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

Low Emissions Zones: 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) Low Emissions Zones Transformative Concept. The Low Emissions Zone Transformative Concept includes the ability for an entity operating the transportation network to define a geographic area that seeks to restrict or deter access by specific categories of high-polluting vehicles into the area to improve the air quality within the geographic area. Alternatively, the Transformative Concept may incentivize traveler decisions that are determined to be environmentally friendly such as the use of alternative fuel vehicles or transit. At the heart of this Transformative Concept is a Low Emissions Zone Management application, which leverages connected vehicle and other technologies to determine fees or incentives for vehicles and travelers entering the low emissions zone. Fees and incentives may be based on the vehicle's engine emissions standard or emissions data collected directly from the vehicle using vehicle-to-infrastructure (V2I) communications. To encourage travelers entering the zone to use public transportation, policies may be in place to further encourage eco-decisions. For example, policy may be in place to waive fees for transit vehicles entering the low emissions zone and provide travelers on-board the transit vehicle with a voucher for future transit trips.

The Low Emissions Zones Transformative Concept provides the capability for the Low Emissions Zone to be responsive to real-time traffic and environmental conditions, allowing the operating entity to change the location, boundaries, fees, or time of the low-emissions zone. For example, this would allow the low emissions zone be commissioned based on various criteria including atmospheric conditions, weather conditions, or special events. While the low emissions zone 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 low emissions zone's parameters.

As such, pre-trip and en-route traveler information is a critical component of the Low Emissions Zones Transformative Concept. Information about criteria for vehicles to enter the low emissions zone, expected fees and incentives for their trip, current and predictive traffic conditions, and the geographic boundaries of the low emissions zone would need to be consistently communicated to the traveling public using traditional traveler information technologies (i.e., dynamic message signs, 511 systems, and webpages) as well as connected vehicle technologies.

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1 Introduction

This document serves as an Operational Concept for the Applications for the Environment: Real-Time Information Synthesis (AERIS) Low Emissions Zones 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 Low Emissions Zones Transformative Concept will operate.

The Low Emissions Zone Transformative Concept includes the ability for an entity operating the transportation network to define a geographic area that seeks to restrict or deter access by specific categories of high-polluting vehicles into the area to improve the air quality within the geographic area. Alternatively, the Transformative Concept may incentivize traveler decisions that are determined to be environmentally friendly such as the use of alternative fuel vehicles or transit. At the heart of this Transformative Concept is a Low Emissions Zone application, which leverages connected vehicle and other technologies to determine fees or incentives for vehicles and travelers entering the low emissions zone. Fees and incentives may be based on the vehicle's engine emissions standard or emissions data collected directly from the vehicle using vehicle-to-infrastructure (V2I) communications. To encourage travelers entering the zone to use public transportation, policies may be in place to further encourage eco-decisions. For example, policy may be in place to waive fees for transit vehicles entering the low emissions zone and provide travelers on-board the transit vehicle with a voucher for future transit trips.

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1.1 Goals

The Low Emissions Zones Transformative Concept, and its associated applications, are expected to meet the following goals:

- **Goal #1: Reduce Environmental Impacts.** This Transformative Concept is expected to: (a) reduce emissions and energy consumption from surface transportation vehicles and (b) provide air quality improvements for the low emissions zone through implementation of emissions pricing strategies for a given area. Emissions pricing or incentives are expected to encourage "green" transportation choices include modal shift, eco-driving, and the use of fuel efficient vehicles.
- **Goal #2: Support "Green Transportation Decisions" by Travelers and Operating Entities.** This Transformative Concept is expected to increase modal shifts to transit, walking, bicycling, carpooling, and vanpooling through the implementation of emissions pricing or incentive strategies. It is also expected to encourage drivers to use alternative fuel vehicles (AFVs) and increase the awareness and practice of eco-driving strategies by providing incentives to drivers that drive "green" within the low emissions zone.
- **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, into the low emissions zone. This reduction in vehicle trips is expected to result in less traffic volumes, thus increasing mobility within and around the low emissions zone.

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 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 Low Emissions Zones 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?

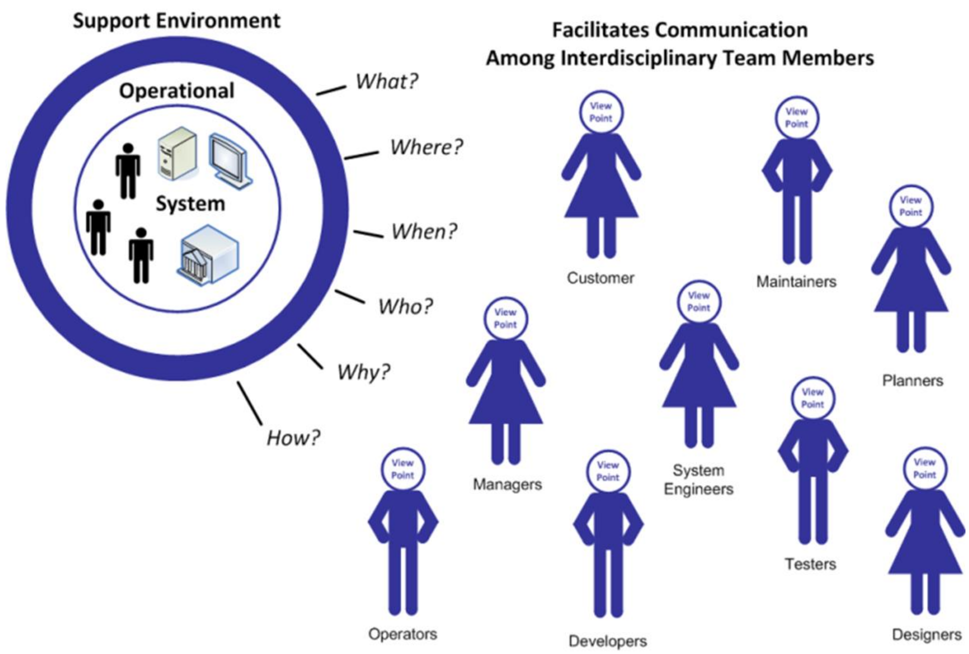

Figure 1-1: Conceptual Representation of the Operational Concept Document
(*Source: Noblis, adapted from ANSI/AIAA's "Guide for the Preparation of Operational Concept Documents" ANSI/AIAA G-043-1992)*

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 low emissions zones. This section is meant to familiarize the reader with the current state of the practice regarding low emissions zones and their environmental benefits.
- **Section 4** describes the shortcomings of current systems, situations, or applications that motivate development of the Transformative Concept. This chapter provides a transition from Chapter 3 of the Operational Concept, which describes the current situation, to Chapter 5, which describes the proposed Transformative Concept.
- **Section 5** provides a description of the Low Emissions Zones 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) a Low Emissions Zone System and (2) an In-Vehicle System. The chapter concludes with a discussion of how these systems interact with one another through a connected vehicle environment.
- **Section 6** describes the Low Emissions Zone System from a systems engineering perspective. This chapter 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 chapter may be more appealing to systems engineers than other readers.
- **Section 7** describes the In-Vehicle System from a systems engineering perspective. This chapter 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 chapter 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 chapter 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 chapter 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 Low Emissions Zones 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 Low Emissions Zones 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.

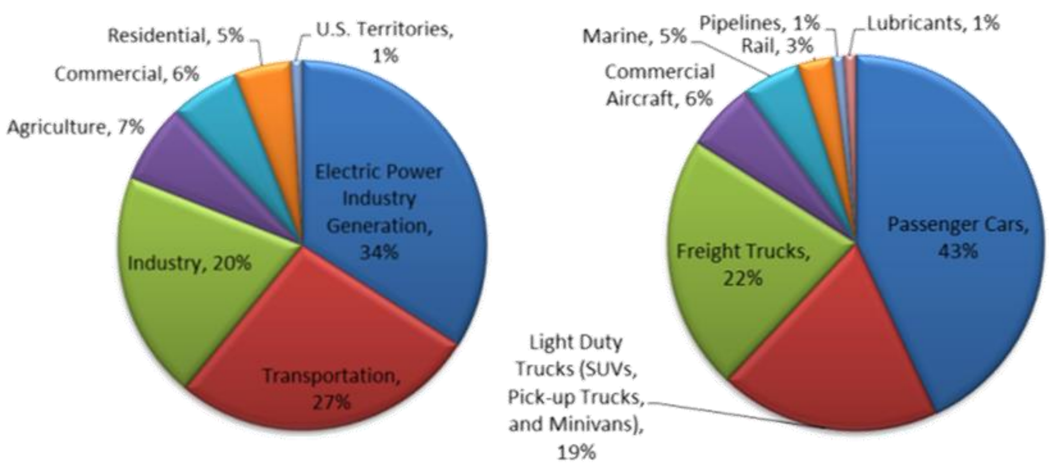

Figure 2-1: Transportation's Impact on the Environment *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012)*

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.

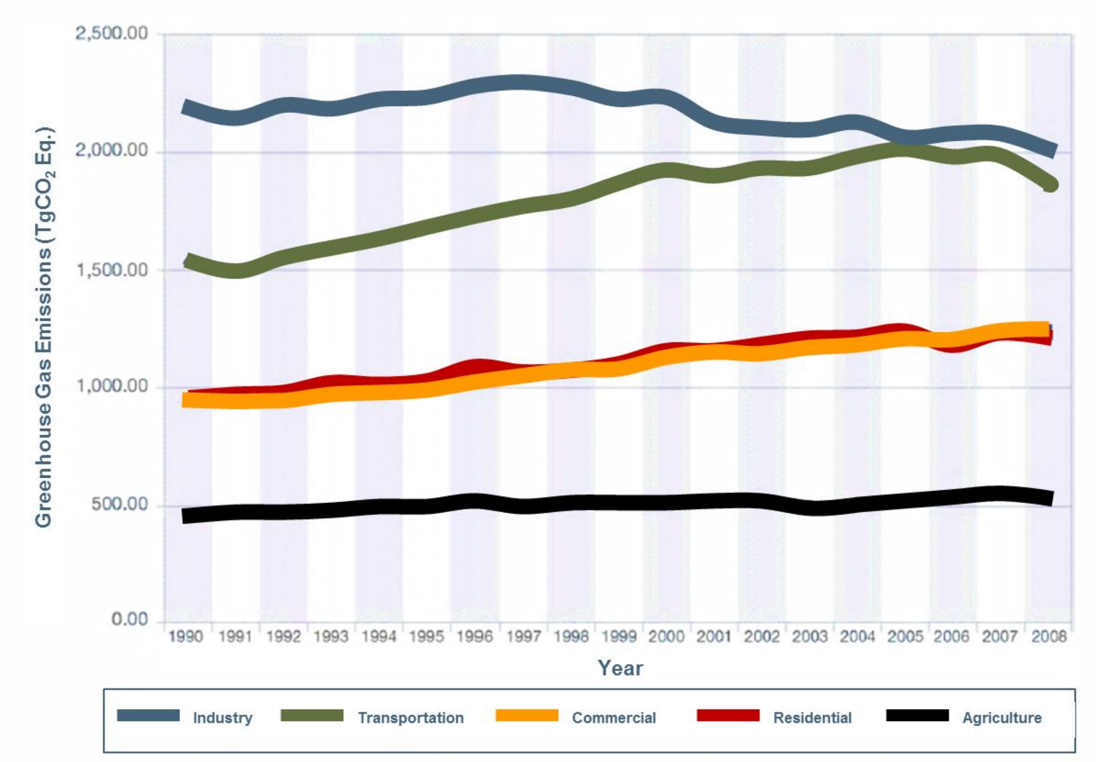

Figure 2-2: GHG Trends 1990 to 2008 *(Source: Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 to 2010. 2012)*

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 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.

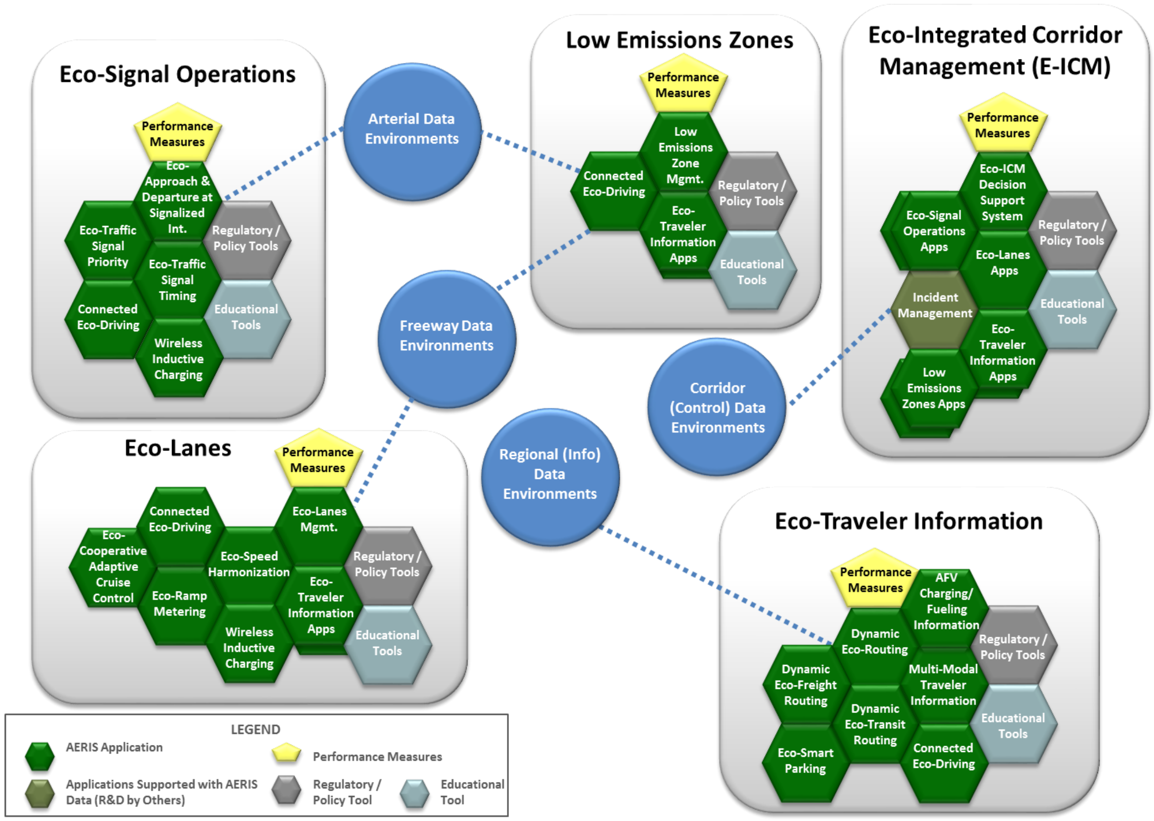

Figure 2-3: AERIS Transformative Concepts (*Source: Noblis, 2013)*

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

Congestion and emissions pricing strategies include surcharging users of the transportation network higher charges during peak periods to reduce traffic congestion or vehicular emissions. Variable pricing regulates demand, making it possible to manage congestion or emissions without increasing supply. Congestion pricing is currently limited to a small number of cities, including London, Stockholm, Singapore, and Milan. Congestion pricing, also known as "value pricing," works by "shifting purely discretionary rush hour highway travel to other transportation modes or to off-peak periods, taking advantage of the fact that the majority of rush hour drivers on a typical urban highway are not commuters." Removing as little as five percent of the vehicles from a congested roadway through pricing "enables the system to flow much more efficiently, allowing more cars to move through the same physical space" and has the potential to reduce vehicular emissions. A similar concept can be implemented to limit heavy polluting vehicles from using a roadway or entering into a zone.

Variable charging strategies have been successful in other industries, including airline tickets, cellular phone rates, and electricity rates. There is a consensus among economists that "congestion pricing represents the single most viable and sustainable approach to reducing traffic congestion" and vehicular emissions.[4] Research indicates that there are four types of pricing strategies:

- Variable priced lanes, including separated express toll lanes (ETLs) and high-occupancy toll (HOT) lanes;
- Variable tolls on entire roadways, roadway segments, bridges or toll-free roads during rush hours;
- Cordon (or zone-based) charging fees that charge drivers to enter and drive in congested areas; and
- Area-wide charges, including distance-based charging or mileage fees based on congestion levels.[5]

The Low Emissions Zones Transformative Concept is focused on the third type of pricing strategy. One of the more promising options to introduce and promote the use of a greater number of cleaner vehicles is through a low emissions zone. Traditional low emissions zones include defined areas that do not charge a fee for specified vehicles meeting certain emissions criteria or standards, but do impose a fee for vehicles not meeting the specified emissions criteria. There are exceptions to fee charging; however, these are usually unique to each low emissions zone. Typically, traditional low emissions zones are permanently defined geographic areas. While traffic volumes may not necessarily change, a higher number of the vehicles travelling in an area are cleaner vehicles with lower emissions, and this leads directly to air quality improvements.

Low emissions zones for commercial vehicles (i.e., trucks) have been successfully implemented and operated for many years in the Swedish cities of Stockholm, Gothenburg, Malmo, and Lund, where they have led to improvements in air quality. Several other European cities have implemented low emissions zones to help reduce emissions. One of the most successful systems is London's Low Emissions Zone that began operating in February 2008 to address the city's poor air quality to improve the health and quality of life of city residents. London has the worst air pollution in the United Kingdom and is one of the most polluted cities in all of Europe. The Low Emissions Zone aims to reduce traffic pollution by deterring the most polluting passenger vehicles, trucks, buses, coaches, mini-buses, and large vans from driving within the city.[6]

Before describing this system it is important to differentiate between a congestion charging zone and a low emissions zone – both of which are implemented in London, but confused by many as being one and the same. Both strategies have to potential to reduce vehicular emissions. Section 3.1 describes London's Congestion Charge Zone and London's Low Emissions Zone is discussed in Section 3.2. Section 3.3 and 3.4 discuss Stockholm's Congestion Charging Zone and Electronic Toll Collection, respectively.

3.1 London's Congestion Charging Zone

In 2003, the Transport of London began operating a congestion charging zone covering eight square miles of Central London. The zone was expanded to portions of West London in 2007, nearly doubling in size. Drivers are assessed a daily fee of £8. However, in October 2010 London's mayor announced a number of changes to the zone. The western extension of the zone was removed after December 24, 2010, and the daily fee was increased to £10 on January 4, 2011.[7]

The zone includes road signs alerting drivers when they are entering and leaving the charging zone, which operates Monday through Friday from 7:00 am to 6:00 pm, excluding holidays and the days between December 25th and January 1st. Upon entry, departure, and driving within the zone, cameras capture vehicle license plate numbers, and automatic license plate recognition (ALPR) technology uses optical character recognition software to identify vehicles. Software then compares the license plate number to a database of vehicle registration numbers (VRN) to analyze whether payment is required. Exemptions are given to a variety of vehicles, such as motorcycles, emergency vehicles, vehicles driven by or carrying disabled drivers, licensed taxis, alternative fuel vehicles (AFVs), and residents that live within the zone who receive a 90 percent discount. Beginning January 4, 2011, plug-in hybrid electric vehicles and vehicles that emitted 100g/km or less of CO_2 and met the Euro V standard for air quality were exempt from the fee.[8,9]

Eligible vehicles and drivers enter the zone and are assessed a daily charge of £10. There are a variety of ways to pay the charge. Drivers who enter the zone on a regular basis can pay in advance in monthly and annual increments at a discounted rate. Otherwise, drivers who are assessed the fee must pay in advance or by midnight on the day of travel. Late fees apply for payments received after this time. London accepts payments online, at select retailers, and by text message, phone, and mail (by mail requires payment 10 days in advance). In January 2011, an automated payment system was deployed allowing drivers to register with the payment system and have their debit or credit card charged on a monthly basis. Users of the automated payment system pay a reduced daily fee of £9.[10,11]

Congestion charging has provided both mobility and environmental benefits to London. As a result of the pricing scheme, travelers made significant mode changes to transit thus reducing congestion within the zone. Studies also show that emissions levels decreased since implementation of the London Congestion Charging Zone. A study by the Transport of London compared emission levels in 2002, when the zone did not exist, with levels in 2003. Both NO_x and Particulate Matter-10 (PM10)[12] were reduced by 13 and 15 percent, respectively. In addition to the environmental benefits, vehicle traffic declined by approximately 20 percent (around 20,000 vehicles per day) within Central London. Traffic speeds in the zone increased by 37 percent during charging hours and taxi travel costs were reduced by 20 to 40 percent due to reduced delays. Impacts at the perimeter of the zone were neutral.[13]

3.2 London's Low Emissions Zone

Complimentary to the London Congestion Charging scheme, the city also established a low emissions zone that began operating in February 2008. The low emissions zone "aims to reduce traffic pollution by deterring the most polluting diesel-engine lorries [trucks], buses, coaches, minibuses, and large vans from driving within the city."[14]

London's Low Emissions Zone covers roadways 24 hours a day, seven days a week within the Greater London Authority boundary and currently applies to older diesel trucks, buses, and coaches, regardless of whether they are operated for commercial or private use or whether the vehicles are registered in the United Kingdom or another country. These vehicles must meet the Euro III standard for particulate matter (PM), or else pay a daily fee of £200 to drive in the Low Emissions Zone. Euro III[15] standards limit emissions of Carbon Monoxide (CO) to 2.1 grams per kilowatt hour (g/kWh), Hydrocarbons (HC) to 0.66 g/kWh, NO_x to 5.0 g/kWh, and PM to 0.10 g/kWh. Vehicles that also travel into the London Congestion Charging Zone must pay any applicable congestion fees. According to a 2006 study, concentrations of small particles from traffic sources were expected to decrease across London by 4.3 percent in 2008 and 8.0 percent in 2010 due to the Low Emissions Zone, and NO_x was expected to decrease by 3.2 percent in 2008 and 4.1 percent in 2010.[16,17]

Similar to London's Congestion Charging Zone, road signs alert drivers when they are entering and leaving the low emissions zone. Cameras capture license plate numbers, and ALPR technology uses optical character recognition software to identify vehicles and the system software compares them to a database of vehicles that meet the low emissions zone emissions standards to analyze whether payment is required. Vehicles registered in other countries that meet the low emissions zone emissions standards and plan to travel in the zone must register with Transport for London to avoid fees. Exemptions are given to vehicles designed primarily for off-road use, classic vehicles built before 1973, military vehicles, and travelling salesperson vehicles.[18]

London's Low Emissions Zone does not apply to cars, motorcycles, and small vans. It was initially planned that large diesel vans and minibuses would also be included in the Low Emissions Zone beginning in October 2010, but inclusion of these vehicles has been delayed due to economic conditions. Ultimately, these vehicles will be required to meet the Euro III standard for PM or drivers will be required to pay a daily fee of £100 to drive in the low emissions zone. According to the Transport of London, it is estimated that "including larger vans and minibuses in the Low Emissions Zone would reduce emissions of Particulate Matter (PM) by around 80 tonnes [sic] and emissions of Oxides of Nitrogen (NO_X) by around 1,200 tonnes [sic] by 2015."[19,20]

3.3 Stockholm's Congestion Charging Zone

Stockholm Sweden's congestion tax was implemented as a tax placed on vehicles traveling into and out of the Stockholm city-center zone as a means to reduce traffic congestion and reduce transportations impact on the environment. The congestion tax began as a seven-month trial program in 2006 and became permanent in August 2007. Vehicles that enter or exit the zone are required to pay 10 to 20 Swedish Krona (approximately $1.49 to $2.98 USD) depending on the time of day.[21]

Vehicles that enter and exit the zone are identified through cameras, laser detectors, ALPR technology, and antennas that are mounted on gantries at each control point. Signs alerting drivers that they are entering and exiting the zone are also mounted on the gantries. The equipment identifies which vehicles have passed the control points, but does not automatically deduct the payment. Congestion tax bills are sent to vehicle owners at the end of each month. [22]

As with London, "Stockholm also achieved environmental objectives as indicated by the observed reduction. CO_2 was reduced 10 to 14 percent in the inner city and 2 to 3 percent in the county. Stockholm also experienced a 7 percent reduction in NO_X and a 9 percent reduction in particulates." Additionally, the tax reduced the number of vehicles entering the zone by 100,000 vehicles per day. Revenue for Stockholm's congestion charging zone averages $60 million USD per year of which the majority of funds are used for new road construction in the Stockholm area. [23]

3.4 Electronic Toll Collection

With congestion pricing, electronic toll collection systems can be used to collect tolls and keep traffic moving at freeway speeds. Existing systems use transponders carried into the vehicle to electronically collect fees from drivers. GPS-based systems may also be used to collect fees and tolls. In Germany, GPS-based units have been used to collect autobahn fees. The GPS-based unit records charges based on the location of the vehicle, and the driver uploads this information and submits payments post trip. GPS devices can also provide other services such as navigation and commercial fleet management services, and roadside equipment needs and other costs may be reduced.[24]

Electronic toll collection systems are defined as a way to "employ various communication and electronic technologies to facilitate commerce between travelers and transportation agencies, typically for the purpose of paying tolls and transit fares. Electronic toll collection systems aim to eliminate the delay at toll booths by collecting tolls electronically. When a vehicle passes electronic sensors near the tolling station, the system determines which vehicles are enrolled in the electronic toll collection program, notifies enforcement authorities of vehicles that passed through but are not enrolled, and electronically debits the accounts of registered vehicle owners without requiring them to stop. Electronic toll collection systems save drivers of registered cars time by eliminating stops at a toll window or machine, allowing them to travel at a higher average speed. As a result, delay at the toll gate is reduced and throughput is increased. These systems also help to reduce excessive acceleration and breaking which reduces emissions.

Electronic toll collection systems involve a number of technologies, including:

- Toll plaza sub-systems, including electronic tool readers and high-speed cameras;
- Toll administration sub-systems, including hardware and software; and
- Roadside telecommunications, including conduit design and installation and fiber optic cable installation.[25]

A telecommunications technology frequently used in the implementation of electronic toll collection systems is DSRC which "is the most common form of electronic toll collection technology in general use and is the standard on most free-flow toll facilities. The technology uses toll tags or transponders to communicate with gantry-mounted equipment at checkpoints. The equipment located at these gantries is used to identify and verify each vehicle's toll tag or transponder unit, and depending on the type of system, either processes a charge from its designated account or confirms its rights of access."[26]

Electronic toll collection systems are deployed in a number of locations in the United States and abroad. E-ZPass is one of the more predominant systems in the United States covering fourteen Northeastern and Midwestern states, from Maine to Virginia, and stretching out to Illinois towards the west.[27] Registered E-ZPass customers are provided with an electronic transponder that attaches to the vehicle's front windshield and contains an electronic chip that holds information on the user's account. When passing through an E-ZPass gantry, the system collects the vehicle's account information from the transponder, and the toll cost is deducted from the user's account.[28] The New Jersey Turnpike Authority (NJTA) and the Delaware River Port Authority (DRPA), both of which use the E-ZPass system, offer reduced toll rates for vehicles that meet California's Super Ultra Low Emission Vehicle standard, which are 90 percent cleaner than the average new vehicle in the model year that it was manufactured.[29] It was estimated that E-ZPass saved 30 million gallons of fuel in 2007, in the states where E-ZPass operates, by eliminating queued, idling vehicles waiting to manually pay tolls. Approximately 265,000 metric tons of carbon equivalents (MTCE) were eliminated as well. According to the EPA's GHG Equivalencies Calculator, this is equivalent to removing 50,669 passenger vehicles from roads annually.[30,31]

Other examples where electronic toll collection systems have reduced emissions include:

- The Carquinez Bridge crosses the Carquinez Strait and connects Vallejo, California, with Crockett, California. An electronic toll collection system was deployed on the bridge for several reasons, including reducing traffic congestion on the bridge and reducing air pollution and fuel consumption. The system resulted in an estimated time savings of 25,000 hours per year with a corresponding fuel savings of approximately 55,000 gallons per year and a reduction of 1.35 million grams of nitrogen oxide (NO_x).[32]
- A 2002 evaluation of the M-Tag electronic toll collection system (Maryland's EZ-Pass predecessor) at three major toll plazas outside Baltimore, Maryland indicated the system reduced environmentally harmful emissions by 16 to 63 percent. The analysis compared emissions prior to ETC deployment with those after ETC deployment. It showed a "40 to 63 percent reduction of HC and CO, and approximately 16 percent reduction of NO_x in the study area."[33]
- A 2000 study of the New Jersey Turnpike's E-ZPass system estimated 1.2 million gallons of fuel saved annually across 27 tolling locations with electronic toll collection systems. As a result, volatile organic compounds (VOCs) emissions were reduced by 0.35 tons per weekday with "80 percent of the reduction resulting from improved light-duty vehicle performance."[34]

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 by vehicle systems) 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 transportation 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.

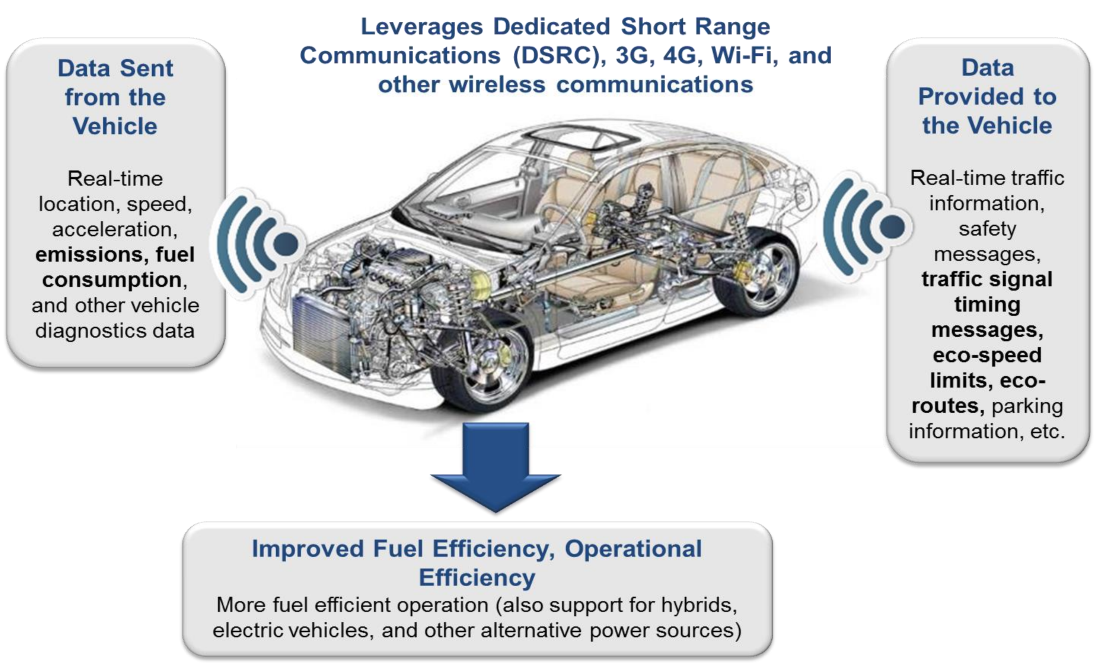

Figure 4-1: A Connected Vehicle (*Source*: *Noblis, 2013*)

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 low emissions zones are fundamentally limited by their exclusive reliance upon infrastructure-based data collection and information dissemination. These limitations are listed below along with justifications for connected vehicle applications:

1. **Current systems are limited geographically by tolling and other roadside infrastructure.** Current low emission zone boundaries are limited by the location of tolling infrastructure – toll plazas or CCTV cameras equipped with ALPR capabilities. As a result, the geographic limits of current low emissions zones are static. Connected vehicle technologies allow for the geographic boundaries of a low emissions zone to be flexible (i.e., capable of expanding or contracting) through the use of geo-fencing capabilities. Leveraging the capabilities of connected vehicle technologies, an entity operating the low emissions zone could geo-fence the boundaries of the zone and provide information about these boundaries directly to vehicles using wireless communications. 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, low emissions zones would rely less on roadside infrastructure and could be

more responsive to real-time traffic and environmental conditions such as code red air quality days or special events taking place within a metropolitan area.

2. **Current systems are not flexible in size, location, nor the time they are operational.** Current systems typically have fixed schedules. Existing systems typically keep to consistent schedules to reduce confusion by the traveling public about the rules or parameters of the low emissions zone. With connected vehicle technologies, entities operating the low emissions zone have greater potential to adjust the size, location, and time of the zone. As connected vehicle penetration rates increase, operating entities will have the potential to communicate changing parameters about the Low Emissions Zone directly to the driver of the vehicle, thus helping to reduce driver confusion if parameters change.
3. **Current systems do not consider real-time traffic and environmental data when establishing parameters for the low emissions zone.** Current systems do not consider real-time traffic and environmental conditions in determining the geographic limits or fee structures for the low emissions zone. Instead these parameters are pre-determined thus limiting the responsive ability for these zones. Collecting traffic and environmental data directly from vehicles allows 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 and be more responsive to actual traffic and environmental conditions. Using these data, the operating entity may decide to change the parameters of the low emissions zone during weather events, special events, and/or code red air quality days. For example, on a code red air quality day, if emissions levels become high for a city center the fees for entering the low emissions zone may be increased deterring high polluting vehicles from enter the zone. As the number of vehicles equipped with connected vehicle technologies increases, these changes can be better communicated to travelers.
4. **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 agencies to optimize the environmental performance of the transportation network.
5. **Current systems do not determine fees for entering the low emissions zone based on vehicle specific data.** Fees for current low emissions zones are based primarily on vehicle type and do not consider the actual emissions levels for individual vehicles. Using connected vehicle technologies, vehicle specific environmental data (e.g., average emissions for the vehicle) can be collected directly from the vehicle allowing fees to be determined based on actual vehicle emissions. By using these data, entities responsible for operating the low emissions zone can target vehicles that may be emitting more emissions than they are supposed to be emitting.
6. **Current systems do not consider incentives for travelers.** Current systems do not provide incentives to travelers that make “green” decisions. Existing low emissions zones seek to change traveler behavior by charging travelers a fee. The AERIS Program believes that traveler choices can also be altered by incentivizing “green” choices. Incentivizes for travelers taking transit, biking, or eco-driving are expected to have

significant impacts to traveler choices. Incentives may include reduced fares to enter a low emissions zone or reduced fares on public transportation.

7. **In-Vehicle Systems do not provide travelers with parameters about the low emissions zone or alternative travel choices for entering the low emissions zone.** 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 a low emissions zone, drivers must have highly accurate and detailed information on the parameters of the zone 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 changing their departure time or switching their mode of travel.

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 a Low Emissions Zones System that addresses the limitations of current systems leveraging connected vehicle technologies.

5 Low Emissions Zones Transformative Concept

5.1 Low Emissions Zones Transformative Concept Overview

The AERIS Program seeks to expand on the concept of low emissions zones by investigating the potential of connected vehicle technologies to support emissions pricing and incentives for travelers. The purpose of these zones would be to encourage decisions by travelers that help reduce transportation's negative impact on the environment. The Low Emissions Zones Transformative Concept envisions entities responsible for the operations of the transportation network that have the ability to define geographic areas that restrict or deter access by specific categories of high-polluting vehicles for the purpose of improving the air quality. Alternatively, the Transformative Concept may incentivize traveler decisions that are determined to be environmentally friendly such as the use of alternative fuel vehicles or transit.

Low emissions zones in a connected vehicle environment would be similar to existing low emissions zones; however they would leverage connected vehicle technologies allowing the systems to be more responsive to real-time traffic and environmental conditions. Connected vehicle technologies provide the ability for entities operating the transportation networks to collect more detailed information from vehicles and infrastructure and better communicate traffic information to travelers directly to in-vehicle systems or handheld devices.

At the heart of this Transformative Concept is a Low Emissions Zone Management application. This application leverages connected vehicle technologies to determine fees or incentives for travelers entering the low emissions zone. In the future, these zones may be permanent, similar to London's Low Emissions Zone or may provide the capability for the zone to be response to real-time traffic and environmental conditions (i.e., allowing the operating entity to change the location, fee structure, or time the low emissions zone is in effect). In a connected vehicle environment, agencies responsible for operating a low emissions zone would be able to commission a zone based on various criteria including air quality conditions or special events. Agencies would also be able to change the geographic boundary and time of a permanent low emissions zone, if needed. For example, if the Los Angeles core had a permanent low emissions zone, the location could be expanded to include surrounding areas that were experiencing high emissions during a code red day. It should be noted that while the capability may exist for a low emissions zone to be more dynamic than it is today, constantly changing the rules of the zone may cause confusion to the traveling public. Thus, it is envisioned that these parameters would not constantly be changing, instead altered periodically in response to major activities.

To restrict or deter access by specific categories of high-polluting vehicles, low emissions zones must charge fees for high-polluting vehicles or provide incentives to travelers making "green" decisions. These fees (or incentives) may be based on the vehicle's engine type, the vehicle's emissions standard, or emissions data collected directly from the vehicle using V2I communications. The low emissions zone's fee or incentive structure should be flexible, allowing the entity operating the system to establish these fees to meet its needs. The fee structure may need to consider waiving fees for emergency vehicles, transportation-related maintenance vehicles, military vehicles, and vehicles owned by residents living within the low emissions zone's boundaries. Additionally, fees may be waived for transit vehicles to encourage travelers entering the zone to use public transportation.

The low emissions zone also needs to consider how to manage violations. A violation may be a vehicle that enters the zone without paying a fee or paying an incorrect fee. Systems operating the low emissions zone need to be able to identify these vehicles and report violators to an enforcement agency.

Finally, pre-trip and en-route traveler information is also a critical component of this Transformative Concept, especially considering the potential for these zones to be flexible. Traveler information must include information about criteria for vehicles to enter the low emissions zone, expected fees and/or incentives for their trips, current and predicted traffic conditions, geographic boundaries of the low emissions zone, and other relevant information.

As the AERIS Program defined the Low Emissions Zones Transformative Concept, it initially envisioned three applications: (1) Low Emissions Zone Management, (2) Connected Eco-Driving, and (3) Eco-Traveler Information Applications. These applications are summarized below.

- **Low Emissions Zone Management.** This application supports the operation of a low emissions zone that is responsive to real-time traffic and environmental conditions. The application uses data collected from vehicles using connected vehicle technologies and from roadside equipment as input to the system. The Low Emissions Zone Management application supports the geo-fencing of a cordon that may be scalable and moveable (e.g., created for a day, removable, flexible in its boundaries) and would be less dependent on conventional ITS infrastructure. The application would establish parameters including the types of vehicles permitted to enter the zone, exemptions for transit vehicles, emissions criteria for entering the zone, fees or incentives for vehicles based on emissions data collected from the vehicle, and geographic boundaries for the low emissions zone. The application would also include electronic toll collection functions that support payments of fees or collection of incentives for registered vehicles using connected vehicle technologies.
- **Connected Eco-Driving.** This application provides customized real-time driving advice to drivers so that they can adjust their driving behavior to save fuel and reduce emissions. This advice includes recommended driving speeds, optimal acceleration, and optimal decelerations profiles based on prevailing traffic conditions and interactions with nearby vehicles. The application also provides feedback to drivers on their driving behavior to encourage them to drive in a more environmentally efficient manner. 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 reduce speed in an eco-friendly manner as the vehicle approaches a traffic signal).
- **Eco-Traveler Information Applications.** Applications included in the Eco-Traveler Information Transformative Concept apply. Eco-Traveler Information Applications provide pre-trip and en-route traveler information about the Low Emissions Zone. This includes information about the geographic boundaries of the low emissions zone, criteria for vehicles to enter the Low Emissions Zone, expected fees and incentives for their trip, and current and predicted traffic and environmental conditions within and adjacent to the zone. Traveler information messages may be provided to various personal devices and in-vehicle systems and used by travelers to adjust their departure time or select an alternate route. Another key component of these applications is providing travelers with transit options to encourage mode

shift. This includes information about transit schedules and real-time transit vehicle arrival and departure times.

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

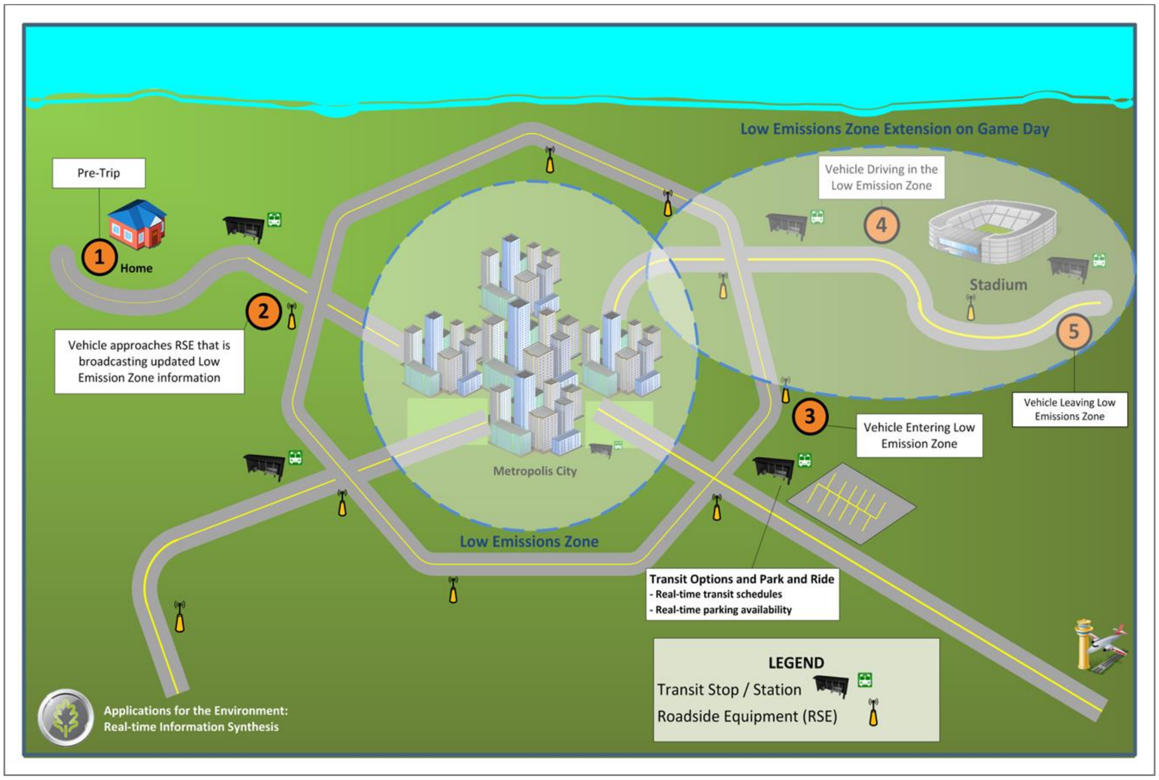

Figure 5-1: Low Emissions Zones Storyboard (*Source*: Noblis, 2013)

Table 5-1: Low Emissions Zones Storyboard

Step	Description
1	**Pre-Trip.** Prior to beginning a trip, the traveler enters his destination (the stadium) into the vehicle's on-board equipment (OBE) unit. An application on the vehicle's OBE unit provides travel options to the driver for getting to the stadium. The application informs the driver that there are two low emissions zones currently in place – one around Metropolis City (through which his route passes) and the other around the stadium. Several travel options are presented to the traveler on his vehicle's OBE unit, including multi-modal options where the traveler would use public transportation and routes where the traveler would travel to the stadium using his personal vehicle. For each option, the application informs the traveler of his travel time to the stadium, the cost for traveling to the stadium (considering fees for entering the low emissions zones), and the traveler's environmental footprint for each option. The traveler considers a route that would use transit. If this option is selected, the traveler would drive his personal vehicle, park at a transit parking lot, and then transfer to a bus that would take him to the stadium. This was the cheapest option and would only add 5 minutes to the traveler's trip. It was also the most environmentally friendly option, producing the least amount of emissions.
2	**Vehicle Approaching RSE Broadcasting Updated Information about the Low Emissions Zone.** The traveler begins his trip. As his vehicle approaches the low emissions zone around Metropolis City, 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 low emissions zone and the fees for entering the zone based on vehicle type and vehicle emissions. The OBE unit collects emissions data from the vehicle and, using the traveler information collected from the RSE unit about the low emissions zone, presents the driver with the fee for entering the Metropolis City zone based on his vehicle's emissions profile. This fee is expensive, so the traveler decides to drive to a bus stop from which a bus would take him to the stadium. The traveler parks his car and transfers to an electric bus headed to the stadium.

Step	Description
3	**Bus Entering the Low Emissions Zone.** As the bus enters the low emissions zone around the stadium, the bus sends information to a nearby RSE unit. This information includes data about the vehicle type, engine type, and the bus' emissions profile. These data are collected by the city's system responsible for operating the low emissions zone. The system determines that the bus may enter the boundaries of the low emissions zone without paying a fee since it is an electric vehicle. Travelers on-board the bus save money by choosing to ride transit into the low emissions zone. Likewise, there are fewer emissions because these travelers decided to take transit instead of driving their own individual vehicles to the stadium. As other vehicles enter the low emissions zone, the city's system collects data from the individual vehicles. This includes data about the number and types of vehicles entering the zone as well as emissions of vehicles entering the zone. These data are used to determine the fee for each vehicle. High emissions vehicles are charged more than low emissions vehicles. Finally, if it is determined that a vehicle should pay a fee for entering the zone, the system collects this fee from the vehicle using wireless communications. The fee is deducted from the traveler's pre-registered account.
4	**Vehicle Driving in the Low Emissions Zone.** While in the low emissions zone, drivers may receive incentives by practicing eco-driving tactics. Vehicle OBE units provide recommended eco-driving tactics within the zone. The recommendations include information about recommended driving speeds, optimal acceleration, and optimal decelerations based on current traffic conditions and interactions with nearby vehicles. Drivers may opt-in to applications allowing their vehicles to collect data about the vehicle's behavior within the low emissions zone, including the number of miles traveled within the zone and/or amount of emissions emitted within the zone.
5	**Vehicle Leaving the Low Emissions Zone.** Upon leaving the low emissions zone, each vehicle sends data about its trip within the zone to the city's system. The system determines if the individual vehicle met the criteria for receiving an incentive for its travel choices. If it is determined that the vehicle made "green choices" an incentive (e.g., a partial rebate of the entry fee) is added to the vehicle's pre-registered account.

5.2 Low Emissions Zone 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 Low Emissions Zones Transformative Concept: (1) Low Emissions Zone System and (2) In-Vehicle System. Figure 5-2 depicts these systems. The Low Emissions Zone 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.

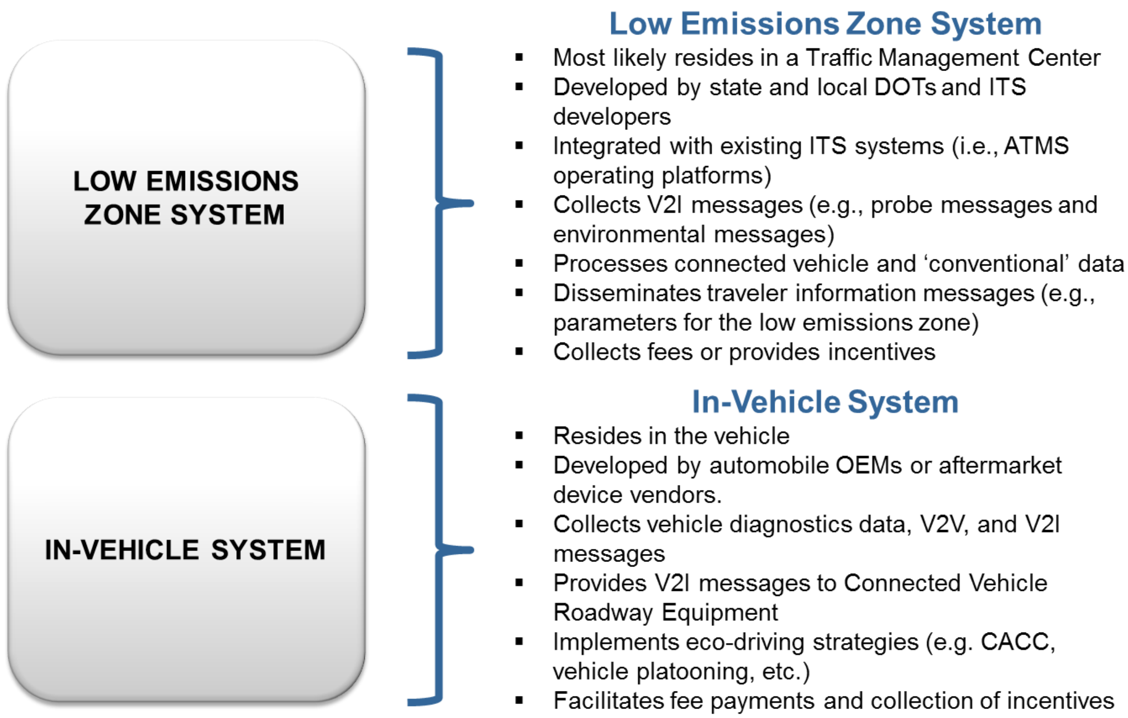

Figure 5-2: Low Emissions Zones Systems (*Source*: Noblis, 2013)

The two systems do not exist in isolation; instead they interact with several actors or physical entities that communicate with the systems. Figure 5-3 depicts the two Low Emissions Zones 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 Low Emissions Zone System resides in the ITS Environment. This environment consists of actors that one would typically associate with conventional ITS such as traffic management centers (TMCs) and their associated systems, CCTV cameras, traffic sensors, and dynamic message signs (DMSs). It is envisioned that the Low Emissions Zone System will be deployed in a manner similar to today's current Low Emissions Zones – most likely by a state or local DOT.

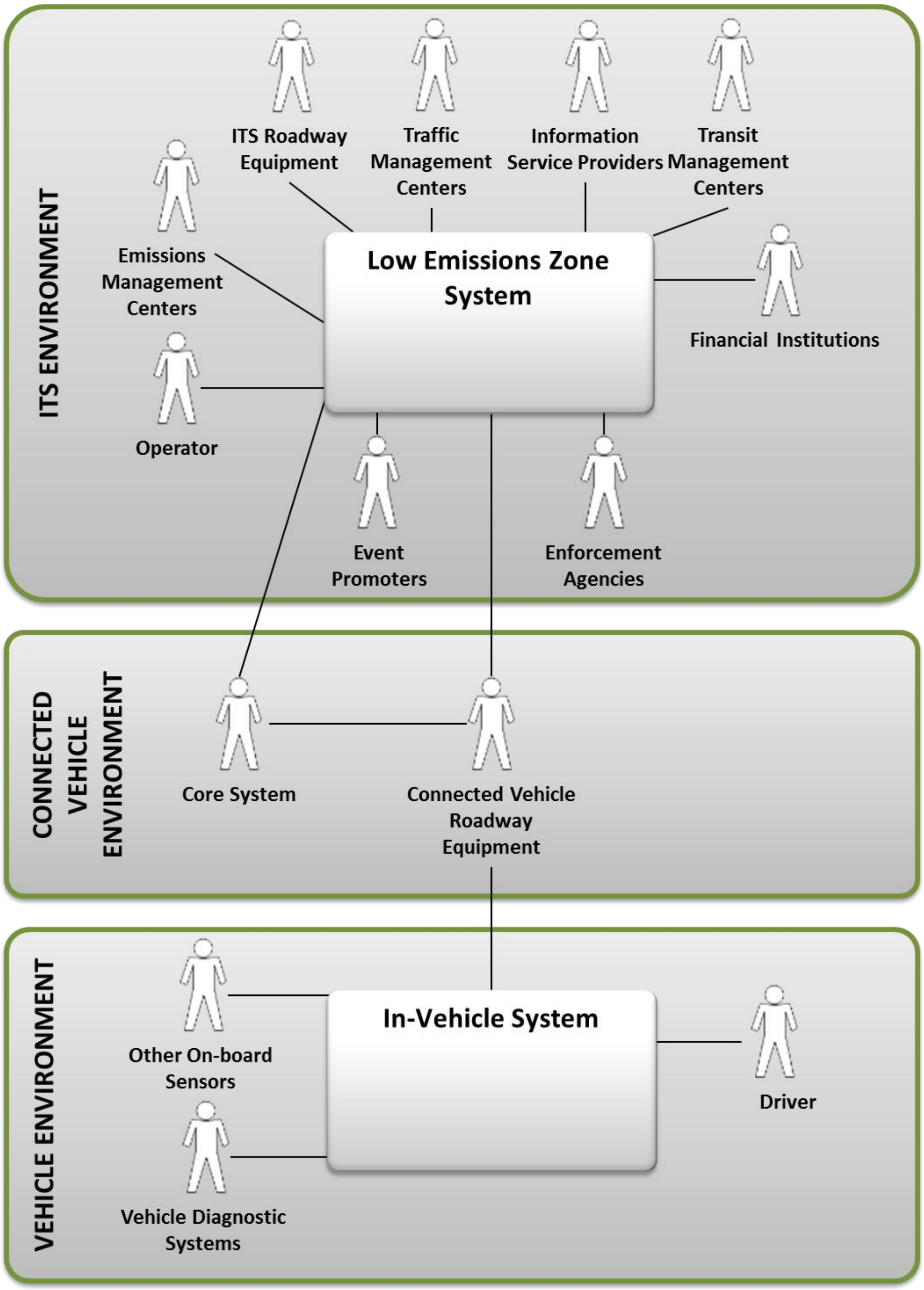

Figure 5-3: Low Emissions Zones Environments (*Source*: Noblis, 2013)

The In-Vehicle System resides in the Vehicle Environment and is expected to be developed by automobile original equipment manufacturers (OEMs) or aftermarket device vendors. It is unlikely that the public sector would deploy these systems; instead they may lead the process of developing communications standards that enable multiple manufacturers to make interoperable equipment. The public sector's role would also be to provide data that could be used to enable the functionality of In-Vehicle Systems located on the vehicle. For example, public agencies may provide parameters of the Low Emissions Zone including its location and fee structure. 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 decisions prior to entering the Low Emissions Zone. Additionally, In-Vehicle Systems would be used to manage the payment of fees or incentives (e.g., partial rebate) for individual vehicles.

The Low Emissions Zone 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 roadside equipment (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 RSE units provide a V2I and I2V link between the two systems.

The boundaries of the two systems – Low Emissions Zone System and In-Vehicle System – are shown by their rectangles. Entities outside of these boundaries represent external actors that may interface with the systems. Additionally, there are interfaces between these actors that contribute to the Transformative Concept, but do not interface directly with the system. For example, drivers (shown as the Driver actor) may need to pre-register their vehicles so that payment of fees or tolls can be electronically debited from their accounts.

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

6 Low Emissions Zone System

The Low Emissions Zone System is envisioned to be a computerized transportation system that employs communication technology to gather traffic and environmental information from multiple sources including ITS Roadway & Payment Equipment, Connected Vehicle Roadway Equipment, and other systems. The system then processes these data and determines whether a low emissions zone should be created or decommissioned along a corridor, for an area, or for a region. Data considered in the creation or decommissioning of a low emissions zone includes real-time and predicted traffic and environmental conditions as well as the location and duration of special events. Once a low emissions zone is created, the system may establish parameters for the zone. These parameters may include the geo-fenced location of the zone, criteria for vehicles entering the zone, duration of the zone, and fee or incentive structures for entering the zone. The Low Emissions Zone System evaluates traffic and environmental parameters for an area in real-time and adapts to fluctuating conditions. 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 be responsive to actual and predicted traffic and environmental conditions so that the traffic network operation is optimized in real-time to reduce emissions and improve air quality within the zone.

The Low Emissions Zone System also supports the collection of fees from vehicles entering the cordoned zone or the determination of incentives for travelers. The system may be set up to have travelers: (a) pay for entering the low emissions zone, preferably using connected vehicle electronic toll collection technology or (b) receive an incentive (e.g., partial or full fee rebate, credit that can be applied to low emissions zone fees in the future) for "green" transportation choices. The system considers criteria such as the type of vehicle, engine type, and emissions profile of the vehicle as it approaches or enters the low emissions zone to determine fees. Incentives may be determined based on the amount of time the vehicle spent in the low emissions zone, mileage driven within the zone, or amount of emissions emitted while in the zone. Additionally, policy may be established to provide incentives to travelers that chose to take transit or bike into the zone.

Traveler information is another major component of the Low Emissions Zone System, especially considering the potential responsive nature of the low emissions zones to traffic and environmental conditions being proposed. Traveler information includes providing travelers with information about the geographic limits and other criteria for the zone. The system allows this information to be disseminated 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 low emissions zone and travel options through in-vehicle systems.

Finally, because the low emissions zone will likely have regional impacts on the transportation network, information sharing is critical. The system must support information exchanges with regional jurisdictions to support coordinated operations. For example, a neighboring jurisdiction responsible for operating traffic signals may adjust its signal timing plans to account for the low emissions zone. Additionally, transit agencies may implement additional transit routes or add transit vehicles to existing routes to support the low emissions zone. For example, in the case where a low emissions zone may be created for a major sporting event, a transit agency may add transit service near the event. Coordination between regional agencies is critical to the success of this Transformative Concept.

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 Low Emissions Zone System – System Context Diagram

Figure 6-1 depicts the System Context Diagram for the Low Emissions Zone System. This diagram represents the actors that interact with the system. The system itself is represented by the large rectangle 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) Event Promoters, (2) Other Centers & ISPs (i.e., Traffic Management Centers, Transit Management Centers, and Emissions Management Centers), (3) Operator, (4) ITS Roadway & Payment Equipment, and (5) Connected Vehicle Roadway Equipment, (6) Information Service Providers, (7) Enforcement Agencies, and (8) Financial Institutions. Appendix B presents a complete list and descriptions of the actors. Actors that provide inputs to the system are depicted on the left side of the diagram, while actors that receive outputs from the system are shown on the right side of the diagram. Relationships between the actors and the system are illustrated by arrows connecting the actors to the Low Emissions Zone System.

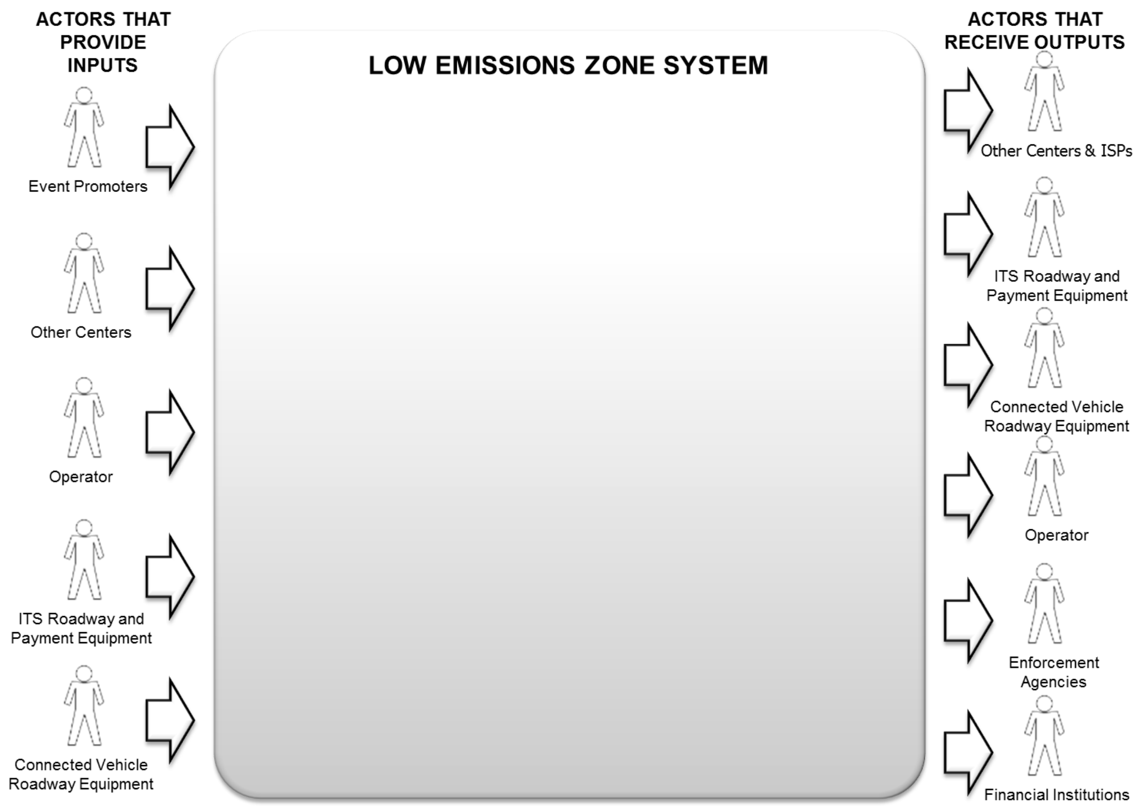

Figure 6-1: Low Emissions Zone System – System Context Diagram (*Source*: Noblis, 2013)

6.2 Low Emissions Zone System – Logic Diagram

Figure 6-2 is a Logic Diagram for the Low Emissions Zone 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 Low Emissions Zone 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 a blue oval, and (4) dissemination which is depicted as purple ovals. The colors of these ovals convey to the next diagram and the headings for the user needs.

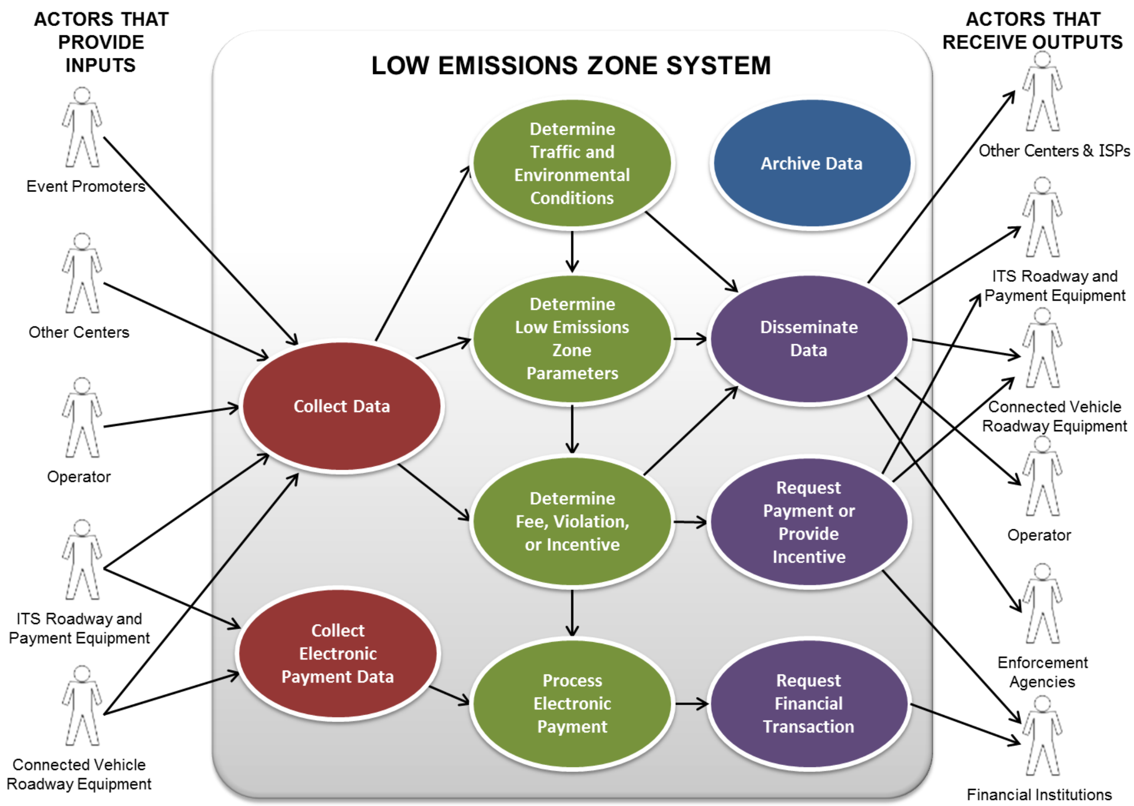

Figure 6-2: Low Emissions Zone System – Logic Diagram (*Source*: Noblis, 2013)

6.3 Low Emissions Zone System – Subsystem Diagram

Figure 6-3 depicts the subsystem diagram for the Low Emissions Zone System. Similar to previous diagrams, the left side of this diagram shows the actors that provide inputs to the Low Emissions Zone 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 Low Emissions Zone 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 Special Event Data Collection Subsystem, Transit Operational Data Collection Subsystem, Traffic Data Collection Subsystem, Environmental Data Collection Subsystem, Operator Input Data Collection Subsystem, Vehicle Specific Data Collection Subsystem, and Electronic Payment 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, Low Emissions Zone Parameters Subsystem, and Vehicle Fee, Incentive, and Violation Subsystem.

- **Data Dissemination Element.** This element consists of the Low Emissions Zone Parameters Dissemination Subsystem, Traffic Conditions Dissemination Subsystem, Environmental Conditions Dissemination Subsystem, Payment and Incentives Dissemination Subsystem, and 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.

Relationships between the inputs, subsystems, and outputs are depicted using directional arrows.

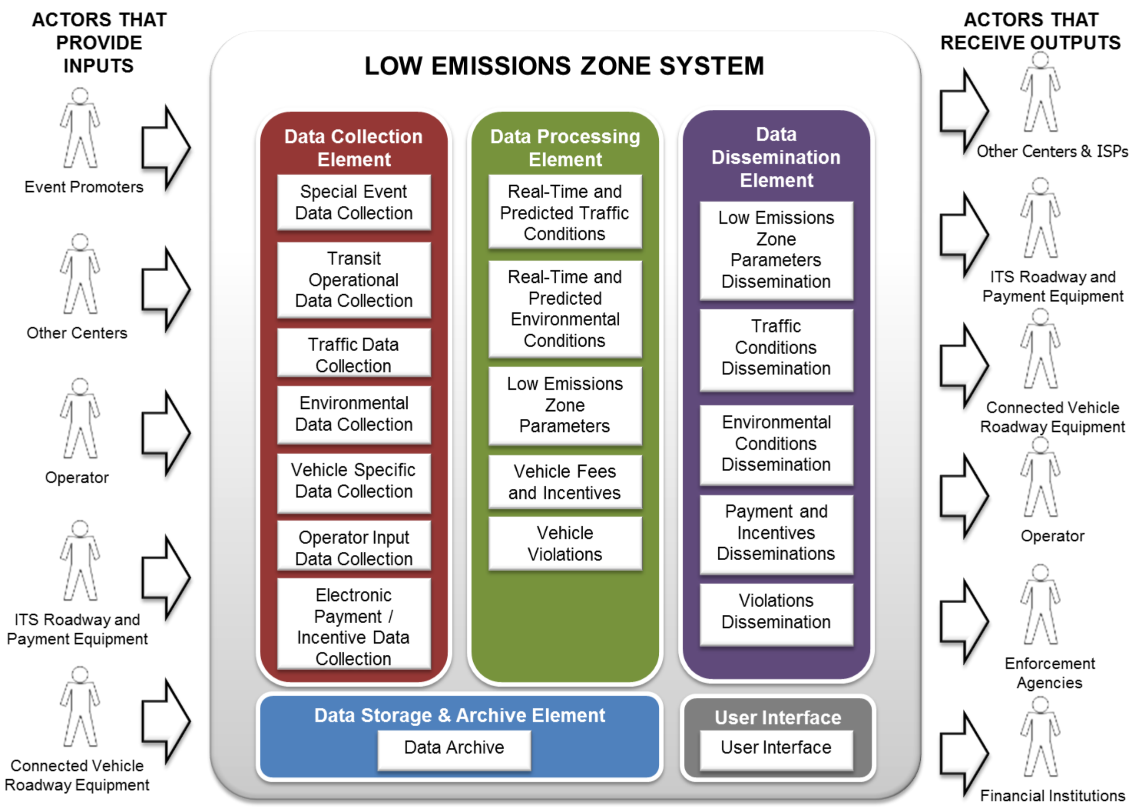

Figure 6-3: Low Emissions Zone System – Subsystem Diagram (*Source*: Noblis, 2013)

6.4 Low Emissions Zone System User Needs

This section identifies user needs, or desired capabilities, for the Low Emissions Zone 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, contains a description and a rationale. Rationales 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: Low Emissions Zone System User Needs

Element	Subsystem	ID	Title	Description
Data Collection	Special Event Data Collection Subsystem	LEZS-DC-01	Collect Special Event Data	**The Low Emissions Zone System needs to collect special event data.** This includes data about events that may impact travel on roadways or other modes. Examples of special events include sporting events, conventions, motorcades/parades, and public/political events. These data should include information such as the date, time, estimated duration, location, and any other information pertinent to traffic movement in the surrounding area. Special event data will be used as input to the Low Emissions Zone System in determining whether the criteria for (establishing) a low emissions zone set by policy of the operating agency are met.
Data Collection	Transit Operational Data Collection Subsystem	LEZS-DC-02	Collect Transit Operations Data	**The Low Emissions Zone System needs to collect data from Transit Agencies about current and planned transit operations, including information about transit routes, services, and ridership.** These data will be used by the Low Emissions Zone System as input to the criteria for the low emissions zone. In determining whether the criteria for the low emissions zone are met, the system should ensure that transit service is available to support an additional influx of travelers deciding to take transit into the zone. This is important because the establishment of the low emissions zone may result in significant mode switch to transit.
Data Collection	Traffic Data Collection Subsystem	LEZS-DC-03	Collect Traffic Data	**The Low Emissions Zone System needs to collect traffic data (e.g., volume, speed, occupancy, vehicle classification, incidents).** Traffic data may be obtained from traffic sensors that detect the presence of vehicles at locations along the network or directly from V2I messages collected from vehicles that report a vehicle's speed, location, and other parameters. Traffic data may be collected from other centers and Information Service Providers (ISPs). Traffic data needs to be processed and then used as input to algorithms that determine whether traffic conditions support the imposition or cessation of a low emissions zone. Traffic data will also be used for demand forecasting or estimating the number of vehicles or people that will use a specific transportation facility in the future or enter into the zone.

Element	Subsystem	ID	Title	Description
Data Collection	Environmental Data Collection Subsystem	LEZS-DC-04	Collect Environmental Data	**The Low Emissions Zone System needs to collect environmental data (e.g. ambient air quality, emissions, temperature, wind speed, and other road weather information).** Environmental data may be obtained from environmental sensors that collect weather and emissions data along the network (e.g. using environmental sensor stations) or directly from V2I messages collected from vehicles. Environmental data may also be collected from other centers. Environmental data will be a key variable for determining the geographic area of the low emissions zone. It will also be used to monitor the environmental conditions in and around the low emissions zone.
Data Collection	Operator Input Data Collection Subsystem	LEZS-DC-05	Collect Operator Input	**The Low Emissions Zone System needs to collect data entered by personnel operating the system.** This desired capability allows the operator to manually enter parameters for establishing or decommissioning the low emissions zone. An operator may establish a low emissions zone, decommission the low emissions zone, or set the fee and incentive structure for the low emissions zone. Operators may also be able to enter and modify the low emissions zone criteria (i.e., the threshold for emissions that must be exceeded or predicted to exceed before imposition of a zone is justified). Additionally, the operator may enter and modify input to algorithms used to calculate zone criteria.
Data Collection	Vehicle Specific Data Collection Subsystem	LEZS-DC-06	Collect Vehicle Specific Data	**The Low Emissions Zone 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, unique identifier (e.g., license plate number or vehicle registration data), the time the vehicle entered the low emissions zone, and number of miles the vehicle traveled within the low emissions zone. These data will be used to determine fees for a vehicle entering or incentives for vehicles leaving the zone. The Low Emissions Zone System shall ensure that measures for security and privacy are taken in collecting and using vehicle-specific data.

Element	Subsystem	ID	Title	Description
Data Collection	Electronic Payment Data Collection Subsystem	LEZS-DC-07	Collect Electronic Payments	**The Low Emissions Zone System needs to collect data from vehicle payment devices being carried on-board the vehicle and used as a payment instrument.** These data may be collected using connected vehicle technologies or more conventional ITS technologies such as toll tag transponders. This capability allows the Low Emissions Zone System to collect payments from vehicles entering the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	LEZS-DP-01	Process Traffic Data	**The Low Emissions Zone System needs to synthesize traffic data from multiple sources (e.g., fixed sensors, connected vehicle roadway equipment, other centers) to provide traffic analyses aggregated at different levels (e.g., intersection, corridor, and regional levels).** Traffic data should also be synthesized for differing time categories (e.g., times of day, day of week, holidays). Once the data are processed, they support the Low Emissions Zone System in determining when and where to establish a low emissions zone. These data may also be used to monitor the performance of the low emissions zone.
Data Processing	Real-Time and Predicted Traffic Conditions Subsystem	LEZS-DP-02	Generate Predicted Traffic Conditions and Forecast Demand	**The Low Emissions Zone System needs to use historical and current traffic data to predict traffic conditions aggregated at different levels (e.g., intersection, corridor, and regional levels).** The Low Emissions Zone 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 low emissions zone are met. 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 the zone would cause.
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	LEZS-DP-03	Process Environmental Data	**The Low Emissions Zone System needs to synthesize environmental data from multiple sources (e.g., fixed sensors, connected vehicle roadside equipment, and other centers) to provide emissions analyses aggregated at different levels (e.g., intersection, corridor, and regional levels).** These data will support algorithms used to determine whether the criteria for low emissions zone are met. These data may also be used to monitor the environmental performance of the zone.

Element	Subsystem	ID	Title	Description
Data Processing	Real-Time and Predicted Environmental Conditions Subsystem	LEZS-DP-04	Generate Predicted Emissions Profile	**The Low Emissions Zone System needs to synthesize environmental data from multiple sources (e.g., sensors, connected vehicle roadside equipment, and other centers) to generate predicted emissions aggregated at different levels (e.g., intersection, corridor, and regional levels).** This includes producing and continually updating a predictive model of the environmental conditions. The prediction may be based on historic data and current environmental conditions. Predictions may be used as input into determining whether the criteria for a Low Emissions Zone are met. For example, the Low Emissions Zone may be established around environmental hot spots (i.e., high emission area) to help reduce transportation's impact on the environment in the area.
Data Processing	Low Emissions Zone Parameters Subsystem	LEZS-DP-05	Create and Decommission Low Emissions Zones	**The Low Emissions Zone System needs to create and decommission Low Emissions Zones. 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 low emissions zone.** Information about available transit service and models that produce real-time and predicted traffic, environmental, and demand forecasts would also be used. The results of these analyses would be used to determine the geographic limits of the zone as well as the criteria for vehicles entering the low emissions zone. These criteria may include vehicle type, engine type, average emissions, or average fuel consumption. Pricing schemes would also be established. For example, a low emissions transit vehicle may be charged a smaller fee than a high emissions passenger vehicle. This would be done to encourage mode shift to transit as well as to discourage the use of high emissions vehicles.

Element	Subsystem	ID	Title	Description
Data Processing	Vehicle Fee, Incentive, and Violation Subsystem	LEZS-DP-06	Determine Fees for Vehicles	**The Low Emissions Zone System needs to use data collected from vehicles to determine fees for vehicles to enter the low emissions zone.** Fees would be determined based on the low emissions zone criteria. For example, the criteria for entering the zone may be established for different engine types. Emergency vehicles and transit vehicles may be allowed to enter the zone at no charge while a high emissions passenger vehicle may be required to pay a fee. Alternatively, criteria may also be established to allow people living inside of the low emissions zone to enter at a lesser fee or no fee. As vehicles enter the zone, data would be collected directly from these vehicles including the vehicle's engine type and emissions data. For each individual vehicle the system would determine if that vehicle should pay a fee. In this example, the system would determine that the emergency and transit vehicles would not be required to pay, but the high emissions passenger vehicle would be required to pay for entering the zone based on a predetermined pricing scheme. Alternatively, fees could be determined based on the number of miles traveled within the low emissions zone or the amount of emissions emitted while the vehicle was driving in the zone.
Data Processing	Vehicle Fee, Incentive, and Violation Subsystem	LEZS-DP-07	Determine Incentives for Individual Vehicles	**The Low Emissions Zone System needs to use data collected from individual vehicles to determine incentives for individual vehicles in the low emissions zone.** Incentives would be determined based on individual vehicle or traveler characteristics. These incentives may vary based on the policy and criteria set for the low emissions zone. Policy for the zone may include charging all vehicles a flat fee based on their vehicle's make, model, and/or engine type. Incentives would then be given to drivers of individual vehicles based on driving characteristics within the low emissions zone. The system would then collect data from vehicles as they were leaving the low emissions zone and determine if an incentive should be given. Determination for the incentive may be based on the amount of time in the zone, the number of miles the vehicle traveled in the zone, or the amount of emissions emitted while the vehicle was driving in the zone. Additionally, the system may be set up to provide incentives for travelers entering the zone using transit.

Element	Subsystem	ID	Title	Description
Data Processing	Vehicle Fee, Incentive, and Violation Subsystem	LEZS-DP-08	Detect Violations for Individual Vehicles	**The Low Emissions Zone System needs to use data collected from vehicles to determine violations for individual vehicles that illegally entered the low emissions zone.** Violations include vehicles entering the low emissions zone without paying the designated fee or vehicles entering the low emissions zone that are prohibited from the zone. The process for detecting violators should be based on the type of technology deployed to collect tolls. Connected vehicle technologies may be used to collect vehicle specific data and payments from vehicles. If the vehicle enters the zone without paying the correct fee or is prohibited from entering the zone, 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 wirelessly.
Data Processing	Vehicle Fee, Incentive, and Violation Subsystem	LEZS-DP-09	Manage Electronic Payment Processing	**The Low Emissions Zone System needs to maintain a log of all fee and incentive transactions carried out by the system. The system should also maintain data about bad toll payments and send details of transactions to the financial institution to enable the travelers to be billed through their credit identities or other information provided when the vehicle was registered for tolling.** The system should be able to support the reconciliation of toll charges and data with other toll administration functions. At periodic intervals, accumulated records should be archived.

Element	Subsystem	ID	Title	Description
Data Dissemination	Low Emissions Zone Parameters Dissemination Subsystem	LEZS-D-01	Disseminate Low Emissions Zone Parameters to Vehicles	**The Low Emissions Zone System needs to provide parameters about the low emissions zone to vehicles.** Messages need to be formatted for use by in-vehicle systems. Information may also be provided to drivers using conventional ITS devices, such as DMS. Low emissions zone information should include parameters of the zone to ensure that drivers receive necessary information about the low emissions zone in advance of the zone's boundaries. Information may include the location of the low emissions zone, fee structure, or other parameters about the low emissions zone needed by a driver. This information allows drivers to make informed pre-trip and en-route decisions as they approach the cordoned zone and may be used by drivers to assist them in making decisions about whether to enter the low emissions zone based on the location, fees, and other parameters.
Data Dissemination	Low Emissions Zone Parameters Dissemination Subsystem	LEZS-D-02	Disseminate Low Emissions Zone Parameters to Other Centers and Travelers	**The Low Emissions Zone System needs to provide parameters about the low emissions zone to other centers and travelers.** Other centers may be adjacent geographically, under control of a different jurisdiction, or part of a more complex hierarchy. They may include Traffic Management Centers, Transit Management Centers, and the media or information service providers responsible for disseminating traveler information. Parameters about the low emissions zone would be considered by adjacent jurisdictions responsible for transportation operations. This information would help to ensure that operations are coordinated across jurisdictional boundaries to ensure integrated management of the transportation system. Additionally, transit providers may use this information to enhance their operations based on the parameters of the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Dissemination	Traffic Conditions Dissemination Subsystem	LEZS-D-03	Disseminate Traffic Conditions to Other Centers and Travelers	**The Low Emissions Zone 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 Traffic Management Centers, 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 Conditions Dissemination Subsystem	LEZS-D-04	Disseminate Traffic Conditions to Vehicles	**The Low Emissions Zone System needs to provide traffic condition messages to vehicles.** These messages need to be formatted for use by in-vehicle systems. These messages should include information that would typically be displayed on a dynamic message sign (e.g., current traffic conditions, predicted traffic conditions, incidents). This information, along with information about the low emissions zone, will help travelers make informed en-route decisions about their trips. For example, as a vehicle approaches a zone the driver of the vehicle may be presented with information about traffic delays or incidents. The driver may use this information to take an alternate route around the congestion or incident or switch to another mode (e.g., transit).
Data Dissemination	Traffic Conditions Dissemination Subsystem	LEZS-D-05	Disseminate Multi-Modal Travel Options	**The Low Emissions Zone System needs to provide multi-modal travel options to vehicles and travelers.** Multi-modal options include information about the locations of transit stops, multi-modal parking facilities, and transit schedules. This information needs to be presented to travelers so that they can choose to use public transportation to enter the low emissions zone. Multi-modal travel options may be provided by the low emissions zone system or by the entity responsible for operating the transit service.

Element	Subsystem	ID	Title	Description
Data Dissemination	Environmental Conditions Dissemination Subsystem	LEZS-D-06	Disseminate Environmental Conditions to Other Centers and Travelers	**The Low Emissions Zone System needs to disseminate environmental data (e.g., regional and/or local air quality, temperature, precipitation) to other centers.** These data should be shared with other jurisdictions to enable coordination of advisory and operational strategies for a corridor or a region. Other centers may use these data to assist in better defining local and regional air quality. Environmental data can be used by other centers as input to algorithms that determine eco-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	Environmental Conditions Dissemination Subsystem	LEZS-D-07	Disseminate Environmental Conditions to Vehicles	**The Low Emissions Zone 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. 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	Payment and Incentive Dissemination Subsystem	LEZS-D-08	Disseminate Information for Request for Electronic Payment to Individual Vehicles	**The Low Emissions Zone System needs to disseminate information specific to individual vehicles for electronic payment of tolls.** The system needs to request the data from the vehicle payment device being carried on board the vehicle and used as a payment instrument. This allows the system to request payment specific to that vehicle for entering the zone. For example, the vehicle’s payment may be determined based on the vehicle type or its emissions.
Data Dissemination	Payment and Incentive Dissemination Subsystem	LEZS-D-09	Request Payment from Financial Institutions	**The Low Emissions Zone System needs to make requests for payment from Financial Institutions.** Once data from the vehicle payment device being carried on board the vehicle and used as a payment instrument is received, the Low Emissions Zone System needs to request transfer of funds from the Financial Institution to collect the fee. This allows the vehicle owner to have an account with the tolling agency and once that account is debited, the tolling agency can request a transfer from the financial institution.

Element	Subsystem	ID	Title	Description
Data Dissemination	Payment and Incentive Dissemination Subsystem	LEZS-D-10	Provide Incentives	**The Low Emissions Zone System needs to use vehicle specific data collected from vehicles to provide an individual vehicle an incentive.** The Low Emissions Zone System may give a vehicle or traveler an incentive or rebate based on the time the vehicle spent within the low emissions zone, the number of miles traveled within the Low Emissions Zone, or the amount of emissions emitted while the vehicle was in the low emissions zone. Alternatively, incentives may be given to travelers choosing to enter the zone using transit.
Data Dissemination	Payment and Incentive Dissemination Subsystem	LEZS-D-11	Provide Confirmation of Payment from or Incentive to Individual Vehicles	**The Low Emissions Zone System needs to provide confirmation of payment from or incentive to individual vehicles.** This confirmation may be sent as a message to in-vehicle systems or sent to a roadway signage. This confirmation of payment allows the Low Emissions Zone System to inform a driver that their payment or incentive was received.
Data Dissemination	Violations Dissemination Subsystem	LEZS-D-12	Provide Notice of Violation to Vehicles	**The Low Emissions Zone 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 Low Emissions Zone System to inform a driver that he or she violated the rules when entering the low emissions zone.
Data Dissemination	Violations Dissemination Subsystem	LEZS-D-13	Notify Enforcement Agencies of Violations	**The Low Emissions Zone System needs to notify enforcement agencies of a violation.** Notification of a violation allows the Low Emissions Zone System to inform an enforcement agency that a vehicle violated the rules when entering the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Storage and Archive	Data Archive Subsystem	LEZS-DA-01	Archive Low Emissions Zone Data	**The Low Emissions Zone System needs to archive traffic data, environmental data, Low Emissions Zone parameters (e.g., geographic limits, fee structure), and event logs (e.g., time the low emissions zone was implemented, time it was decommissioned, etc.).** This capability allows the Low Emissions Zone 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 when the Low Emissions Zone should be created or decommissioned.
Data Storage and Archive	Data Archive Subsystem	LEZS-DA-02	Archive Financial Data	**The Low Emissions Zone System needs to archive all financial data for toll transactions.** This should include all operational data, toll pricing data, incentives, as well as violations. This capability allows the Low Emissions Zone System to keep records of all toll transactions.
Data Storage and Archive	Data Archive Subsystem	LEZS-DA-03	Determine Performance Measures	**The Low Emissions Zone 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 Subsystem	LEZ-UI-01	User Interface	**The Low Emissions Zone System needs to provide a user interface.** The user interface allows an operator to interact with the Low Emissions Zone 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. A major function of the In-Vehicle System is to collect information about the low emissions zone, 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 before entering the zone. This information may include the location of the low emissions zone, the fee structure for entering the zone, or restrictions for entering the zone. Additionally, the In-Vehicle System may present drivers with information about traffic conditions within the zone or trip/route options through or around the zone. For example, the driver should be presented with multi-modal options for entering the zone and/or with alternate routes around the low emissions zone.

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 Low Emissions Zone System – located at a center – to determine when a low emissions zone should be established or decommissioned based on real-time traffic and environmental conditions data. These data would also be used to help determine the fee structure for the low emissions zone.

The In-Vehicle System facilitates the payment of a fee when a vehicle enters or incentives (e.g., partial or full rebate) when a vehicle leaves a low emissions zone. The In-Vehicle System facilitates payment of fees or collection of incentives much like electronic toll collection systems work today. However, data such as the vehicle's engine type or emissions may be used to determine a vehicle's fee. Higher emitting vehicles may be charged a higher fee to enter the zone than lower emitting vehicles. Likewise, vehicles driving more in the low emissions zone may receive no or a lesser incentive than vehicles driving less in the zone. Criteria may be established to allow people living inside the low emissions zone to enter and drive within the zone at a lesser fee or no fee. To deter higher emitting vehicles from entering the zone, data need to be collected directly from vehicles so that a fee can be determined for individual vehicles.

The time or mileage driven within the low emissions zone and a vehicle's driving style within the zone (e.g., adherence to eco-driving tactics) may also be used to determine incentives or rebates for vehicles as they leave the zone. For example, the Low Emissions Zone System may collect the time or vehicle's mileage when it entered the low emissions zone and when it exited the zone. Additionally, the In-Vehicle System may provide data about the amount of emissions emitted while in the zone. These data may be used by the Low Emissions Zone System to determine if a rebate or incentive should be given to the vehicle. Vehicles driving less and emitting fewer emissions may receive a financial incentive when they leave the zone. Incentives may be provided through I2V communications back to the vehicle or sent directly to the driver's financial institution.

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 rectangle in the middle of the diagram. This diagram represents the external actors that interact with the system. These actors are shown as people outside of the system boundary, although actors may be devices or organizations rather than individual people. Actors that interact with the system include: (1) Driver, (2) Connected Vehicle Roadway Equipment, (3) ITS Roadway & Payment Equipment, (4) Vehicle Diagnostic Systems, and (5) Other Onboard Sensors. Appendix B presents a complete list and descriptions of the actors. Actors that provide inputs to the system are depicted on the left side of the diagram, while actors that receive outputs from the system are depicted on the right side of the diagram. Relationships between the actors and the system are illustrated by arrows connecting the actors to the In-Vehicle System.

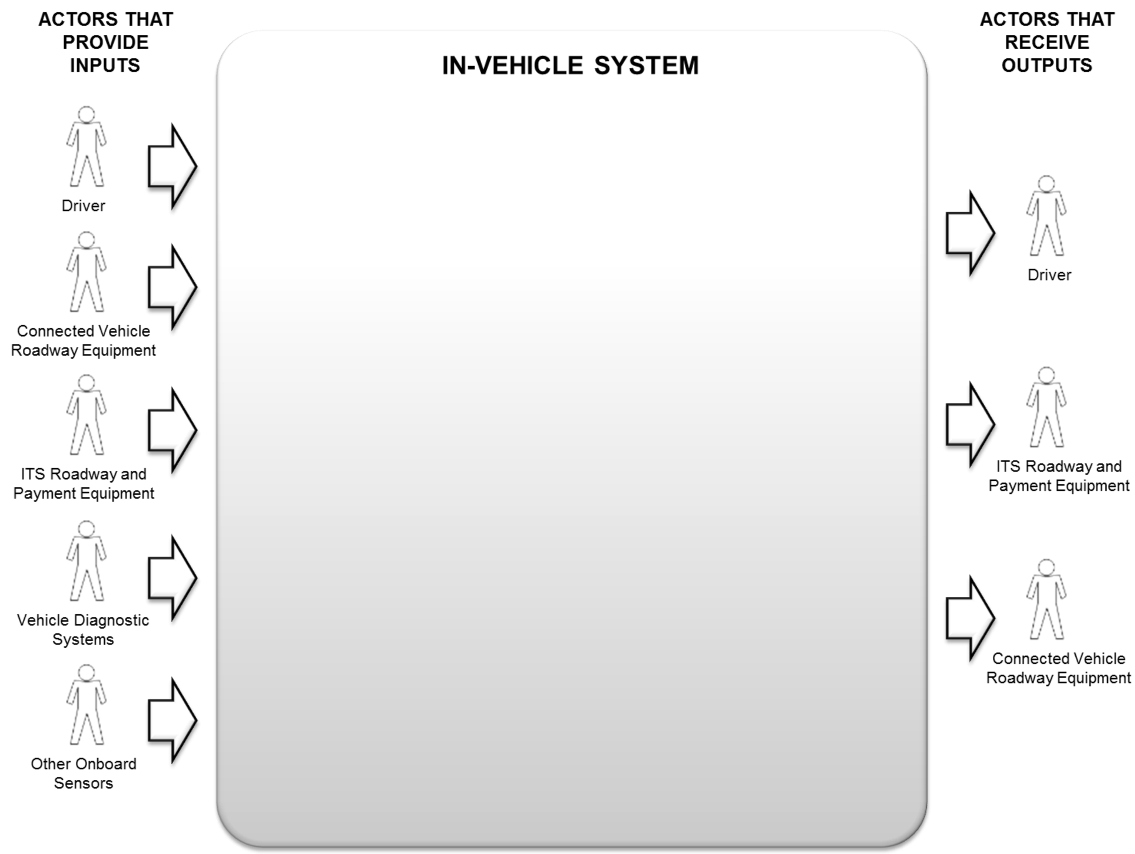

Figure 7-1: In-Vehicle System – System Context Diagram (*Source*: Noblis, 2013)

7.2 In-Vehicle System – Logic Diagram

Figure 7-2 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. These include (1) data collection, depicted as a red oval, (2) data processing, depicted as green ovals, and (3) dissemination, depicted as purple ovals. The colors of these ovals convey to the next diagram and the headings for the user needs table.

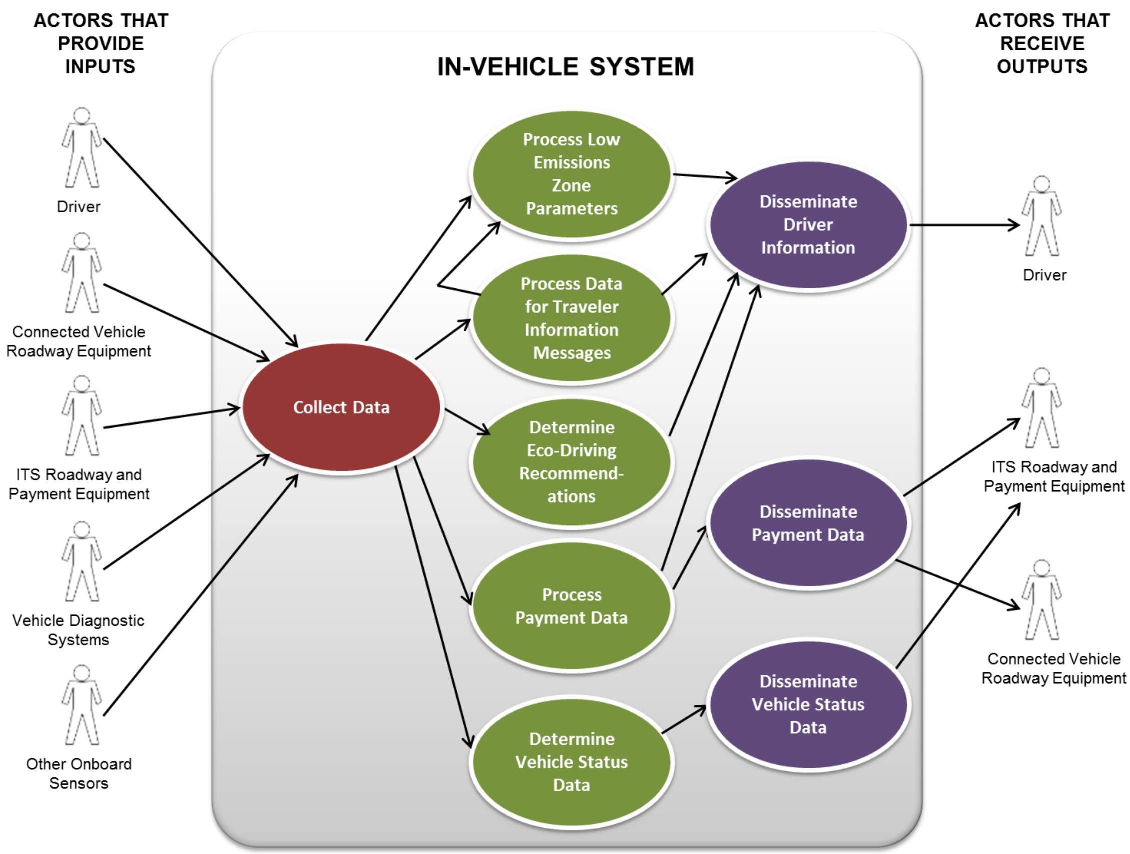

Figure 7-2: In-Vehicle System – Logic Diagram (*Source*: Noblis, 2013)

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, Low Emissions Zone Parameters Data Collection Subsystem, Payment Request / Incentive Data Collection Subsystem, and Vehicle Status Data Collection Subsystem.
- **Data Processing Element.** This element consists of the Traveler Information Processing Subsystem, Eco-Driving Strategies Subsystem, Low Emissions Zone Criteria Determination Subsystem, Vehicle Status Processing Subsystem, and Payment/Incentive Criteria Determination Subsystem.
- **Data Dissemination Element.** This element consists of the Driver Information Dissemination Subsystem, Payment/Incentive Dissemination Subsystem, and Vehicle Status Dissemination Subsystem.
- **Driver Interface Element.** This elements consists of the Driver Interface Subsystem.

Relationships between the inputs, subsystems, and outputs are depicted using directional arrows.

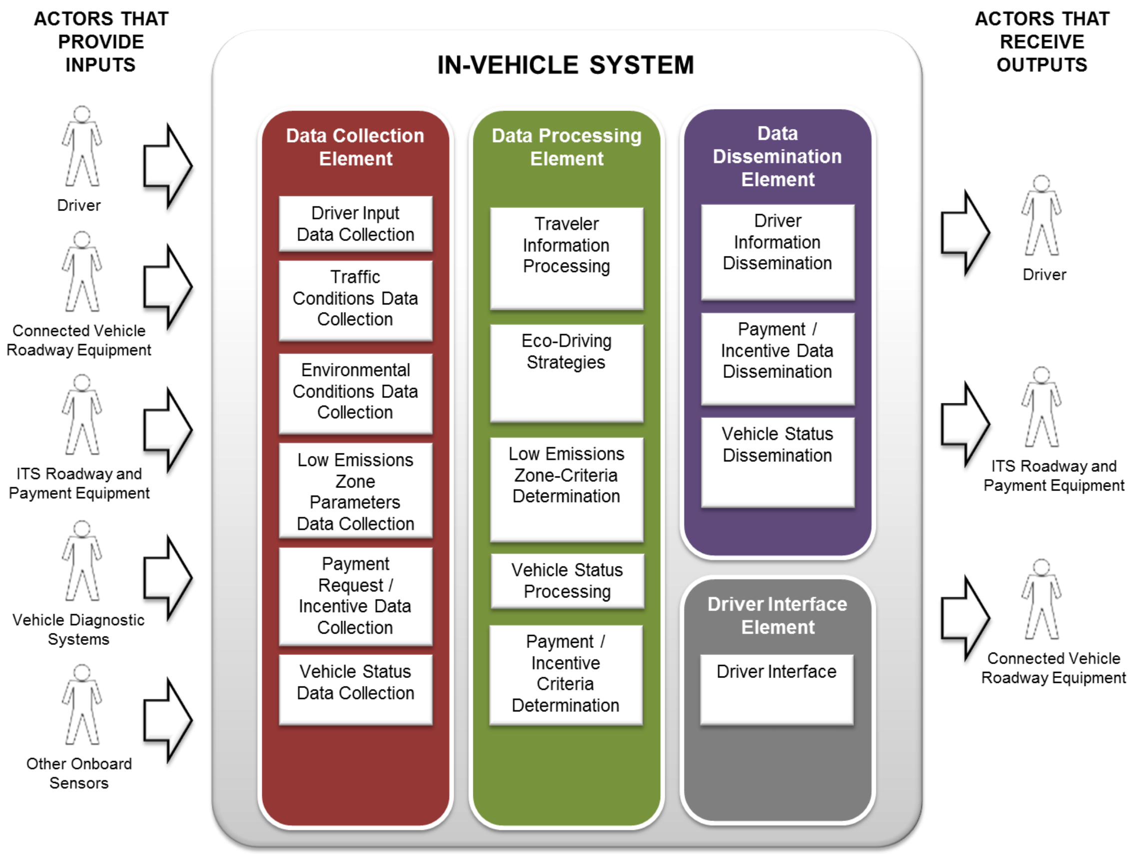

Figure 7-3: In-Vehicle System – Subsystem Diagram (*Source*: Noblis, 2013)

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. Such information could be used to customize the messages when a fee or incentive is determined as a vehicle enters or leaves a low emissions zone.
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, construction, and posted speed limits, and transit options). The In-Vehicle System needs to provide this information to drivers allowing him or her to make pre-trip and en-route travel choices based on the traffic conditions. These data may assist travelers in determining whether or not to make trips into or around the low emissions zone.
Data Collection	Environmental Conditions Data Collection Subsystem	IVS-DC-03	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). 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. These data may assist travelers in determining trips into or around the low emissions zone. Road weather information may also be used as input to eco-driving applications.

Element	Subsystem	ID	Title	Description
Data Collection	Low Emissions Zone Parameters Data Collection Subsystem	IVS-DC-04	Receive Low Emissions Zone Parameter Data	**The In-Vehicle System needs to receive parameters about low emissions zones that have been created and decommissioned.** This information should include parameters to ensure that drivers receive necessary information about the low emissions zone, including the location of the zone, fee structure, and other parameters about the low emissions zone needed by a driver. This information allows drivers to make informed pre-trip and en-route decisions as they approach the zone. This information may be used by drivers to assist them in making decisions about whether to enter the zone based on the location, fees, and other parameters.
Data Collection	Payment Request / Incentive Data Collection Subsystem	IVS-DC-05	Receive Payment / Incentive Request Information	**The In-Vehicle System needs to receive requests for payment or incentives.** These requests may be provided to vehicles using connected vehicle technologies (e.g., DSRC messages) or other wireless technologies including short range communications at electronic toll collection plazas. This capability allows the vehicle system to receive information it will need to pay a fee to enter the low emissions zone. Payment request information may ask the vehicle to provide data on the vehicle type, engine type, emissions, or other criteria. Incentives information may be specific to the number of miles traveled within the zone or eco-driving strategies used while driving within the zone.
Data Collection	Payment Request / Incentive Data Collection Subsystem	IVS-DC-06	Receive Confirmation of Payment or Incentive	**The In-Vehicle System needs to receive confirmation of payment or incentive.** This confirmation of payment or incentive allows the Low Emissions Zone System to inform a driver that their payment or incentive was received.
Data Collection	Payment Request / Incentive Data Collection Subsystem	IVS-DC-07	Receive Notice of Violation	**The In-Vehicle System needs to receive a notice of a violation.** Notification of a violation allows the Low Emissions Zone System to inform a driver that they violated the rules when entering the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Collection	Vehicle Status Data Collection Subsystem	IVS-DC-08	Collect Vehicle Diagnostics Data	**The In-Vehicle System needs to collect diagnostics data from onboard systems and sensors 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 also 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 Low Emissions Zone System as input for determining traffic and environmental conditions for a roadway segment, corridor, or region. These data may also be sent to the Low Emissions Zone System as a vehicle enters the zone or leaves a zone in response to a request for payment or a request for incentive or rebate.

Element	Subsystem	ID	Title	Description
Data Processing	Traveler Information Processing Subsystem	IVS-DP-01	Process Traffic and Environmental Data for Traveler Information Messages	**The In-Vehicle System needs to process traffic and environmental data from the Low Emissions Zone System and develop traveler information messages to be provided to the driver.** Traffic data may include information on traffic conditions including travel times, incidents, 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	Traveler Information Processing Subsystem	IVS-DP-02	Determine Trip/Route Options	**The In-Vehicle System needs to determine trip/route options to present to the driver.** These options may include routes that require the vehicle to enter the low emissions zone or travel around (or avoid) the Low Emissions Zones, or may recommend transit options. In determining trip/route options, the system needs to consider parameters of the low emissions zone, including its location and fee structure. Information about traffic and environmental conditions as well as transit schedules may also be considered.
Data Processing	Eco-Driving Strategies Subsystem	IVS-DP-03	Determine Eco-Driving Recommendations	**The In-Vehicle System needs to determine driving recommendations with the objective of promoting a driving style that lowers vehicle emissions.** This may include recommendations about 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 systems that automatically implement the eco-driving tactics (e.g., change gears, switch power sources, or reduce speed in an eco-friendly manner as the vehicle approaches a traffic signal.)
Data Processing	Low Emissions Zones Criteria Determination Subsystem	IVS-DP-04	Determine the Vehicle's Criteria for Entering the Low Emissions Zone	**The In-Vehicle System needs to determine if the vehicle meets the criteria for entering the low emissions zone.** Criteria that the In-Vehicle System may consider include the vehicle type, average fuel consumption, average vehicle emissions, or other parameters established by the entity responsible for operating the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Processing	Vehicle Status Processing Subsystem	IVS-DP-05	Determine Vehicle Emissions Data	**The In-Vehicle System needs to calculate estimates of tailpipe emissions and fuel consumption if these data cannot be collected directly from the vehicle.** 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. Additionally, estimates for emissions and fuel consumption may not be required if these data can be collected directly from vehicle sensors. This information may be disseminated to the Low Emissions Zone System as input for determining when a low emissions zone should be established or decommissioned. Additionally, estimates of vehicle emissions may also be provided to the driver through an in-vehicle interface to inform drivers of their environmental footprint.
Data Processing	Payment/ Incentive Criteria Determination Subsystem	IVS-DP-06	Manage Fee or Incentive Payment	**The In-Vehicle System needs to process requests for payment or ncentives.** The In-Vehicle System will send data specific to the vehicle (e.g., engine type, real-time emissions data, and emissions profile for the vehicle) to the Low Emission Zone System for fee calculation or determination of incentives. The In-Vehicle System will notify the driver of the fee or incentive for entering the low emissions zone and provide the driver with payment confirmation.

Element	Subsystem	ID	Title	Description
Data Dissemination	Driver Information Dissemination Subsystem	IVS-D-01	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). These data may assist travelers in determining trips into or around the low emissions zone. 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.
Data Dissemination	Driver Information Dissemination Subsystem	IVS-D-02	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). 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.
Data Dissemination	Driver Information Dissemination Subsystem	IVS-D-03	Provide Low Emissions Zone Parameters to the Driver	**The In-Vehicle System needs to provide Low Emissions Zone parameters to the driver.** This information should include parameters to ensure that drivers receive necessary information about the Low Emissions Zone, including the location of the low emissions zone, fee structure, and other parameters about the low emissions zone needed by a driver. This information allows drivers to make informed pre-trip and en-route decisions as they approach the zone. This information may be used by drivers to assist them in making decisions about whether or not to enter the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Dissemination	Driver Information Dissemination Subsystem	IVS-D-04	Provide Trip/Route Information to the Driver	**The In-Vehicle System needs to provide trip/route information to drivers including options for the driver to reach their destination.** The system needs to provide eco-routing navigation capabilities that find the most eco-friendly route in terms of minimum fuel consumption or emissions between a trip origin and a destination. This includes multi-modal options, information about low emissions zone including the geographic limits and time the zone is established. The system may inform the driver of potential routes that go through or avoid the low emissions zone. The system may also direct the driver to transit options. Once the route is selected, the driver may be provided with specific turn-by-turn driving instructions similar to current navigation systems.
Data Dissemination	Driver Information Dissemination Subsystem	IVS-D-05	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 (see the following need IVS-DI-01).
Data Dissemination	Payment/ Incentive Data Dissemination Subsystem	IVS-D-06	Disseminate Payment / Incentive Data	**The In-Vehicle System needs to provide payment or incentive information so that the account associated with the vehicle can be debited for the amount required to enter the low emissions zone or credited for the amount received when leaving the zone.** Payment information may be transmitted to Connected Vehicle Roadway Equipment or traditional ITS Roadway & Payment Equipment. Payment information may also be presented to drivers to inform them of their payments or balances on their vehicle payment device being carried on-board the vehicle and used as a payment instrument. Finally, vehicles may send data requesting incentives based on their driving behavior within the low emissions zone.

Element	Subsystem	ID	Title	Description
Data Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-07	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 a vehicle entering the zone or leaving the zone. Data about the vehicle's speed, accelerations, and other data may also be used to estimate vehicle emissions.
Data Dissemination	Vehicle Status Dissemination Subsystem	IVS-D-08	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 an individual vehicle's fee prior to entering the zone or incentive as the vehicle is leaving the zone. Additionally, this information may be disseminated to the Low Emissions Zone System as input for determining when a low emissions zone should be established or decommissioned.

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, confirmation of payment or incentives, notice of violation, and feedback on driving behavior can be provided to the driver. The interface also needs to allow the user to opt-in to applications.** 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 parameters about low emissions zones, traffic conditions, and environmental conditions such as that typically displayed on a DMS, trip/route options, and payment for tolls or collection of incentives. The interface also needs to provide drivers with speed recommendations that support eco-driving and eco-approaches and departures at intersections. The system should include an interface that may provide its outputs in audible or visual forms. Visual output should not impair the driver's ability to control the vehicle in a safe manner.

8 Low Emissions Zones Interfaces and Data Exchanges

To better understand how the Low Emissions Zone 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 Low Emissions Zone 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 Low Emissions Zone System and the In-Vehicle System. The first option includes data exchanges through the Connected Vehicle Roadway Equipment or an RSE unit that is 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 and incident information.

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.

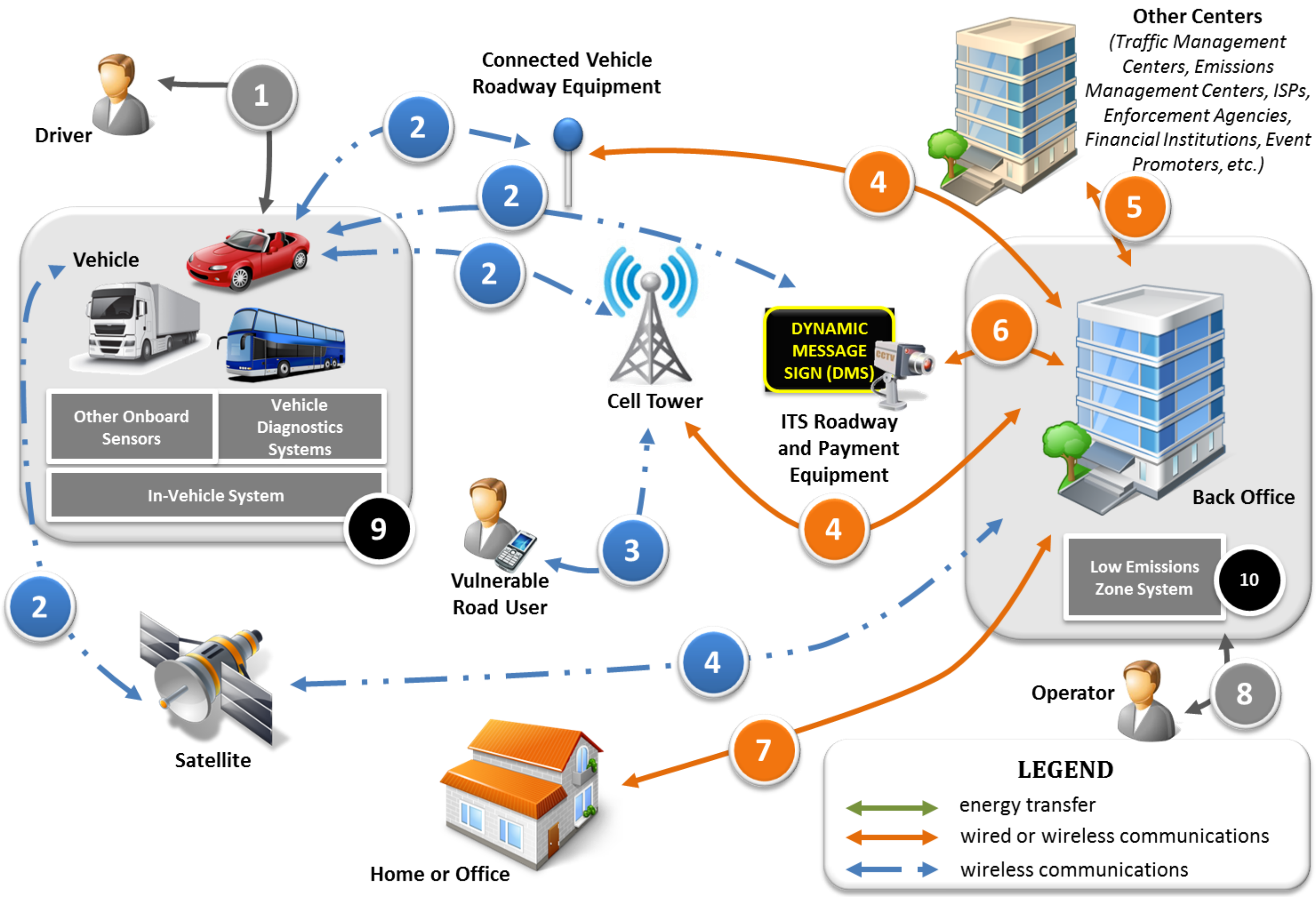

Figure 8-1: Low Emissions Zones Interface and Data Exchange Diagram (*Source*: Noblis, 2013)

Table 8-1: Low Emissions Zones 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> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics) • Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.) • Multi-modal options • Traffic conditions • Environmental conditions (e.g., code red air quality alerts) • Road weather conditions • Incentive received (or fee paid) • Financial information • Notice of violation <u>Driver Sends to In-Vehicle System</u> • Activation of Application (e.g., activate eco-driving application, activate incentive application) • Updates to configurable parameters for Low Emissions Zone access, fees, and/or incentives • Origin-Destination (O-D) information	• IVS-DC-01: Collect Driver Input • IVS-D-01: Provide Traffic Conditions to the Driver • IVS-D-02: Provide Environmental Conditions to the Driver • IVS-D-03: Provide Low Emissions Zone Parameters to the Driver • IVS-D-04: Provide Trip/Route Information to the Driver • IVS-D-05: Provide Eco-Driving information to the Driver • IVS-DI-01: Provide Driver Interface
2	In-Vehicle System and Connected Vehicle Roadway Equipment In-Vehicle System and Cell Tower In-Vehicle System and Satellite In-Vehicle System and ITS Roadway	<u>In-Vehicle System sends to Connected Vehicle Roadway Equipment, Cell Tower, Satellite, and ITS Roadway and Payment Equipment</u> • 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) • Vehicle specific data (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data), the time the vehicle entered the Low Emissions Zone, and number of miles traveled within the Low Emissions Zone)	• IVS-DC-02: Receive Traffic Conditions Data • IVS-DC-03: Receive Environmental Conditions Data • IVS-DC-04: Receive Low Emissions Zone Parameter Data • IVS-DC-05: Receive Payment or Incentive Request

Item	Actors	Data Exchange / Action	Related User Needs
	and Payment Equipment	• Incentive / payment data <u>Connected Vehicle Roadway Equipment, Cell Tower, Satellite, and ITS Roadway and Payment Equipment sends to the In-Vehicle System</u> • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Environmental conditions (e.g., air quality information, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Request for electronic payment or incentive • Confirmation of payment or incentive • Notice of violation	Information • IVS-DC-06: Receive Confirmation of Payment or Incentive • IVS-DC-07: Receive Notice of Violation • IVS-D-06: Disseminate Payment / Incentive Data • IVS-D-07: Disseminate Vehicle Status Data • IVS-D-08: Disseminate Vehicle Status Environmental Data
3	Cell Tower and Vulnerable Road User	<u>Cell Tower to Vulnerable Road User</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Multi-modal travel options • Environmental conditions (e.g., air quality information, code red air quality alerts)	• LEZS-D-02: Disseminate Low Emissions Zone Parameters to Other Centers and Travelers • LEZS-D-03: Disseminate Traffic Conditions to Other Centers and Travelers • LEZS-D-05: Disseminate Multi-Modal Travel Options • LEZS-D-06: Disseminate Environmental Conditions to Other Centers and Travelers
4	Connected Vehicle Roadway Equipment and Low Emissions Zone System	<u>Connected Vehicle Roadway Equipment, Cell Tower, and Satellite sends to Low Emissions Zone System</u> • Vehicle status data (e.g., vehicle's location, heading, speed, acceleration, braking status, size, etc.)	• LEZS-DC-03: Collect Traffic Data • LEZS-DC-04: Collect Environmental Data

Item	Actors	Data Exchange / Action	Related User Needs
	Cell Tower and Low Emissions Zone System Satellite and Low Emissions Zone System	• 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) • Vehicle specific data (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data), the time the vehicle entered the Low Emissions Zone, and number of miles traveled within the Low Emissions Zone) • Electronic payment or incentive <u>Low Emissions Zone System sends to Connected Vehicle Roadway Equipment, Cell Tower, and Satellite</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Multi-modal travel options • Environmental conditions (e.g., air quality information, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) • Request for electronic payment or incentive • Confirmation of payment or incentive • Notice of violation	• LEZS-DC-06: Collect Vehicle Specific Data • LEZS-DC-07: Collect Electronic Payments • LEZS-D-01: Disseminate Low Emissions Zone Parameters to Vehicles • LEZS-D-04: Disseminate Traffic Conditions to Vehicles • LEZS-D-05: Disseminate Multi-Modal Travel Options • LEZS-D-07: Disseminate Environmental Conditions to Vehicles • LEZS-D-08: Disseminate Information for Request for Electronic Payment to Individual Vehicles • LEZS-D-10: Provide Incentives • LEZS-D-11: Provide Confirmation of Payment from or Incentive to Individual Vehicles • LEZS-D-12: Provide Notice of Violation to Vehicles
5	Low Emissions Zone System and Other Centers	<u>Low Emissions Zone System sends to Other Centers</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.)	• LEZS-DC-01: Collect Special Event Data • LEZS-DC-02: Collect Transit Operations Data

Item	Actors	Data Exchange / Action	Related User Needs
		• Multi-modal travel options • Traffic signal timing plans in operation • Environmental conditions (e.g., air quality data, code red air quality alerts) • Road weather data (e.g., road conditions) • Financial data – sent to Financial Institutions • Violation data – sent to Enforcement Agencies <u>Other Centers sends to Low Emissions Zone System</u> • Special event data • Transit operations data (e.g., transit routes) • 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 data (e.g., road conditions) • Financial data - sent from Financial Institutions • Violation data – sent from Enforcement Agencies	• LEZS-DC-03: Collect Traffic Data • LEZS-DC-04: Collect Environmental Data • LEZS-D-02: Disseminate Low Emissions Zone Parameters to Other Centers and Travelers • LEZS-D-03: Disseminate Traffic Conditions to Other Centers and Travelers • LEZS-D-06: Disseminate Environmental Conditions to Other Centers and Travelers • LEZS-D-09: Request for Payment from Financial Institutions • LEZS-D-13: Notify Enforcement Agencies of Violations
6	ITS Roadway and Payment Equipment and Low Emissions Zone System	<u>ITS Roadway</u> and Payment <u>Equipment sends to Low Emissions Zone System</u> • Traffic data (e.g., speed, volume, occupancy, travel times, etc.) • Environmental data (e.g., air quality data, etc.) • Road weather data (e.g., road friction, precipitation, temperature, etc.) • Vehicle specific data – sent using conventional toll tag readers (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data)) • Electronic payment or incentive data <u>Low Emissions Zone System sends to ITS Roadway</u> and Payment <u>Equipment</u> • Low Emissions Zone parameters – sent to DMS (e.g., fees and rules for using the Low	• LEZS-DC-03: Collect Traffic Data • LEZS-DC-04: Collect Environmental Data • LEZS-DC-06: Collect Vehicle Specific Data • LEZS-DC-07: Collect Electronic Payments

Item	Actors	Data Exchange / Action	Related User Needs
		Emissions Zone) • ITS device control functionality (e.g., control of DMS, cameras, etc.)	
7	Low Emissions Zone System and Home/Office	<u>Low Emissions Zone System send to Home/Office</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Multi-modal travel options • Environmental conditions (e.g., air quality information, code red air quality alerts) • Confirmation of payment or incentive • Notice of violation	• LEZS-D-02: Disseminate Low Emissions Zone Parameters to Other Centers and Travelers • LEZS-D-03: Disseminate Traffic Conditions to Other Centers and Travelers • LEZS-D-05: Disseminate Multi-Modal Travel Options • LEZS-D-06: Disseminate Environmental Conditions to Other Centers and Travelers
8	Low Emissions Zone System and Operator	<u>Low Emissions Zone System sends to Operator</u> • Low Emissions Zone parameters and operational status • Traffic conditions • Environmental conditions • Road weather conditions • Multi-modal travel options • Performance measures • Archived data <u>Operator sends to Low Emissions Zone System</u> • Operator inputs (e.g., creating Low Emissions Zone, code red air quality alerts, or adding new equipment (e.g., new RSE units) to the system)	• LEZS-DC-05: Collect Operator Input • LEZS-UI-01: User Interface
9	In-Vehicle System	<u>Collect Data</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Driver input (e.g., activation of application, configurable parameters for Low Emissions	• IVS-DC-01: Collect Driver Input • IVS-DC-02: Receive Traffic

Item	Actors	Data Exchange / Action	Related User Needs
		Zone access, fees, and/or incentives, O-D information, etc.) • 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) • Request for electronic payment or incentive • Confirmation of payment or incentive • Notice of violation • Vehicle diagnostics data (e.g., engine, emissions, GPS, vehicle type, unique identifier, etc.) <u>Process Data</u> • Process traffic conditions for presentation to driver • Process environmental conditions for presentation to driver • Determine alternative routes (e.g., routes around the Low Emissions Zone) • Determine eco-driving recommendations (e.g., recommended speeds) • Determine the vehicle's criteria for entering the Low Emissions Zone based on the parameters of the Low Emissions Zone • Determine vehicle emissions data (e.g., determine BEM for disseminate) • Manage payment of fees or collection of incentives <u>Disseminate Data</u> • Electronic payment or incentive • 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) • Vehicle specific data (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data), the time the vehicle entered the Low Emissions Zone, and number of miles traveled within the Low Emissions Zone) <u>Driver Interface</u>	Conditions Data • IVS-DC-03: Receive Environmental Conditions Data • IVS-DC-04: Receive Low Emissions Zone Parameter Data • IVS-DC-05: Receive Payment or Incentive Request Information • IVS-DC-06: Receive Confirmation of Payment or Incentive • IVS-DC-07: Receive Notice of Violation • IVS-DC-08: Collect Vehicle Diagnostics Data • IVS-DP-01: Process Traffic and Environmental Data for Traveler Information Messages • IVS-DP-02: Determine Trip/Route Options • IVS-DP-03: Determine Eco-Driving Recommendations • IVS-DP-04: Determine Vehicle's Criteria for Entering the Low Emissions Zone • IVS-DP-05: Determine Vehicle Emissions Data • IVS-DP-06: Manage Fee

<table>
<tr><th>Item</th><th>Actors</th><th>Data Exchange / Action</th><th>Related User Needs</th></tr>
<tr><td></td><td></td><td>Display information to the driver
Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone)
Eco-driving recommendations (e.g., recommended driving speeds, driver feedback, etc.)
Multi-modal options
Traffic conditions
Environmental conditions (e.g., code red air quality alerts)
Road weather conditions
Incentive received (or fee paid)
Financial information
Notice of violation
Activation of Application (e.g., activate eco-driving application, activate incentive application)
Updates to configurable parameters for Low Emissions Zone access, fees, and/or incentives
Origin-Destination (O-D) information</td><td>Payment
IVS-D-01: Provide Traffic Conditions to the Driver
IVS-D-02: Provide Environmental Conditions to the Driver
IVS-D-03: Provide Low Emissions Zone Parameters to the Driver
IVS-D-04: Provide Trip/Route Information to the Driver
IVS-D-05: Provide Eco-Driving Information to the Driver
IVS-D-06: Disseminate Payment/Incentive Data
IVS-D-07: Disseminate Vehicle Status Data
IVS-D-08: Disseminate Vehicle Status Environmental Data
IVS-DI-01: Provide Driver Interface</td></tr>
<tr><td>10</td><td>Low Emissions Zone System</td><td><u>Collect Data</u>
Traffic data (e.g., speed, volume, occupancy, travel times, etc.)
Environmental data (e.g., air quality data, etc.)
Road weather data (e.g., road friction, precipitation, temperature, etc.)
Vehicle specific data – sent using conventional toll tag readers (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data))</td><td>LEZS-DC-01: Collect Special Event Data
LEZS-DC-02: Collect Transit Operations Data
LEZS-DC-03: Collect Traffic Data</td></tr>
</table>

Item	Actors	Data Exchange / Action	Related User Needs
		• Vehicle status data (e.g., vehicle's location, heading, speed, acceleration, braking status, size, etc.) • Vehicle status environmental data (e.g., BEM data including the vehicle's fuel type, engine type, current emissions, average emissions, current fuel consumption, and average fuel consumption) • Vehicle specific data (e.g., vehicle's make and model, engine type, number of axles, average emissions, average fuel consumption, unique identifier (license plate number or vehicle registration data), the time the vehicle entered the Low Emissions Zone, and number of miles traveled within the Low Emissions Zone) • Electronic payment or incentive data <u>Process Data</u> • Process traffic data • Generate predicted traffic conditions • Process environmental data • Generate predicted emissions profile • Create and decommission Low Emissions Zones • Determine fees for vehicles • Determine incentives for vehicles • Detect and determine violations • Manage electronic payment processing <u>Disseminate Data</u> • Low Emissions Zone parameters (e.g., location, duration, fee structure, and other characteristics about the Low Emissions Zone) • Traffic conditions (e.g., link speeds, queues, incidents, travel times, etc.) • Multi-modal travel options • Environmental conditions (e.g., air quality information, code red air quality alerts) • Road weather conditions (e.g., pavement conditions) • Request for electronic payment or incentive • Confirmation of payment or incentive – sent to vehicles and travelers • Notice of violation – sent to vehicles and travelers • ITS device control functionality (e.g., control of DMS, cameras, etc.) • Financial data – sent to Financial Institutions	• LEZS-DC-04: Collect Environmental Data • LEZS-DC-05: Collect Operator Input • LEZS-DC-06: Collect Vehicle Specific Data • LEZS-DC-07: Collect Electronic Payments • LEZS-DP-01: Process Traffic Data • LEZS-DP-02: Generate Predicted Traffic Conditions and Forecast Demand • LEZS-DP-03: Process Environmental Data • LEZS-DP-04: Generate Predicted Emissions Profile • LEZS-DP-05: Create and Decommission Low Emissions Zones • LEZS-DP-06: Determine Fees for Vehicles • LEZS-DP-07: Determine Incentives for Individual Vehicles • LEZS-DP-08: Detect Violations for Individual Vehicles • LEZS-DP-09: Manage Electronic Payment

Item	Actors	Data Exchange / Action	Related User Needs
		• Violation data – sent to Enforcement Agencies User Interface • Low Emissions Zone parameters and operational status • Traffic conditions • Environmental conditions • Road weather conditions • Multi-modal travel options • Performance measures • Archived data • Operator inputs (e.g., creating Low Emissions Zone, code red air quality alerts, or adding new equipment (e.g., new RSE units) to the system)	Processing • LEZS-D-01: Disseminate Low Emissions Zone Parameters to vehicles • LEZS-D-02: Disseminate Low Emissions Zone Parameters to Other Centers and Travelers • LEZS-D-03: Disseminate Traffic Conditions to Other Centers and Travelers • LEZS-D-04: Disseminate Traffic Conditions to Vehicles • LEZS-D-05: Disseminate Multi-Modal Travel Options • LEZS-D-06: Disseminate Environmental Conditions to Other Centers and Travelers • LEZS-D-07: Disseminate Environmental Conditions to Vehicles • LEZS-D-08: Disseminate Information for Request for Electronic Payment to Individual Vehicles • LEZS-D-09: Request for Payment from Financial Institutions • LEZS-D-10: Provide Incentives • LEZS-D-11: Provide

Item	Actors	Data Exchange / Action	Related User Needs
			Confirmation of Payment from or Incentives to Vehicles • LEZS-D-12: Provide Notice of Violation to Vehicles • LEZS-D-13: Notify Enforcement Agencies of Violations • LEZS-DA-01: Archive Low Emissions Zone Data • LEZS-DA-02: Archive Financial Data • LEZS-DA-03: Determine Performance Measures • LEZS-UI-01: User Interface

9 Scenarios

This section describes scenarios for the Low Emissions Zones 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 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; these details enable 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 a Low Emissions Zone

Actors. Low Emissions Zone System, In-Vehicle System, ITS Roadway & Payment Equipment, Connected Vehicle Roadway Equipment, Traffic Management Centers, Emissions Management Centers, and Transit Management Centers

Description. Metropolis City is one of the more 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 a low emissions zone that is responsive to real-time traffic and environmental conditions. It also allows MCDOT to establish a fee and incentive structure in accordance to regulation or policy established by state legislation. The purpose of the low emissions zone is to reduce traffic pollution and improve air quality by deterring the most polluting passenger vehicles, trucks, buses, coaches, mini-buses, and large vans from driving within the city.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchanges 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 ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment deployed throughout Metropolis City.
- The ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment is located surrounding the zone and connected to the Low Emissions Zone System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.

- Conventional ITS technologies (e.g., DMS, CCTV cameras, and roadside sensors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement low emissions zones in accordance to state legislation.

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

Table 9-1: Establishing a Low Emissions Zone: 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 Low Emissions Zone System which would estimate vehicle emissions at a center.
2	Other Centers provide traffic, environmental, special event, and transit data to the Low Emissions Zone System. These data are sent from center to center. Traffic data includes volumes, speeds, occupancy, travel times, incidents, or other traffic data collected by a Traffic Management Center. These data may be collected using ITS Roadway & Payment Equipment such as traffic sensors, probe vehicles, or other ITS technologies. Environmental data includes air quality data or road weather data collected by Emissions Management Centers. Finally, transit data includes information about transit routes, transit schedules, and other transit related information from the Transit Management Center.
3	The Low Emissions Zone System uses the data collected from Connected Vehicle Roadway Equipment, ITS Roadway Equipment, and Other Centers as well as historical data to determine whether a low emissions zone should be established, and if so, the parameters of the low emissions zone. These parameters include the geographic limits of the zone, duration of the zone, and fee/incentive structure parameters.
4	The low emissions zone is established by the Low Emissions Zone System and is approved by the operator. The Low Emissions Zone System geo-fences the geographic limits of the zone and assigns parameters including the fee/incentive structure for the zone. Once the zone is established, traffic and environmental data continue to be collected and monitored by MCDOT staff to track the performance of the low emissions zone.

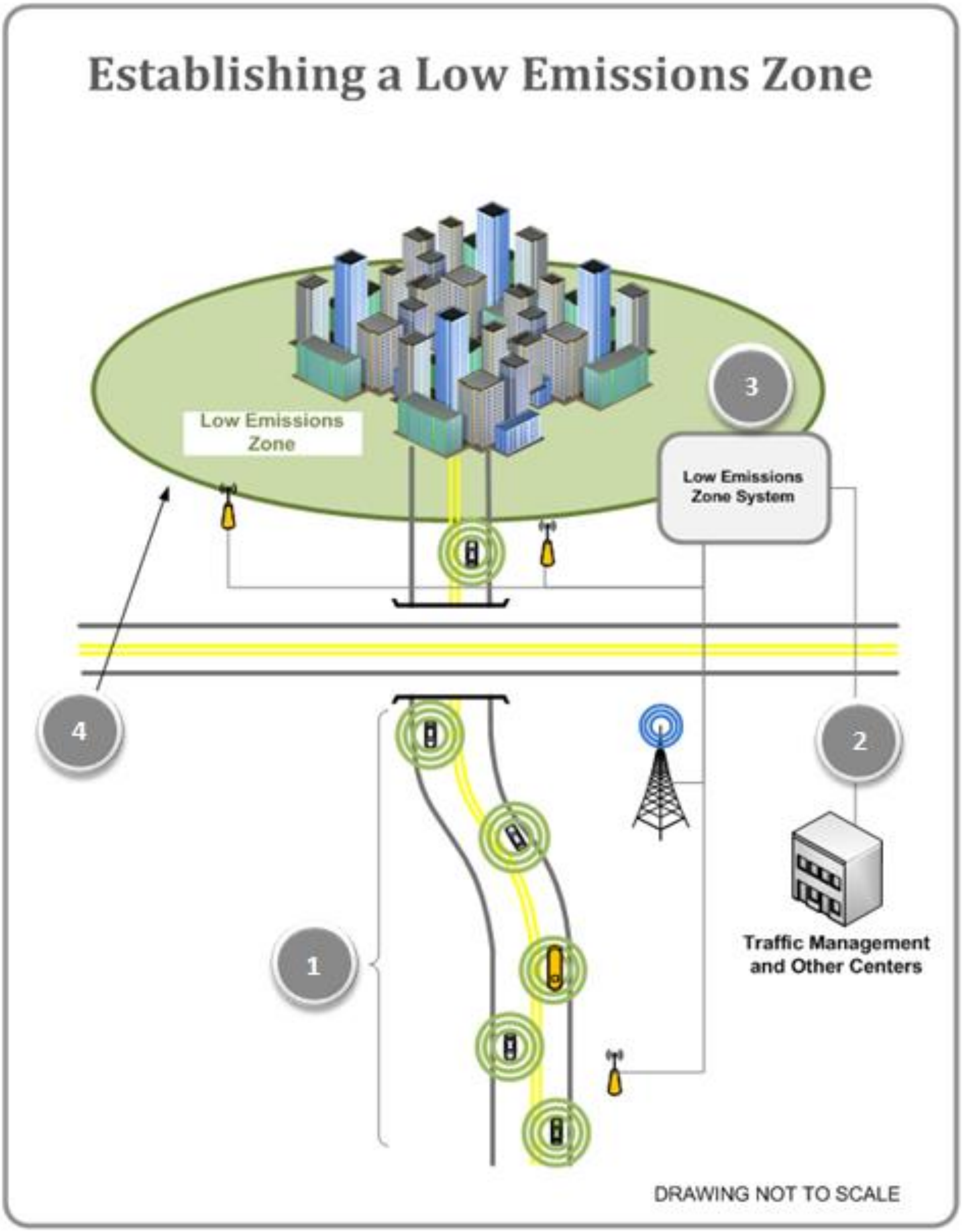

Figure 9-1: Establishing a Low Emissions Zone Scenario (*Source*: Noblis, 2013)

9.2 Scenario: Low Emissions Zone Traveler Information

Actors. Low Emissions Zone System, In-Vehicle System, ITS Roadway & Payment Equipment, Connected Vehicle Roadway Equipment, Traffic Management Centers, Emissions Management Centers, Transit Management Centers, and Information Service Providers

Description. Based on traffic and environmental data collected, the Low Emissions Zone System determines that a low emissions zone should be placed around Metropolis City. Parameters for the low emissions zone are established defining the geographic limits, time the zone will be established, and fee/incentive structure. Information about the parameters of the zone 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 street network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchanges 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 ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment deployed throughout Metropolis City.
- The ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment is located surrounding the zone and connected to the Low Emissions Zone System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and roadside sensors) are deployed throughout and around the city. This allows the operating entity to disseminate traveler information to drivers of vehicles that are not equipped with connected vehicle technologies.
- Policies are in place allowing the operating entity to implement low emissions zones in accordance to state legislation.

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

Table 9-2: Low Emissions Zone Traveler Information: Scenario Steps

Step	Description
1A	**Step 1 A.** The Low Emissions Zone System determines the parameters for the low emissions zone.
1B	**Step 1 B.** The Low Emissions Zone System sends parameters about the low emissions zone to Other Centers such as Traffic Management Centers and Transit Management Centers. These centers use information about the low emissions zone to support traffic and transit operations in the vicinity of the zone. 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	**Step 1 C.** Connected Vehicle Roadside Equipment and Cell Towers broadcast messages about the parameters of the low emissions zone. Messages may be broadcast using DSRC communications or other wireless communications (e.g., 4G). This includes information such as the geographic limits of the low emissions zone, the time the zone will be established and decommissioned, and the fee structure for entering the zone.
1D	**Step 1 D.** ITS Roadway & Payment Equipment including DMS and 511 systems provide information about the parameters of the low emissions zone. This includes information such as the geographic limits of the low emissions zone, the time it will be commissioned and decommissioned, and the fee structure for entering the zone. *Note: ITS Roadway & Payment Equipment may be needed to disseminate information to motorists who are not equipped with Connected Vehicle technologies.*
2	Travelers receive pre-trip traveler information about the parameters of the low emissions zone and other traveler information. This information may be received by travelers from MCDOT or other Information Service Provider on their personal computers, cell phones, tablets, television, radio, or 511 traveler information systems. Travelers use this information to plan their trips accordingly. For example, upon receiving information about the low emissions zone, travelers may decide to switch their mode to transit or change their departure time to avoid entering the zone while it is commissioned.
3	In-Vehicle Systems receive information about the parameters of the Low Emissions Zone. This information is presented to drivers to assist them in making informed en-route travel choices as they approach the low emissions zone. Upon receiving this information, drivers may decide to change their route to avoid the low emissions zone or decide to switch their travel mode to transit.

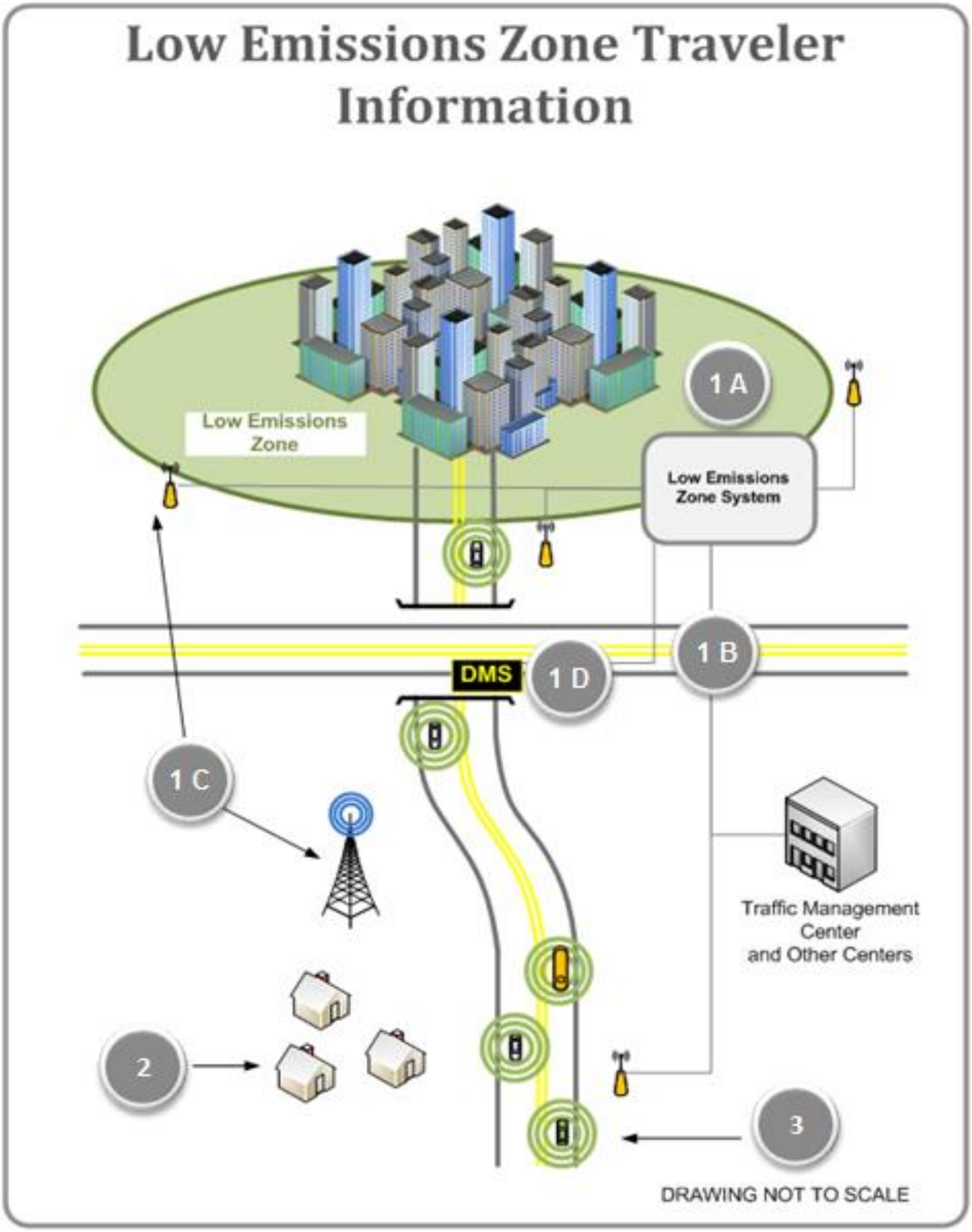

Figure 9-2: Low Emissions Zone Traveler Information Scenario (*Source*: Noblis, 2013)

9.3 Scenario: Low Emissions Zone Fee Collection

Actors. Low Emissions Zone System, In-Vehicle System, ITS Roadway & Payment Equipment, Connected Vehicle Roadway Equipment, and Financial Institutions

Description. Based on traffic and environmental data collected, the Low Emissions Zone System determines that a low emissions zone should be placed around Metropolis City. Travelers are provided with traveler information about the low emissions zone that allows them to make informed decisions as the approach and enter the zone. As vehicles approach the entrance to the low emissions zone, vehicles are required to pay a fee based on the zone parameters.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchanges 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 ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment deployed throughout Metropolis City.
- The ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment is located surrounding the zone and connected to the Low Emissions Zone System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and roadside sensors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement low emissions zones in accordance to state legislation.

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

Table 9-3: Low Emissions Zone Fee Collection: Scenario Steps

Step	Description
1A	The Low Emissions Zone System determines the parameters for the low emissions zone.
1B	Connected Vehicle Roadside Equipment broadcast messages about the parameters of the low emissions zone. Messages may be broadcast using DSRC communications or other wireless communications. This includes information such as the geographic limits of the low emissions zone, time the zone will be established and decommissioned, and fee structure for entering the zone. This information is received by In-Vehicle Systems.
1C	ITS Roadway & Payment Equipment provide information to travelers about the geographic limits of the low emissions zone, time the zone will be commissioned and decommissioned, and fee structure for entering the zone. This information is provided to travelers using conventional ITS equipment such as DMSs.
2	Connected Vehicle Roadway Equipment and/or ITS Roadway & Payment Equipment (e.g., electronic toll collection systems) provide information about the fee structure to In-Vehicle Systems as vehicles approach the low emissions zone boundary. Drivers are informed that there is a $5.00 fee to enter the low emissions zone; however vehicles meeting the low emissions criteria may enter at a reduced fee of $1.00. Transit Vehicles may enter the low emissions zone at no cost. Connected Vehicle Roadway Equipment and/or ITS Roadway & Payment Equipment also send requests for payment messages to In-Vehicle Systems. These messages request that vehicles provide information about the vehicle's engine type, average emissions, or other vehicle specific data to determine the fee for individual vehicles.
3	In-Vehicle Systems send data about the vehicle's engine type, average emissions, a unique identification number, and payment information via secure communications to Connected Vehicle Roadway Equipment and/or ITS Roadway & Payment Equipment and then to the Low Emissions Zone System. Upon receiving this information, the Low Emissions Zone System compares these data to the parameters established for the zone and determines the fee for the vehicle.
4	The Low Emissions Zone System requests payment from the financial institution. The financial institution transfers funds to the entity operating the low emissions zone.

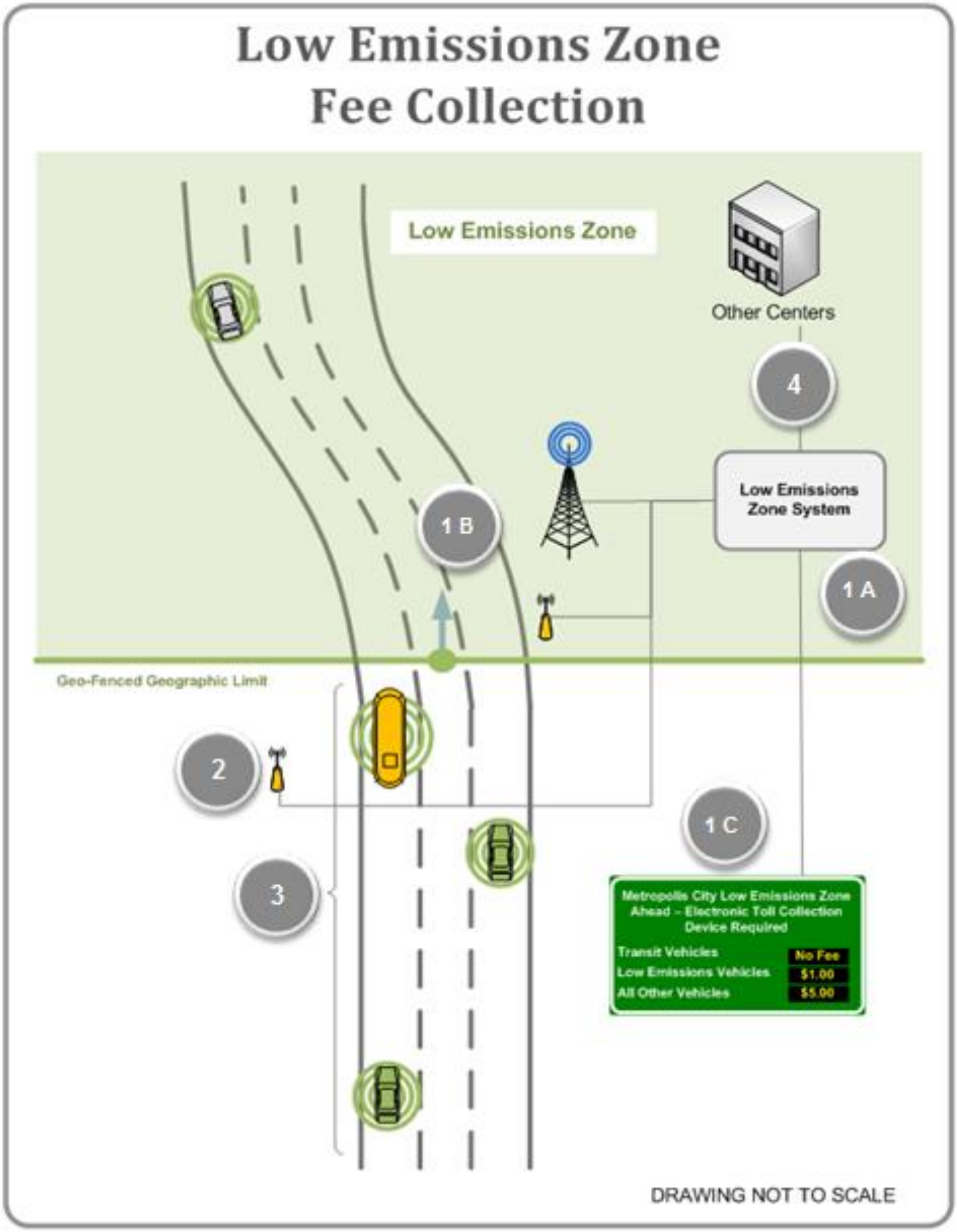

Figure 9-3: Low Emissions Zone Fee Collection Scenario (*Source*: Noblis, 2013)

9.4 Scenario: Low Emissions Zone Incentives Upon Leaving the Zone

Actors. Low Emissions Zone System, In-Vehicle System, ITS Roadway & Payment Equipment, and Connected Vehicle Roadway Equipment

Description. A low emissions zone is placed around Metropolis City. Drivers of vehicles were required to pay a fee prior to entering the low emissions zone. Upon entrance, In-Vehicles System record the time the vehicle entered the zone and the mileage of the vehicle when it entered the zone. Additionally, In-Vehicle Systems record the amount of emissions emitted by the vehicle while driving within the geographic limits of the low emissions zone. These data are transmitted to the Low Emissions Zone System which determines if the vehicle may receive an incentive once it leaves the zone.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchanges 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 ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment deployed throughout Metropolis City.
- The ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment is located surrounding the zone and connected to the Low Emissions Zone System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and roadside sensors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement low emissions zones in accordance to state legislation.

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

Table 9-4: Low Emissions Some Incentives Upon Leaving the Zone: Scenario Steps

Step	Description
1	In-Vehicle Systems collect data that may be used for receiving incentives or rebates upon leaving the low emissions zone. This may include information about: • The amount of time spent within the low emissions zone – This would require the In-Vehicle System to record the time the vehicle entered and exited the low emissions zone and provide this information to the Low Emissions Zone System. The Low Emissions Zone System would receive the time the vehicle was in the Low Emissions Zone and if it was less than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate. • Number of miles driven within the low emissions zone – This would require the In-Vehicle System to record the number of miles driven within the low emissions zone and provide this information to the Low Emissions Zone System. If the vehicle traveled less miles in the zone than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate. • Amount of emissions emitted while in the low emissions zone – This would require the In-Vehicle System to record the amount of emissions emitted while within the low emissions zone and provide this information to the Low Emissions Zone System. If the vehicle emitted fewer emissions in the zone than a pre-determined threshold, the driver of the vehicle would be eligible for an incentive or rebate.
2	Connected Vehicle Roadway Equipment and/or ITS Roadway & Payment Equipment disseminates a message to In-Vehicle Systems requesting them to provide data for incentives or rebates. This may include information about the amount of time spent in the zone, number of miles driven within the zone, and/or the amount of emissions emitted while in the zone.
3	In-Vehicle Systems provide data for incentives or rebates to the Low Emissions Zone System through Connected Vehicle Roadway Equipment and/or ITS Roadway & Payment Equipment. This information would be sent using secure communications to ensure privacy. Upon receiving these data, the Low Emissions Zone System determines if an individual vehicle should be given an incentive. If it is determined that the vehicle should receive an incentive, the system provides the incentive to the account of the vehicle. The Low Emissions Zone System archives all data related to the incentive request and financial transaction.

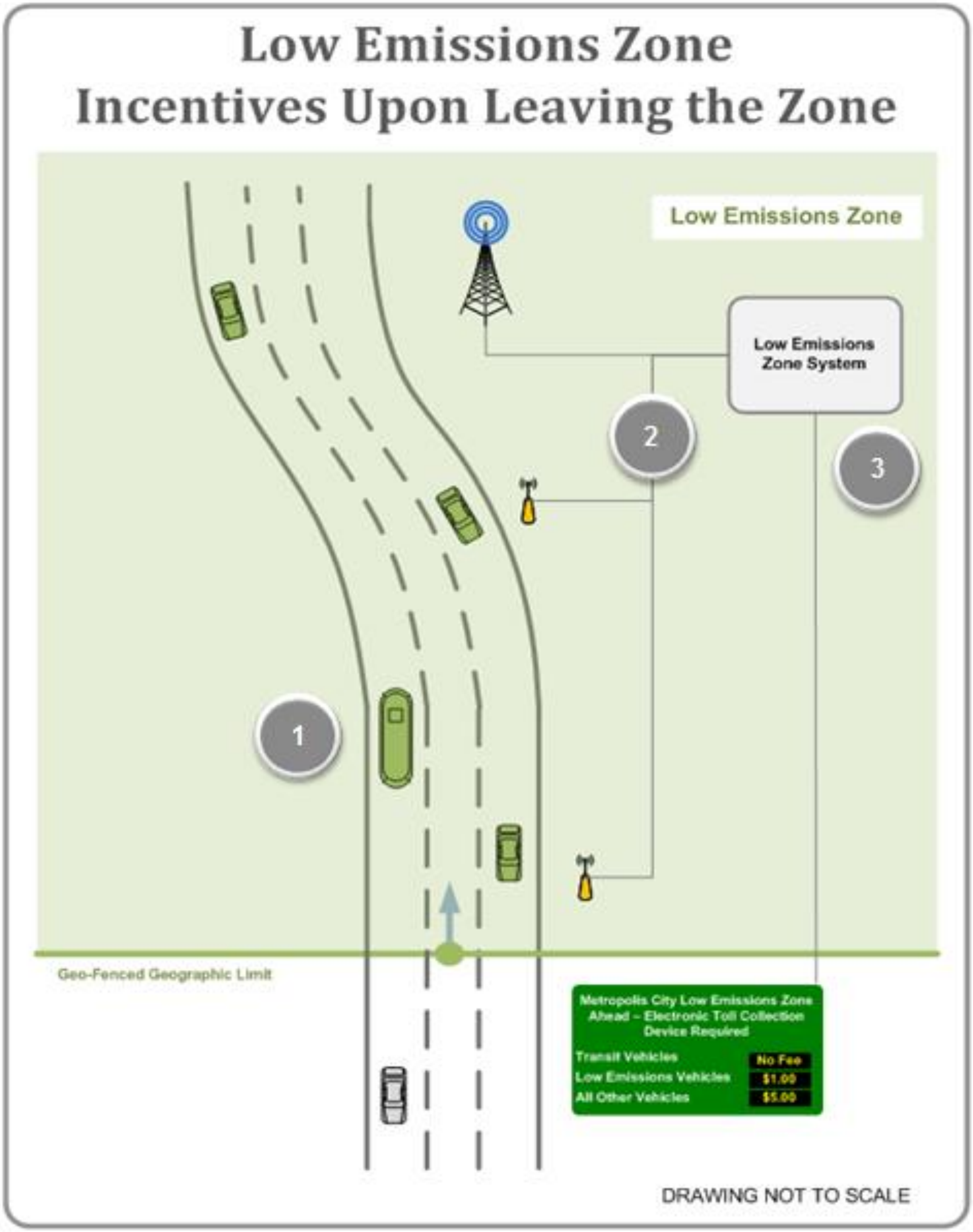

Figure 9-4: Low Emissions Zone Incentives Upon Leaving the Zone Scenario
(*Source*: Noblis, 2013)

9.5 Scenario: Low Emissions Zone Violations

Actors. Low Emissions Zone System, In-Vehicle System, , Connected Vehicle Roadway Equipment, and Enforcement ITS Roadway & Payment Equipment Agencies

Description. A low emissions zone is placed around Metropolis City. Drivers of vehicles are required to pay a fee prior to entering the low emissions zone; however a driver attempts to enter the low emissions zone without paying a fee – the driver removed the toll tag transponder from the vehicle. The Metropolis City Police Department (MCPD) is responsible for enforcing the low emissions zone, but does not have enough officers to sit at all the boundaries of the zone. Instead, the Low Emissions Zone System uses ITS technology to assist the enforcement agency in enforcing the parameters of the zone. In particular, automatic license plate recognition (ALPR) technology is used to detect violators.

Assumptions. The following assumptions apply to this scenario:

- It is assumed that the vehicles have an on-board, map database that can be used for identifying a route through the street network. The map database will contain information regarding the identification of the arterials, intersections, freeways, and interchanges 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 ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment deployed throughout Metropolis City.
- The ITS Roadway & Payment Equipment and Connected Vehicle Roadway Equipment is located surrounding the zone and connected to the Low Emissions Zone System.
- Transit Vehicles, Commercial Vehicles, and Passenger Vehicles are equipped with In-Vehicle Systems.
- Conventional ITS technologies (e.g., DMS, CCTV cameras, and roadside sensors) are deployed throughout and around the city.
- Policies are in place allowing MCDOT to implement low emissions zones in accordance to state legislation.

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

Table 9-5: Low Emissions Zone Violations: Scenario Steps

Step	Description
1	The low emissions zone requires electronic payment of fees using either Connected Vehicle technologies or a toll tag transponder. A vehicle not equipped with Connected Vehicle technologies, or other means for paying a toll electronically, approaches the low emissions zone. Static signs and messages on DMS prior to the limits of the zone inform the driver about the upcoming zone and requirement for in-vehicle electronic payment systems or transponders. Signage also informs motorists of alternative routes around the low emissions zone to avoid entering the zone in violation of the zone's parameters.
2	The driver decides to enter the low emissions zone. Since the vehicle is not equipped with an in-vehicle electronic payment systems or transponder, it is in violation.
3	At the entrance on the low emissions zone, an ALPR system takes a picture of every vehicle's license plate. This information is compared to messages collected from vehicles using connected vehicle technologies and/or ITS Roadway & Payment Equipment as they enter the zone and pay their fees. The Low Emissions Zone System cannot match the vehicle's information to the payment of a fee and determines it is in violation.
4	Once the Low Emissions Zone System determines that a vehicle is a violator, data about the violation and the vehicle (e.g., the vehicle's license plate number) are sent to an Enforcement Agency which issues a citation to the owner of the vehicle. This citation could be given to the vehicle owner by mail, requesting payment for entering the zone.

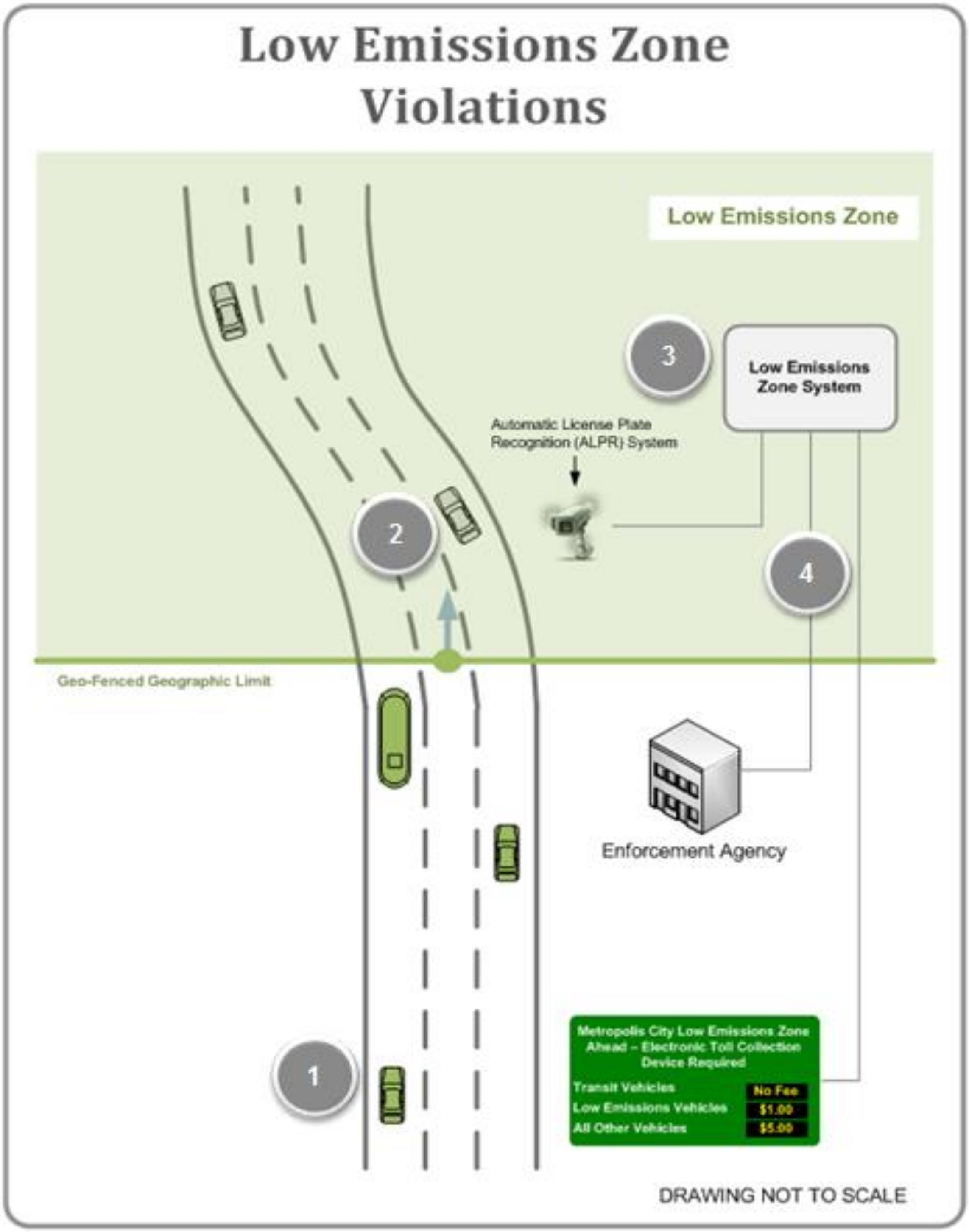

Figure 9-5: Low Emissions Zone Violations Scenario (*Source*: Noblis, 2013)

10 Goals, Objectives, and Performance Measures

This section presents an analysis of the goals, objectives, and potential performance measures for the Low Emissions Zones 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 a Low Emissions Zone 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.

Three goals are identified for the Low Emissions Zones Transformative Concept. The first goal looks at reductions in emissions and energy consumption. The second goal is focused on supporting green transportation decisions by travelers and operating entities, 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 results 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.

Goal #1 Reduce Environmental Impacts

- Reduce Emissions from Surface Transportation Vehicles
    - Reduce carbon dioxide (CO_2) emissions by X percent by Y.
    - Reduce carbon monoxide (CO) emissions by X percent by Y.
    - Reduce Nitric Oxide (NO_x) emissions by X percent by Y.
    - Reduce Sulfur Dioxide (SO_2) emissions by X percent by Y.
    - Reduce emissions of coarse particulates (PM10) by X percent by Y.
    - Reduce emissions of fine particulates (PM2.5) by X percent by Y.
    - Reduce volatile organic compounds (VOCs) by X percent by Y.
- Reduce Energy Consumption Associated with Surface Transportation Vehicles
    - Reduce excess fuel consumed by X percent by Y.
    - Reduce excess energy consumption by X percent by Y.
    - Reduce total fuel consumption per capita for transportation by X percent by Y.
    - Reduce total energy consumption per capita for transportation by X percent by Y.

Goal #2 Support “Green Transportation Decisions” by Travelers and Operating Entities

- Increase Modal Shifts to Transit, Walking, Bicycling, 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 active (bicycle/pedestrian) mode share 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 Usage of Alternative Fuel Vehicles (AFVs)
  - Increase usage of personal AFVs by X percent by Y.
  - Increase usage of transit AFVs by X percent by Y.
  - Increase usage of freight alternative fuel vehicles (AFVs) by X percent by Y.
- Increase Vehicle Miles Traveled (VMT) of AFVs
  - 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.

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

- Improve the Efficiency of the Transportation System
  - Reduce the annual monetary cost of congestion per capita by X by Y.
  - Reduce hours of delay per capita by X percent by Y.
  - Reduce hours of delay per driver by X percent by Y.
  - Improve the Efficiency of Arterials
    - Increase the miles of arterials in the region operating at level of service (LOS) Z 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 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 the Efficiency of Freight Operating Efficiency
  - Decrease hours of delay per 1,000 vehicle miles traveled on selected freight-significant routes by X percent by Y.
  - Decrease point-to-point travel times on selected freight-significant routes by X minutes by Y.
  - Increase ratings for customer satisfaction with freight mobility in the region among shippers, receivers, and carriers by X percent by Y.in the region among shippers, receivers, and carriers by X percent by Y.

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APPENDIX A. List of Acronyms

Acronym	Meaning
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
AERIS	Applications for the Environment: Real-Time Information Synthesis
ALPR	Automatic License Plate Recognition
AFV	Alternative Fuel Vehicle
ALPR	Automatic License Plate Recognition
ANSI	American National Standards Institute
BRT	Bus Rapid Transit
BEM	Basic Environmental Message
BRT	Bus Rapid Transit
BSM	Basic Safety Message
CAN	Controller Area Network
CCTV	Closed Circuit Television
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DCM	Data Capture and Management
DMS	Dynamic Message Sign
DOT	Department of Transportation
DRPA	Delaware River Port Authority
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface

Acronym	Meaning
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
g/kWh	Grams per Kilowatt Hour
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	Institute of Electrical and Electronics Engineers
ISP	Information Service Provider
ITS	Intelligent Transportation Systems
IVS	In-Vehicle System
I2V	Infrastructure-to-Vehicle

Acronym	Meaning
JPO	Joint Program Office
LEZS	Low Emissions Zone System
LOS	Level of Service
MCDOT	Metropolis City Department of Transportation
MCPD	Metropolis City Police Department
mpg	Miles per Gallon
MTCE	Metric Tons of Carbon Equivalent
NHTSA	National Highway Traffic Safety Administration
NJTA	New Jersey Turnpike Authority
NO_x	Nitric Oxide
NTCIP	National Transportation Communications for ITS Protocol
OBD	On-Board Diagnostics
OBE	On-Board Equipment
OEM	Original Equipment Manufacturers
PM	Particulate Matter
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SO_2	Sulfur Dioxide
SOV	Single-Occupancy Vehicle
TCIP	Transit Communications Interface Profiles
TMDD	Traffic Management Data Dictionary
U.S.	United States
USD	United States Dollars

Acronym	Meaning
USDOT	U.S. Department of Transportation
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Wi-Fi	Wireless Fidelity
X2D	Vehicle or Infrastructure-to-Device
3G	Third Generation
4G	Fourth Generation

APPENDIX B. Actor Definitions

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

- **Commercial Vehicle.** The Commercial Vehicle actor resides in a commercial vehicle and provides the sensory, processing, storage, and communications functions necessary to support efficient, safe, and environmentally efficient travel. Both one-way and two-way communications options, including 5.9 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 Federal Communications Commission (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 passeneger, 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.
- **Emergency Vehicle.** The Emergency Vehicle actor includes vehicles that provide the sensory, processing, storage, and communications functions necessary to support safe and efficient incident response. The actor represents a range of vehicles including those operated by police, fire, and emergency medical services. In addition, this actor represents other incident response vehicles including towing and recovery vehicles and freeway service patrols. The Emergency Vehicle actor includes two-way communications to support coordinated response to emergencies. Emergency vehicles are equipped with automated vehicle location capability for monitoring by vehicle tracking and fleet management. Using these capabilities, the appropriate emergency vehicle to respond to each emergency is

determined. Route guidance capabilities within the vehicle enable safe and efficient routing to the emergency. In addition, the emergency vehicle may be equipped to support signal preemption.

- **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.
- **Event Promoter.** The Event Promoter actor represents special event sponsors that have knowledge of events that may impact travel on roadways or other modes. Examples of special event sponsors include sporting events, conventions, motorcades/parades, and public/political events. These promoters interface to the ITS to provide event information such as date, time, estimated duration, location, anticipated number of attendees, and any other information pertinent to traffic movement in the surrounding area.
- **Financial Institution.** The Financial Institution actor represents the organization that handles all electronic fund transfer requests to enable the transfer of funds from the user of the service to the provider of the service. The functions and activities of financial clearinghouses are subsumed by this entity.
- **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 & Payment Equipment.** The ITS Roadway & Payment 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 road conditions, surface weather, and vehicle emissions. In adverse conditions, automated systems can be used to apply anti-icing materials, disperse fog, etc. This actor also represents the roadway components of a toll collection, VMT, congestion charging, and other systems that support payment from a vehicle. As a toll collection system, this subsystem provides the capability for vehicle operators to pay tolls without stopping their vehicles. It supports use of locally determined pricing structures and includes the capability to implement various variable road pricing policies. Each transaction is accompanied by feedback to the customer indicating the general status of the customer account.
- **Maintenance and Construction Vehicle.** The Maintenance and Construction Vehicle actor includes vehicles that provide the sensory, processing, storage, and communications functions necessary to support highway maintenance and construction. All types of maintenance and construction vehicles are covered, including heavy equipment and supervisory vehicles. The subsystem provides two-way communications between drivers/operators and dispatchers and maintains and communicates current location and status information. A wide range of operational status is monitored, measured, and made available, depending on the specific type of vehicle or equipment. For example, for a snow plow, the information would include whether the plow is up or down and material usage information. The actor may also contain capabilities to monitor vehicle systems to support maintenance of the vehicle itself and other sensors that monitor environmental conditions including the road condition and surface weather information. This actor can represent a diverse set of mobile environmental sensing platforms, including wheeled vehicles and any other vehicle that collects and reports environmental information.
- **Operator.** The Operator actor represents the human entity that directly interfaces with the Low Emissions Zone 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, sensors may be equipped on a vehicle to measure atmospheric, surface (i.e., pavement and soil), and/or hydrologic 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, as well as 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 Center actors 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 Center 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.
- **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 Low Emissions Zones Transformative Concept. The columns of the table are documented as follows:

- **Subsystem.** The subsystems for the Low Emissions Zones 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 human machine interface (HMI) sometimes appears here. Strictly speaking, input or display of data via a HMI is not a communications message, but it is included for completeness.
- **Latency.** The latency of the information contained in the message. Low means 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.
- **Other Comments.** Other comments about some aspects of the data transmissions, or questions to be discussed.

Table C-1: Low Emissions Zone System Communication Needs and Standards

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Special Event Data Collection Subsystem	Collect Special Event Data (LEZS-DC-01)	Information about upcoming special events	Event Promoters	Low Emissions Zone System	Backhaul	High	TBD	Sent only for special occasions. Used to determine whether criteria for Dynamic Low Emissions Zone are or will be met	Modeling may be used to predict conditions
Transit Operational Data Collection Subsystem	Collect Transit Operations Data (LEZS-DC-02)	Transit schedules, status, ridership, etc.	Transit Management Centers	Low Emissions Zone System	Backhaul	Medium	TCIP	Determine whether criteria for Dynamic Low Emissions Zone are met and transit capacity exists	None
Traffic Data Collection Subsystem	Collect Traffic Data (LEZS-DC-03)	Speed, volume, occupancy, classification, CCTV images, etc.	Infrastructure Traffic Sensors	Low Emissions Zone System	Backhaul	Medium	TMDD	Determine whether criteria for Dynamic Low Emissions Zone are met	"Traditional" ITS sensors
Traffic Data Collection Subsystem	Collect Traffic Data (LEZS-DC-03)	Speed, volume, occupancy, classification, CCTV images, etc.	Other Centers	Low Emissions Zone System	Backhaul	Medium	TMDD	Determine whether criteria for Dynamic Low Emissions Zone are met	None
Traffic Data Collection Subsystem	Collect Traffic Data (LEZS-DC-03)	Speed, turns, location, etc.	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then backhaul	Medium	Current J2735 BSM	Determine whether criteria for Dynamic Low Emissions Zone are met	Connected Vehicle data
Environmental Data Collection Subsystem	Collect Environmental Data (LEZS-DC-04)	Environmental readings from fixed sensors	Infrastructure Sensors such as Environmental Sensor Stations (ESS)	Low Emissions Zone System	Backhaul	Medium	NTCIP 1204	Determine whether criteria for Dynamic Low Emissions Zone are met	"Traditional" ITS sensors
Environmental Data Collection Subsystem	Collect Environmental Data (LEZS-DC-04)	Environmental readings from mobile sensors	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then backhaul	Medium	Pending J2735SE	Determine whether criteria for Dynamic Low Emissions Zone are met	Connected Vehicle data
Environmental Data Collection Subsystem	Collect Environmental Data (LEZS-DC-04)	Environmental readings from environmental centers	Environmental or Emissions Management Centers	Low Emissions Zone System	Backhaul	5 min.	TMDD	Determine whether criteria for Dynamic Low Emissions Zone are met	None

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Operator Input Data Collection Subsystem	Collect Operator Input (LEZS-DC-05)	Configurable Dynamic Low Emissions Zone Parameters	Centers	Low Emissions Zone System	Backhaul	Medium-low	TBD	An operator sitting in a center may enter data into the system to configure the system, enter attributes, etc.	None
Vehicle Specific Data Collection Subsystem	Collect Vehicle-Specific Data (LEZS-DC-06)	Vehicle emissions-related characteristics, unique identifier, vehicle type, engine type, etc.	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then backhaul	Low	J2735	Overall low emissions zone criteria analysis, Low Emissions Zone entry fee for individual vehicle	Vehicle probe may not be a good name for this subsystem
Electronic Payment Data Collection Subsystem	Collect Electronic Payments (LEZS-DC-07)	Vehicle account identification	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then backhaul	Low	Same function as for toll tags but using DSRC	Vehicle owner account information for charging	Same function as current std. for toll tags but using DSRC
Low Emissions Zone Parameters Dissemination Subsystem	Disseminate Low Emissions Zone Parameters to Vehicles (LEZS-D-01)	Low Emissions Zone Characteristics	Low Emissions Zone System	DMS and Other ITS Devices	Backhaul	Medium	NTCIP		Updates every 1-5 minutes
Low Emissions Zone Parameters Dissemination Subsystem	Disseminate Low Emissions Zone Parameters to Vehicles (LEZS-D-01)	Low Emissions Zone Characteristics	Low Emissions Zone System	RSEs, then to Vehicles (in-vehicle signage)	Backhaul, then I2V	Medium-low	J2735 (future)	Continual notification to traffic approaching low emissions zone	None
Low Emissions Zone Parameters Dissemination Subsystem	Disseminate Low Emissions Zone Parameters to Other Centers and Travelers (LEZS-D-02)	Low Emissions Zone Characteristics	Low Emissions Zone System	Other Centers (Traffic, Transit, & Emissions Management as well as the Media and ISPs), Travelers	Backhaul	Medium	TMDD (future)	Coordinate with other centers	One-time notification
Traffic Conditions Dissemination Subsystem	Disseminate Traffic Conditions to Other Centers and Travelers (LEZS-D-03)	Speed, volume, occupancy, classification, CCTV images, etc.	Low Emissions Zone System	Other Traffic and Transit Management Centers, Travelers	Backhaul	Medium	TMDD		None

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Traffic Conditions Dissemination Subsystem	Disseminate Traffic Conditions to Vehicles (LEZS-D-04)	Delays, incidents, congestion, travel times	Low Emissions Zone System	Vehicles	I2V, HMI	Medium-low	J2735	Helping drivers make green decisions approaching a low emissions zone	Info may be displayed in-vehicle with HMI
Traffic Conditions Dissemination Subsystem	Disseminate Multi-Modal Options (LEZS-D-05)	Transit Options	Low Emissions Zone System	Vehicles, Travelers	I2V	High		Provide multi-modal travel options to drivers	
Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Other Centers and Travelers (LEZS-D-06)	Environmental conditions gathered from all sources	Low Emissions Zone System	Emissions Management Centers	Backhaul	Medium	TMDD	Coordinate with other centers	None
Environmental Conditions Dissemination Subsystem	Disseminate Environmental Conditions to Vehicles (LEZS-D-07)	Environmental conditions gathered from all sources	Low Emissions Zone System	Vehicles	I2V	Medium	J2735SE	Helping drivers make green decisions approaching a low emissions zone	Info may be displayed in-vehicle with HMI
Payment and Incentive Dissemination Subsystem	Disseminate Information for Request for Electronic Payment to Individual Vehicles (LEZS-D-08)	Entrance fees or factors for fee, incentive amount	Low Emissions Zone System	RSEs, then to vehicles (in-vehicle signage)	Backhaul, then I2V	Low	Similar to current toll tag, but using DSRC		None
Payment and Incentive Dissemination Subsystem	Request for Payment from Financial Institutions (LEZS-D-09)	Fee or incentive amount, owner account number	Low Emissions Zone System	Financial Institutions	Backhaul	Low			None
Payment and Incentive Dissemination Subsystem	Provide Incentives (LEZS-10)	Amount of incentive, user account information	Low Emissions Zone System	Financial Institutions, Vehicles	Backhaul, I2V	Low			Maybe make this two messages, one to driver and one to bank

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Payment and Incentive Dissemination Subsystem	Provide Confirmation of Payment to Individual Vehicles (LEZS-D-11)	Confirmation of fee deducted from account, or incentive added	Low Emissions Zone System	RSEs, then to Vehicles (in-vehicle signage)	Backhaul, then I2V	Low	Similar to current toll tag, but using DSRC		None
Payment and Incentive Dissemination Subsystem	Provide Notice of Violation to Vehicles (LEZS-D-12)	License plate or other ID of offender	Low Emissions Zone System	Vehicles	I2V	5 sec.	Similar to current toll tag, but using DSRC		None
Payment and Incentive Dissemination Subsystem	Notify Enforcement Agencies of Violations (LEZS-D-13)	License plate or other ID of offender	Low Emissions Zone System	Enforcement Agencies	Backhaul	Medium	Same as current std. for toll tags		None

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)	O/D, vehicle configuration info	Driver	Low Emissions Zone System	I2V	Medium		Allows drivers to enter data into the system such as whether they have a trailer on their vehicle, whether they are a HOV, etc. It may also let them enter O-D data.	None
Traffic Conditions Data Collection Subsystem	Receive Traffic Conditions Data (IVS-DC-02)	Traffic Information	Low Emissions Zone System	In-Vehicle System	Wireless or I2V	Medium	J2735SE	Helps driver make green driving decisions	Received info must be displayed on driver interface
Environmental Conditions Data Collection Subsystem	Receive Environmental Conditions Data (IVS-DC-03)	Traffic and Environmental Information	Low Emissions Zone System	In-Vehicle System	Wireless or I2V	Medium	J2735SE	Helps driver make green driving decisions	Received info must be displayed on driver interface
Low Emissions Zone Parameters Collection Subsystem	Receive Low Emissions Zone Parameters Data (IVS-DC-04)	Low Emissions Zone Characteristics, including location and fees	Low Emissions Zone System	In-Vehicle System	I2V	Medium	J2735 (Future)	Helps driver make green driving decisions regarding the low emissions zone	Received info must be displayed on driver interface
Payment Request/Incentive Data Collection Subsystem	Receive Payment or Incentive Request Information (IVS-DC-05)	Fee payment or incentive rebate amount	Low Emissions Zone System	In-Vehicle System	I2V or Current Toll Tag	Low	Same as current std. for toll tags but with DSRC	Required for payment or incentive system	Received info must be displayed on driver interface
Payment Request/Incentive Data Collection Subsystem	Receive Confirmation Of Payment to Individual Vehicles (IVS-DC-06)	Confirmation of fee deducted from account, or incentive added	Low Emissions Zone System	In-Vehicle System	I2V or Current Toll Tag	Low	Same as current std. for toll tags but with DSRC	Required for payment or incentive system	Received info must be displayed on driver interface
Payment Request/Incentive Data Collection Subsystem	Receive Notice Of Violation to Vehicles (IVS-DC-07)	Notice of violation	Low Emissions Zone System	In-Vehicle System	I2V or Current Toll Tag	Low	Same as current std. for toll tags but with DSRC	Required for payment system	Received info must be displayed on driver interface
Vehicle Status Data Collection Subsystem	Collect Vehicle Diagnostics Data (IVS-DC-08)	Engine, emissions, GPS data	OBD, external sensors	On-Board Eco-Driving Application	CAN Bus	Medium	J1939	Enables sending vehicle and sensor data to other entities	No external communication involved

Subsystem	Need	Data to be Transmitted	From	To	Type of Communication	Latency	Applicable Standards	Use	Other Comments
Driver Information Dissemination Subsystem	Provide Traffic Conditions to the Driver (IVS-D-01)	Traffic conditions	Vehicle	Driver	DVI	Low		Display traffic information to the driver	
Driver Information Dissemination Subsystem	Provide Environmental Conditions to the Driver (IVS-D-02)	Environmental conditions	Vehicle	Driver	DVI	Medium		Display environmental information to the driver	
Driver Information Dissemination Subsystem	Provide Low Emissions Zone Parameters to the Driver (IVS-D-03)	Low Emission Zone parameters	Vehicle	Driver	DVI	Medium		Display low emission zone parameters to the driver	
Driver Information Dissemination Subsystem	Provide Trip/Route Information (IVS-D-04)	Multi-modal options, eco-routes, Low Emissions Zone info	OBE	Driver	HMI	Medium		Enables green choices by driver	None
Driver Information Dissemination Subsystem	Provide Eco-Driving Information (IVS-D-05)	Recommendations for more environmentally efficient driving	In-Vehicle System	Driver	HMI	Med		Encourages greed driving	None
Payment/ Incentive Data Dissemination Subsystem	Disseminate Payment/Incentive Data (IVS-D-06)	Account and emissions information	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then Backhaul	Low	J2735	Enables billing or incentive refund	None
Payment/ Incentive Data Dissemination Subsystem	Disseminate Payment/Incentive Data (IVS-D-06)	Account information	In-Vehicle System	Driver	HMI	Low		Informs the driver of charge or rebate	None
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Data (IVS-D-07)	Vehicle location, speed, heading, etc.	Vehicles	RSEs, then to Low Emissions Zone System	V2I, then Backhaul	Medium	Current J2735 BSM		Same as Low Emissions Zone System data collection
Vehicle Status Dissemination Subsystem	Disseminate Vehicle Status Environmental Data (IVS-D-08)	Environmental information from engine and onboard sensors	OBE	RSEs, then to Low Emissions Zone System	V2I, then Backhaul	Medium-low	J2735	Support all environmental applications.	Low latency needed to support low emissions zone charging function

APPENDIX D. Relationship to the National ITS Architecture

Appendix D is intended to show the relationship of the Low Emissions Zone 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’.

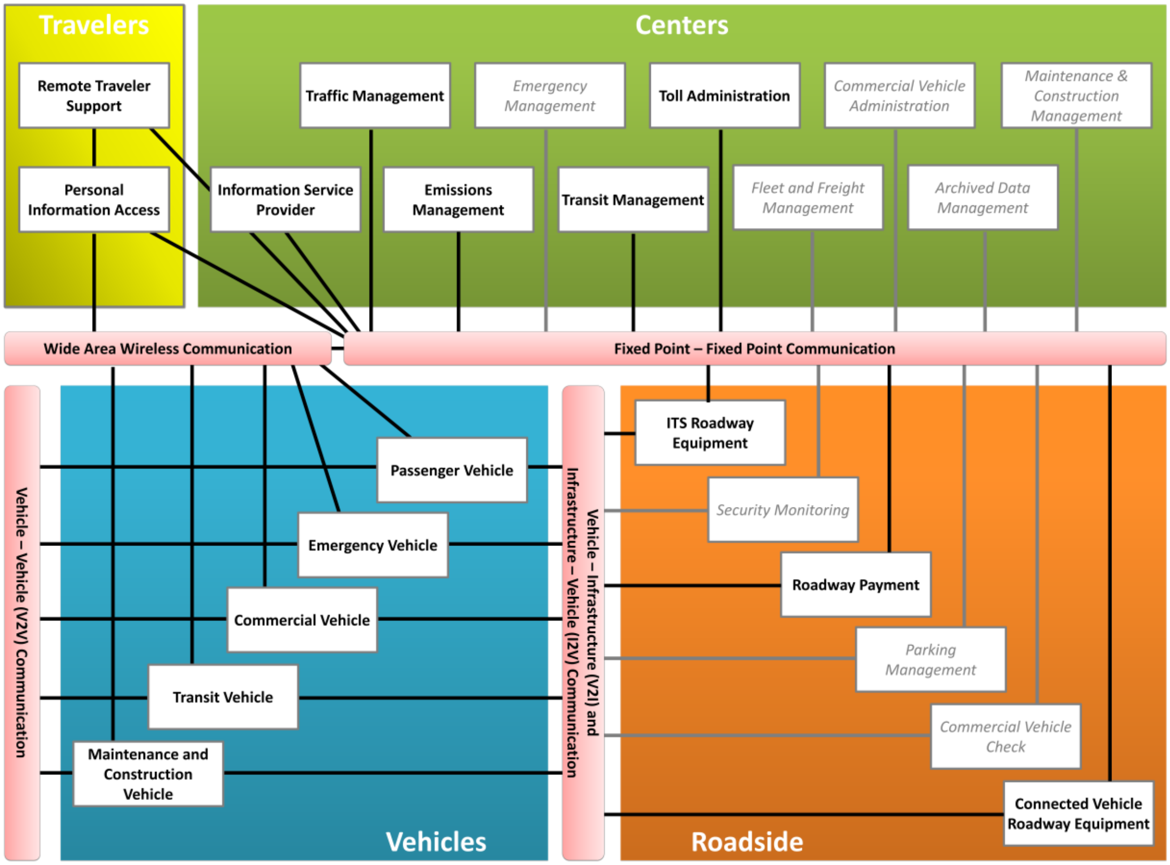

Figure D-1: Low Emissions Zone Interconnect Diagram (*Source*: Adapted from the National ITS Architecture by Noblis, 2013)

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

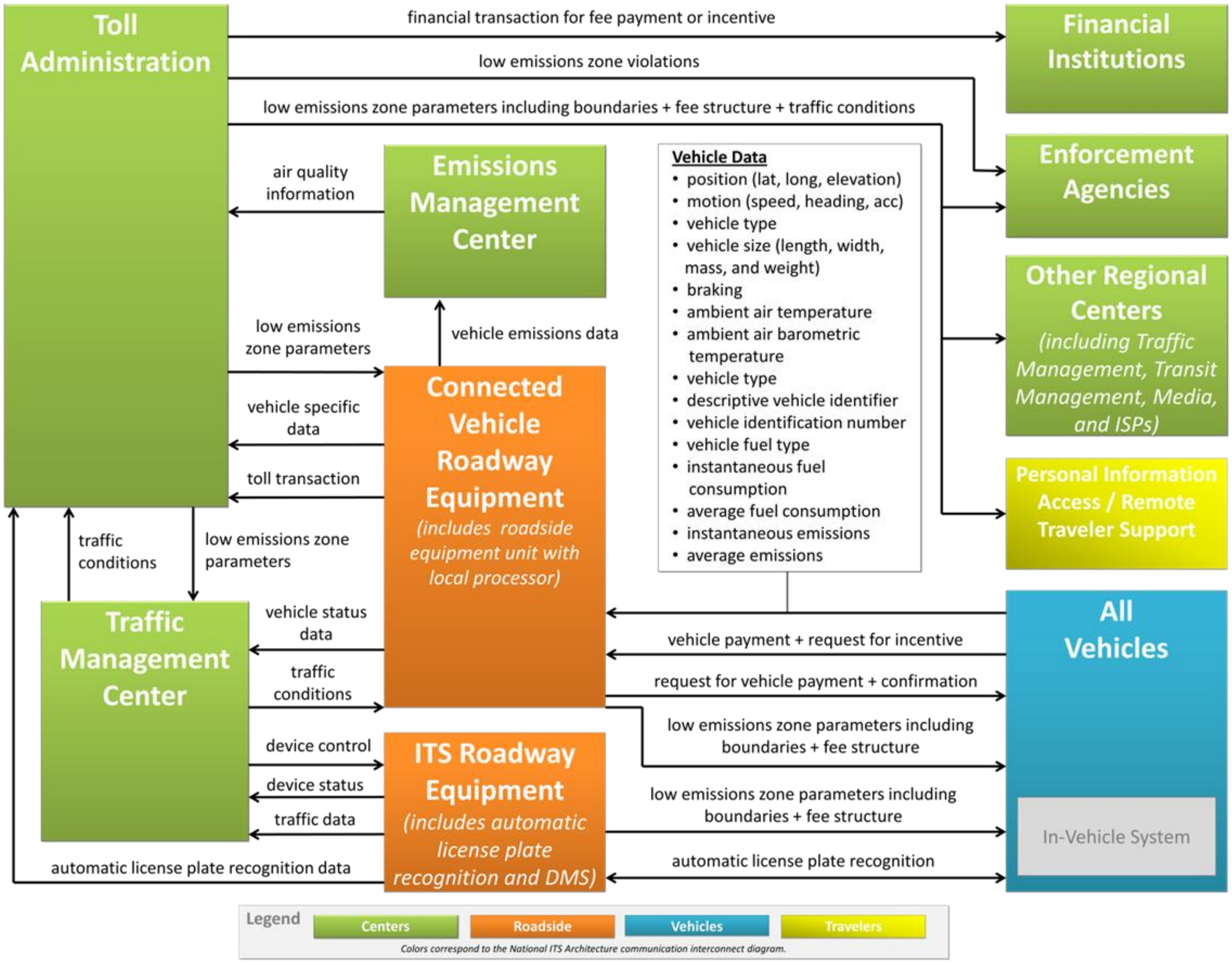

Figure D-2: Low Emissions Zone Information Flow Diagram (Source: Noblis, 2013)

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