weather conditions
Traffic and Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Vehicles (ELS-D-05)	Environmental conditions	Eco-Lanes System	Vehicles	I2V	Medium	J2735, ATIS	Present weather-related warnings
Eco-Speed Limit Dissemination Subsystem	Disseminate Eco-Speed Limits to Vehicles (ELS-D-06)	Eco-speed limits	Eco-Lanes System	VSL signs	Backhaul	Medium	NTCIP	Display speed limits on signs
Eco-Speed Limit Dissemination Subsystem	Disseminate Eco-Speed Limits to Vehicles (ELS-D-06)	Eco-speed limits	Eco-Lanes System	Vehicles	I2V	Medium	J2735	Display speed limits to drivers in vehicle
Parameters for Vehicle Platooning Dissemination Subsystem	Disseminate Vehicle Platooning Parameters (ELS-D-07)	Platooning parameters	Eco-Lanes System	Vehicles	I2V	Medium	TBD	Inform drivers of platooning start, stop, speeds and gaps parameters, credential requirements

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use
Parameters for Eco-Lanes Dissemination Subsystem	Disseminate Eco-Lanes Parameters to Vehicles (ELS-D-08)	Eco-lane parameters	Eco-Lanes System	Vehicles	I2V	Medium	J2735, ATIS	Inform drivers of eco-lane parameters
Parameters for Eco-Lanes Dissemination Subsystem	Disseminate Eco-Lanes Parameters to Other Centers and Travelers (ELS-D-09)	Eco-lane parameters	Eco-Lanes System	Other Centers, ISPs, Travelers	Backhaul	Medium	NTCIP	Inform other centers and travelers of eco-lane parameters
Eco-Lanes Violations Dissemination Subsystem	Provide Notice of Violations to Vehicles (ELS-D-10)	Notice of Violation	Eco-Lanes System	Vehicles	I2V	Low	TBD	Notify driver if eco-lane violation
Eco-Lanes Violations Dissemination Subsystem	Provide Notice of Violations to Vehicles (ELS-D-10)	Notice of Violation	Eco-Lanes System	Roadway sign	Backhaul	Low	NTCIP	Notify driver if eco-lane violation
Eco-Lanes Violations Dissemination Subsystem	Notify Enforcement Agencies of Violations (ELS-D-11)	Notice of Violation	Eco-Lanes System	Enforcement Agencies	Backhaul or I2V	Low	TBD	Notify law enforcement if eco-lane violation

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)	Driver input	Driver	IVS	DVI	Low	TBD	Enables driver to configure the in-vehicle system	
Traffic Conditions Data Collection Subsystem	Receive Traffic Conditions Data (IVS-DC-02)	Traffic conditions	Eco-Lanes System	Vehicle	I2V	Medium	J2735, ATIS	Receive traffic information	
Environmental Conditions Data Collection Subsystem	Receive Environmental Conditions Data (IVS-DC-04)	Environmental conditions	Eco-Lanes System	Vehicles	I2V	Medium	J2735, ATIS	Receive road weather information	
Vehicle Platooning Parameters Data Collection Subsystem	Receive Vehicle Platooning Parameters (IVS-DC-05)	Vehicle platooning parameters	Eco-Lanes System	Vehicle	I2V	Medium	J2735	Receive information defining extent, speed of platoons	
Eco-Lanes Parameters Data Collection Subsystem	Receive Eco-Lanes Parameter Information (IVS-DC-06)	Eco-lane parameters	Eco-Lanes System	Vehicles	I2V	Medium	J2735	Information about location and duration of eco-lanes	
Eco-Speed Limit Data Collection Subsystem	Receive Eco-Speed Limits (IVS-DC-07)	Eco-speed limits	Eco-Lanes System	Vehicle	I2V	Low	J2735	Receive information about speed limits on eco-lane	
'Other Vehicle' Vehicle Status Data Collection Subsystem	Receive Vehicle Status Data from Other Vehicles (IVS-DC-08)	Vehicle status data	Other vehicles	Vehicle	V2V	Low	J2735	BSM data for adapting trajectories to those of other vehicles	

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Diagnostics Data Collection Subsystem	Collect Vehicle Diagnostics Data (IVS-DC-09)	Vehicle Diagnostics	Vehicle sensors	Vehicle OBE	CAN bus	Low	J1939	Engine and onboard sensor data	
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Data (IVS-D-01)	Vehicle Status	Vehicle	Eco-Lanes System	V2I	Low	J2735	Tell the Eco-Lanes System about itself	
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Data (IVS-D-01)	Vehicle Status	Vehicle	Other Vehicles	V2V	Low	J2735	Enable CACC, platooning	
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Environmental Data (IVS-D-02)	Environmental observations	Vehicle	RSE, the Eco-Lanes System	V2I	Medium	J2735	Report to the system on road weather conditions	
Driver Information Dissemination Subsystem	Provide Traffic Conditions to the Driver (IVS-D-03)	Traffic conditions	Vehicle	Driver	DVI	Low	TBD	Display traffic information to the driver	
Driver Information Dissemination Subsystem	Provide Environmental Conditions to the Driver (IVS-D-04)	Environmental conditions	Vehicle	Driver	DVI	Medium	TBD	Display environmental information to the driver	
Driver Information Dissemination Subsystem	Provide Eco-Lanes Parameters to the Driver (IVS-D-05)	Eco-lane parameters	Vehicle	Driver	DVI	Medium	TBD	Display eco-lane parameters to the driver	
Driver Information Dissemination Subsystem	Provide Vehicle Platooning Parameters to the Driver (IVS-D-06)	Platooning parameters	Vehicle	Driver	DVI	Medium	TBD	Display platooning parameters to the driver	

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Driver Information Dissemination Subsystem	Provide Eco-Driving Information to the Driver (IVS-D-07)	Eco-driving information	Vehicle	Driver	DVI	Medium	TBD	Display eco-driving information to the driver	

APPENDIX D. Relationship to the National ITS Architecture

Appendix D is intended to show the relationship of the Eco-Lanes 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-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'.

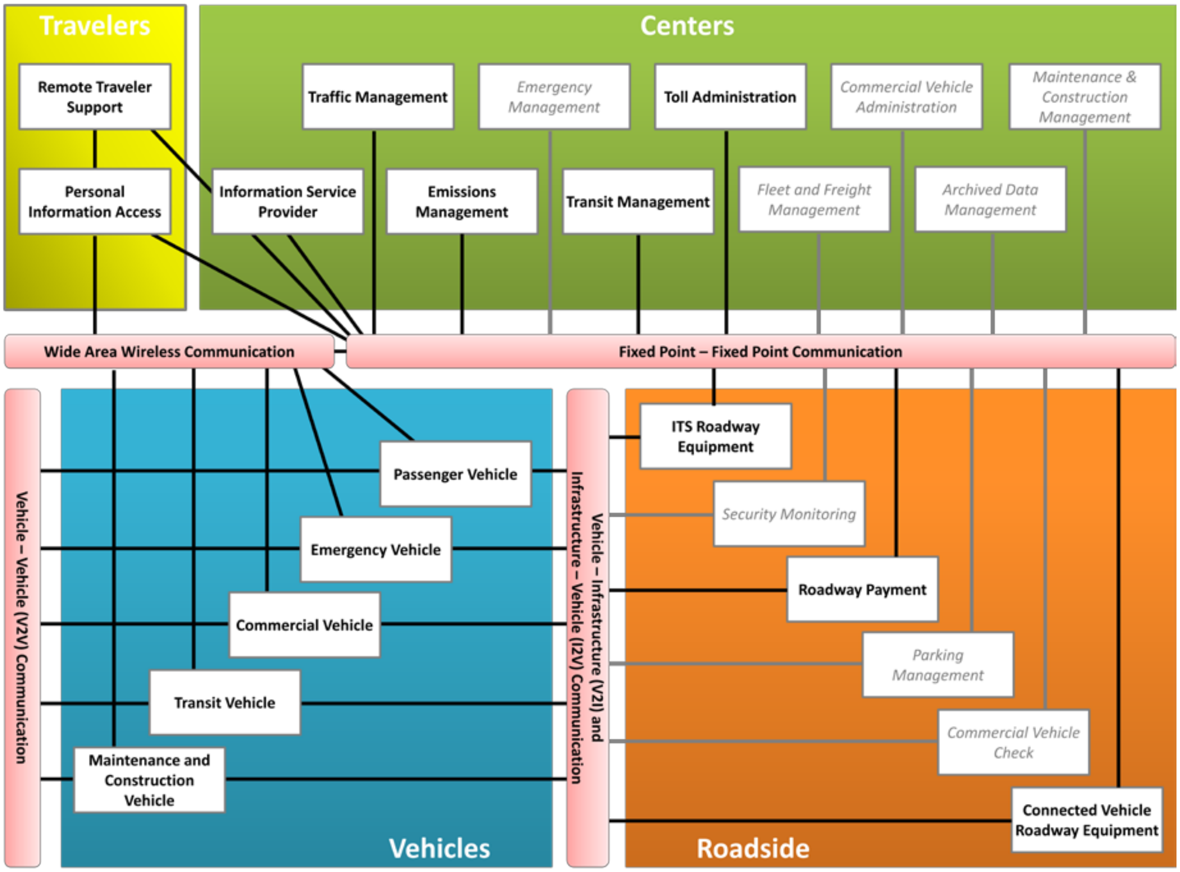

Figure D-1: Eco-Lanes Interconnect Diagram (*Source*: Adapted from the National ITS Architecture by Noblis, 2013)

The National ITS Architecture uses Market Packages diagrams to provide a graphical representation of the "flow" of information between subsystems. Figure D-2 includes a sample Market Package diagram for the Eco-Lanes 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.

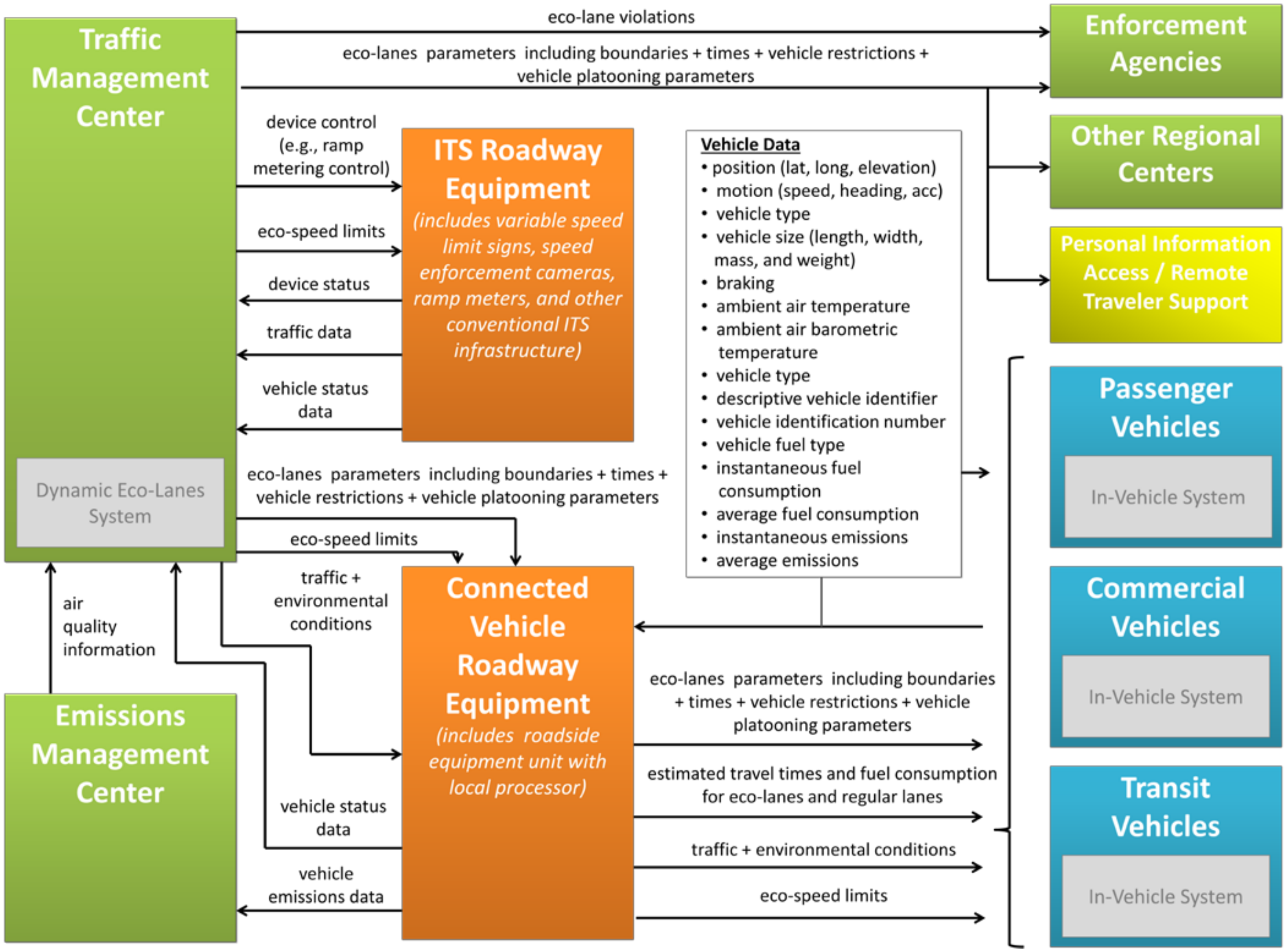

Figure D-2: Eco-Lanes Information Flow Diagram (*Source*: Noblis, 2013)

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