Eco-Approach and Eco-Departure Planning Study

Final Report

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Produced by Crash Avoidance Metrics Partners LLC in response to Cooperative Agreement Number DTFH6114H00002

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16. Abstract

A long term (10 year) research roadmap is proposed to guide the development and potential deployment of Eco-Approach and Departure (Eco A/D) functionality at signalized intersections, with a focus on commercialization of initial system concepts in 5+ years. A review of Eco-Signal relevant research yielded a comprehensive set of key technical issues and knowledge gaps. Data sharing, privacy, security and liability issues associated with implementing Eco A/D functionality were also examined. Analysis of the AERIS Eco-Signal Operational Concept identified numerous assumptions regarding system operation. These assumptions were prioritized and merged with the results of the literature search to produce a refined Eco A/D operational concept and associated set of research needs. A process workflow was developed and a chronology was established to addressi near-term (0-4 years), mid-term (4-6 years) or long-term (6-10 years) research needs in an evolutionary fashion. The near-term phase of the plan focuses on combining commercial deployment of Level 1 longitudinal control systems with evolving Vehicle to Infrastructure (V2I) communications capabilities, where individual intersections would interact with ad-hoc strings of equipped vehicles to provide Eco A/D functionality in mixed flow conditions. Conducting the near-term portion of the research plan is recommended and a two-phase approach proposed, first modeling an existing traffic corridor to develop an Eco A/D system architecture and vehicle / infrastructure algorithms, then implementing system elements in a progressive fashion culminating in a field operational test.

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Executive Summary

This report presents the final results of the Eco-Approach and Eco-Departure Planning Study conducted under the Vehicle-to-Infrastructure (V2I) Program between June 1, 2015 and January 31, 2016. Eco-Signal Operations use Connected Vehicle (CV) technologies to decrease fuel consumption and emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections [1]. This project developed a long term (10 year) research roadmap to guide the development and potential deployment of Eco-Approach and Departure (Eco A/D) functionality at signalized intersections, with a focus on commercialization of initial system concepts in 5+ years.

<u>Literature Review</u>

To begin the process of developing a research plan, a review of existing Eco-Signal relevant research was conducted. A total of 169 Eco A/D relevant references were identified. Based on a review of abstracts, a subset of 63 publications were selected for further analysis. Key Issues and Knowledge Gaps were identified and assigned to one of six categories of Eco A/D research interest:

1. Eco A/D Concept
2. Vehicle Technical Issues
3. Infrastructure Technical Issues
4. Communications and Standards
5. Human Factors
6. Performance Measures.

<u>Refined Operational Concept</u>

Review of the Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Signal Operational Concept [1] identified over 200 assumptions regarding system operation, which were prioritized based on technical team evaluation and merged with the results of the literature search to produce a refined set of Eco A/D research needs. A refined Eco A/D operational concept was then developed describing the desired system functionality and associated set of knowledge gaps in each of the following areas:

- Overall Objective
- Trajectory Planning
- Vehicle Types Addressed
- Infrastructure-side Functionality
- Infrastructure-side Data Synthesis
- Vehicle-side Automation Level
- Sensor Fusion

- Vehicle Positioning
- Environmental Condition Data
- Optimization of Eco A/D Functions on Signal Operations
- Queue Length
- Queue Balancing
- Presence of Unexpected Objects
- Vehicle System

Research Workflow and Progression

A research process workflow was developed to describe the recommended approach to conducting Eco A/D research to address the knowledge gaps identified. Key to this process is the need to engage both vehicle and infrastructure stakeholders in identifying real-world traffic corridors to use as the basis for system development. The refined set of Key Issues and Knowledge Gaps were grouped into research plan component sets: vehicle; signal; roadway; driver; system function. Considering the complexities within each component set and their interrelationship, a logical research progression was defined assigning component set elements to near-term (0-4 years), mid-term (4-6 years) or long-term (6-10 years) research in an evolutionary fashion.

Issues in Data Sharing

An analysis of the current and future policy-related impacts of sharing transportation data to support Eco A/D systems was performed, specifically with respect to data ownership, data security, privacy concerns, and liability issues. Directly applicable and / or analogous policies and legislation in place at the state level were identified in each of these areas. Various forms of data, both current and anticipated, that agencies may need to share across jurisdictions were identified and potential shortcomings that may limit sharing to facilitate Eco A/D operations were investigated.

Next Steps

The near-term phase of the Eco A/D research plan focuses on leveraging the existing commercial deployment of Level 1 longitudinal control systems combined with Vehicle to Infrastructure (V2I) communications to operate Eco A/D functionality with individual intersections interacting with ad-hoc strings of equipped vehicles in mixed flow conditions. The recommended action is to conduct the near-term portion of the research plan using a two-phase approach, first modeling an existing traffic corridor to develop an Eco A/D system architecture and vehicle/infrastructure algorithms, then building and implementing system elements in a progressive fashion culminating in Field Operational Test (FOT).

1 Introduction

This report describes work performed by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium in conjunction with Texas A&M Transportation Institute (TTI), The University of Michigan Transportation Institute (UMTRI) and the University of California Riverside (UCR). The participating companies in the V2I Consortium are FCA US LLC, Ford, General Motors, Hyundai-Kia, Honda, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi. The project is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement DTFH611H0002, Work Order 0004.

1.1 Project Description

As part of the CV research effort, the United States Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) initiated the Applications for the Environment: Real-Time Information Synthesis (AERIS) research program to generate and/or acquire environmentally relevant real-time transportation data to create actionable information to support and facilitate “green” transportation choices by transportation system users and operators [1].

The FHWA has identified the AERIS as a Transformative Concept that includes Eco-traveler information for more informed travel decision making and Eco-integrated corridor management to maximize efficiency across all modes. Eco-Signal Operations use CV technologies to decrease fuel consumption and emissions by reducing idling, the number of stops, unnecessary accelerations and decelerations, and improving traffic flow at signalized intersections. Eco-Signal Operations include five inter-related applications: (1) Eco-Traffic Signal Timing, (2) Eco-Traffic Signal Priority, (3) Eco-Approach and Departure at Signalized Intersections, (4) Connected Eco-Driving, and (5) Wireless Inductive Charging [1].

This project explores Eco-Approach and Departure (Eco A/D) at signalized intersections, focusing on planning research and development activities necessary to support potential deployment.

1.2 Eco-Approach / Eco-Departure System Objectives

The Eco A/D application uses wireless data communications sent from a Roadside Equipment (RSE) unit to CVs to encourage “green” approaches to signalized intersections. The application, located in a vehicle, collects signal phase and timing (SPaT) and intersection geometry (SAE J2735 MAP message) using Vehicle-to-Infrastructure (V2I) communications and data from nearby vehicles using Vehicle-to-Vehicle (V2V) communications. Upon receiving these messages, the application performs calculations to determine the vehicle’s optimal speed to pass through one or more traffic signal on a green light or to decelerate to a stop and subsequently launch in the most eco-friendly manner. This information is then sent to longitudinal vehicle control capabilities in the host vehicle to support partial automation.

According to prior modeling work funded by the FHWA, the Eco A/D application provides fuel reduction benefits up to 13% above the baseline, for a coordinated corridor [2]:

- a benefit of 8% is attributable to signal coordination
- a benefit of 5% is attributable to the Eco A/D application

1.3 Organization of the Report

The project examines questions that arise with the development and deployment of the Eco A/D CV applications. The specific objectives of the project are to:

- Review the literature and comprehend what has been done in past Eco-Signal research
- Identify gaps in information regarding the applications and define future research needs
- Define technical and safety issues associated with the Eco-Signal applications
- Plan an evolutionary approach (i.e., a 'roadmap') for Eco A/D research and development

The following sections outline the steps taken to accomplish these goals. General technical project management is described in Task 1 and specific project-related activities are described in Task 2.

2 Summary of Project Activities

2.1 Task 1: Technical Project Management

Activities performed under this task include the general administrative and technical support required to complete project tasks and achieve project goals while maintaining compliance with the schedule and budget. These activities include periodic meetings, other general administrative tasks and the delivery of a final project report. In order to accomplish this task the following interactions were established and conducted for the duration of the project:

- Weekly meetings were held between the CAMP Technical Management Team (TMT), the CAMP Principal Investigator (PI) and the TTI Technical Manager to review technical progress and update the project work plan
- Bi-weekly discussions were held between the PI and FHWA staff to maintain awareness of project status
- Face-to-face review meetings were held between the CAMP TMT, TTI technical staff, project members from UCR and UMTRI (the 'CAMP Project Team') and FHWA staff to support completion of Subtasks 2.1-2.3

2.2 Task 2: Prepare Research and Development Plan

This task was structured to accomplish the following objectives:

- Understand what has been done in past Eco-Signal research
- Identify gaps in information regarding the applications and define future research needs
- Define technical / safety issues associated with the Eco-Signal applications
- Plan an evolutionary approach (i.e., a 'roadmap') for Eco A/D research and development
- Recommend the next steps for developing the applications

2.2.1 Subtask 2.1: Conduct Literature Review

The CAMP Project Team identified Eco-Signal relevant literature, categorized the list and distributed review responsibilities across the team. A total of 169 Eco A/D relevant references were identified. During the early stages of the literature review process, six key categories of Eco A/D research interest were identified:

1. Eco A/D Concept
2. Vehicle Technical Issues
3. Infrastructure Issues
4. Communications / Standards

5. Human Factors

6. Performance Measures

A complete list of documents considered is provided in Appendix B. Based on a review of abstracts, 63 references were selected for detailed review by the team. Selections were balanced across the key categories to ensure comprehensive review of the issues. In addition to general technical references identified, each Original Equipment Manufacturer (OEM) team member also suggested reports, USDOT provided additional information, and other documents were identified from the reference sections of the general technical references. These documents were reviewed independently by two different team members, with each reviewer completing a common review template and sharing their conclusions with the entire team for each of the documents. The results of this detailed review were summarized and grouped by key category to provide an initial list of Key Issues and Knowledge Gaps for Eco A/D applications. This preliminary list was reviewed with FHWA staff and provided input for work in the next subtask.

2.2.2 Subtask 2.2: Eco-Signal Application Concept, Assumptions and Research Questions

The preliminary list of key issues and knowledge gaps from Subtask 2.1 was combined with a set of assumptions extracted from the AERIS Eco-Signal Operational Concept [1] (over 200 assumptions were identified). Each team member prioritized the resulting list of issues and research needs as high, medium or low, with justifications given for high rankings. A weighted summary of the rankings produced a set of priority issues for further analysis, which were summarized by key category into assumptions, key issues and next steps. A Refined Eco A/D Operational Concept was developed and a face-to-face review meeting was held with FHWA staff to review assumptions and key issues in order to refine the set of research needs for use in developing a research 'roadmap.' The refined set of Eco A/D research needs is summarized by key research category in Appendix C. The refined Eco A/D operational concept and associated knowledge gaps are described below.

2.2.2.1 Refined Eco A/D Operational Concept

2.2.2.1.1 Overall Objective

An Eco A/D system is comprised of two functions; an infrastructure-side function and a vehicle-side function that cooperate with one another to implement combinations of mobility, fuel economy or emissions reductions based on decision parameters that are used to determine which should be optimized for a given situation. The Eco A/D system optimizes mobility / fuel economy / emissions reductions along the cross street as well as the arterial. The optimization parameters can be adjusted in real time depending on traffic management goals.

Knowledge Gaps:

- The decision criteria / parameters which are used to determine the optimization
- How to balance the optimization of traffic flow in all directions for flexible speed profiles tailored to optimize mobility, fuel economy or emissions reductions and how to accomplish this in an evolutionary manner
- The criteria by which the type of speed profile optimization is selected, along with how and by whom the decision is made

2.2.2.1.2 Trajectory Planning

In addition to Vehicle to Vehicle / Infrastructure (V2X) Over the Air (OTA) messages broadcast by equipped vehicles, the Eco A/D function utilizes SPaT plus MAP messages broadcast from Roadside Equipment (RSE) located in the proximity of intersections to determine, among other things, whether the vehicle or string of vehicles will be able to clear the intersection during the green phase of the signal. In the case of the vehicle or string of vehicles approaching a red phase, the Eco A/D function calculates a desired speed and acceleration profile that will minimize the need to stop at the intersection, taking into account the length of time needed to disperse the queue of vehicles already stopped at the intersection. The calculation is done either on board the vehicle, by the infrastructure, or some combination of the two. If done by the infrastructure, desired speed and acceleration profile is broadcast to approaching vehicles. Speed and acceleration profiles may be different for individual vehicles versus a string of vehicles. In the case of a string, the lead vehicle has primary effect of the speed and acceleration profiles of the upstream vehicles.

Knowledge Gaps:

- Method of calculation of speed profiles
  - Should the vehicle or infrastructure calculate the optimal speed profile?
  - Is a combination of the two optimal?
  - How do the infrastructure and vehicle(s) manage coordinated queue discharge?
- Method of transmission and message format and content of desired speed and acceleration profile if broadcast by the infrastructure
- Whether high speed differential between vehicles or an individual vehicle and a string of vehicles has a negative safety impact
- Method of communicating Eco A/D activation information to the driver and/or vehicle (e.g., through Dedicated Short Range Communication (DSRC) vs. cellular communication)

2.2.2.1.3 Vehicle Types Addressed

The existence of personal, transit, freight, non-motorized, emergency, and construction / maintenance vehicles in the Eco A/D environment is a given. The Eco A/D system however, will initially focus on light and heavy vehicles independently and together.

Knowledge Gaps:

- The processes and procedures used by the infrastructure to determine which vehicle type(s) receives preferential treatment at a signalized intersection and under what circumstances
- The performance benefits and privacy risks associated with new Eco A/D OTA messages, or modifications to existing OTA messages, to include data elements (aka, potential identifiers) associated with vehicle classification, messages generated by an Eco A/D equipped vehicle and/or a vehicle with the Eco A/D application

enabled, such as powertrain configuration (e.g., start/stop, hybrid / electric / diesel / gas) and other data elements

2.2.2.1.4 Infrastructure-side Contribution to Eco A/D Function

The infrastructure employs SAE J2735 BSM data as well as data from other V2X communication (e.g., queue length and traffic volume estimation) to influence Eco A/D timing plans. The infrastructure uses sensor data (e.g., inductive loops, intersection cameras, video detection systems, and other sensors, in addition to BSMs and other V2X OTA messages) to estimate, after accounting for traffic already waiting in a queue at the intersection, whether an approaching string / platoon of vehicles will clear the intersection during the green phase, and whether additional action (e.g., extending or returning early to the green within limits) is feasible if the infrastructure determines that the entire string will not clear within the current green phase. The infrastructure also communicates its estimate of when the queue will be dispersed to waiting vehicles. The infrastructure facilitates this concept for all modes of operation (e.g., whether the signals are fixed-time or actuated; isolated or in coordination).

Knowledge Gaps:

- Methods and criteria used to generate Eco A/D control timing parameters under different traffic signal control system architectures
- Method(s) for identifying strings of Eco A/D vehicles
- How differences in Cooperative Adaptive Cruise Control (CACC) vehicles traveling in strings impact infrastructure operation, especially in situations where CACC and AERIS applications will merge together
- How the current features in the signal controller (e.g., Phase Holds, Phase Omits, Force Offs) contribute to Eco A/D timing plans
- How the BSM data will be used to influence Eco A/D timing plans
- The scenarios under which the vehicles should adjust to signals and those for which the signals should adjust to approaching vehicles
- How to forecast and utilize future SPaT conditions into the future, particularly for actuated signals and evolutionary versions of the Eco A/D applications, and for how many cycles
- The corridor characteristics that provide the highest Eco A/D benefits
- The optimum balance between arterial vs. side street Eco A/D traffic
- The need for the infrastructure to communicate Eco A/D functionality/status
- Method of estimating a “Green Number” for each Eco A/D equipped intersection based on geometric and existing intersection status information, to be transmitted by the infrastructure to the approach vehicle/s and used to help calculate and display the eco benefits of the Eco A/D system to the driver

- Method of estimating an "Efficiency Number" for each Eco A/D intersection based on the traffic or time of day, to be transmitted by the infrastructure to the approaching vehicle/s and used for route setting and calculating the mobility benefits

2.2.2.1.5 Infrastructure-side Data Synthesis

The Eco A/D synthesizes traffic data from multiple sources (e.g., fixed sensors, CV roadway equipment, V2X OTA messages) to provide traffic analyses aggregated at different levels (e.g., intersection, corridor, and regional levels) that improve the effectiveness of the Eco A/D.

Knowledge Gaps:

- Process and procedures for fusing data from both infrastructure and equipped vehicles to determine queue length and queue dissipation times at traffic signals
- How to disseminate information needed to generate vehicle speed profiles, from downstream intersections to upstream intersections
- The impact of upstream and/or downstream intersection cross traffic on the Eco A/D route

2.2.2.1.6 Vehicle-side Automation Level

Level 1 automation, in which the vehicle controls longitudinal motion by manipulating the brakes and accelerator while the driver remains vigilant and prepared to assume direct control, is a critical element of an optimum Eco A/D function. Vehicles equipped with the Eco A/D function will also be equipped with Level 1 automation capable of bringing the vehicle to a complete stop and automatically accelerating from a stop to achieve an accurate approach and departure profile.

Knowledge Gaps:

- The applicability of full speed range Adaptive Cruise Control (ACC) to Eco A/D
  - Calculating the time delay before the host vehicle launches after the preceding vehicle launches
  - Need for Cooperative Adaptive Cruise Control (CACC) to achieve coordinated launch
- Ability to predict and control Level 2 automation to achieve eco-merging to achieve lane balance or queue bypass
- The need to apply Level 2 automation to strings/platoons of vehicles
- Acceptable driver and passenger headways and acceleration and deceleration rates for various types of vehicles
- The need for communication of automation status to other vehicles on the roadway

2.2.2.1.7 Sensor Fusion

Fusion of sensor data from both the vehicle and infrastructure components of an Eco A/D system that allows, among other things, the ability to detect the location of other vehicles that are not capable of broadcasting the V2X OTA messages, is a part of the Eco A/D function.

Knowledge Gaps:

- Approach to fusing sensor data to V2X data

2.2.2.1.8 Vehicle Positioning

The Eco A/D function utilizes automotive grade global positioning system (GPS) equipment to determine the location of the Eco A/D equipped vehicle. V2V relative positioning requires the use of Wide Area Augmentation System (WAAS) corrections. The Eco A/D function may also benefit from infrastructure-based Radio Technical Commission for Maritime Services (RTCM) differential corrections for GPS via the RTCM Corrections message as defined in SAE J2735. Vehicles could utilize the information in the message to improve their absolute and relative accuracy estimates.

Knowledge Gaps:

- The ability of automotive grade GPS equipment to provide positioning accuracy sufficient for the Eco A/D to function as intended

2.2.2.1.9 Environmental Condition Data

The Eco A/D function may benefit from receiving environmental condition data, including road weather conditions from the infrastructure, if the data and the means for the Eco A/D function to capture the data are available. Vehicles are not expected to broadcast environmental condition data.

Knowledge Gaps:

- Method of transmission, message format, and content of environmental condition data broadcast by the infrastructure
- How environmental condition data is utilized
- How the use of environmental condition data might change the development of vehicle speed profiles

2.2.2.1.10 Signal Priority Request Optimization

The Eco A/D function accommodates the presence of personal, transit, freight, non-motorized, emergency, and construction/maintenance vehicles in the Eco A/D environment. Some vehicles, such as transit and emergency vehicles, will have the capability of requesting signal priority which may affect Eco A/D optimization objectives; therefore, the Eco A/D function must accommodate not only signal priority requests but also mitigate the effect of the request on optimization objectives in as short a time as practicable.

Knowledge Gaps:

- The criteria/parameters (e.g., the number of passengers on a transit vehicle) which are used to determine the optimization
- How to deal with pedestrian requests which are difficult to achieve with standard means of communications
- Methods of communicating optimization parameters from multiple classes of vehicles

2.2.2.1.11 Queue Length

Both the infrastructure and vehicles are capable of utilizing sensor data and V2X OTA messages to determine, among other things, the length of a queue of vehicles waiting at an intersection. Knowledge of queue length is seen as critical to the Eco A/D function. Vehicles use queue length information to determine the speed profile for the individual or string of vehicles approaching the intersection as well as for queue dispersal. Calculation of queue length is done either on board the vehicle, by the infrastructure, or both. If done by the infrastructure, queue length is broadcast to approaching vehicles.

Knowledge Gaps:

- Method of transmission, message format and content of queue length messages broadcast by the infrastructure
- Methods for vehicle to determine its position in the queue, and estimate queue length and time to clear queues at signalized intersections
- Methods for determining and communicating queue spillback information to Eco A/D equipped vehicles
- Pedestrian flow/discharge and how it affects vehicle movement through signalized intersections

2.2.2.1.12 Queue Balancing

Both the infrastructure and vehicles are capable of utilizing sensor data and V2X OTA messages to determine, among other things, an optimum balancing of vehicle queue lengths waiting at an intersection for multi-lane arterials. Optimizing queue lengths may provide added value to the Eco A/D function. Drivers or Level 2 automation equipped vehicles use queue length information to determine whether to stay in the current lane or change to a lane that has a shorter queue based on driver intention (e.g., pass through the intersection, turn left, turn right). Calculations are done on board the vehicle, in the infrastructure, or by some combination thereof.

Different lanes may have different speeds associated with them. The presence of businesses located along the right side of the road, for example, may result in vehicles taking off more slowly and continuing to travel more slowly than vehicles in the adjacent lane(s) in order to make right turns into the business locations.

Eco A/D has the capability to broadcast a slower recommended speed for the rightmost through lane to facilitate greater mobility for vehicles intending to travel through the area rather than stop.

Knowledge Gaps:

- The overall process of determining a course of action and how to communicate proposed action to the driver
- The limitations of queue length estimation needed
- The need for queue balancing mid-block in addition to intersections
- When to depend on drivers, and when and how to assist drivers
- Definition of a queue, including the boundary conditions at which a queue becomes a string
- The factors that constrain the vehicle's opportunity to move
- The need/advantages of a hierarchal MAP message that is lower resolution at farther distance and becomes more detailed as the vehicle approaches the intersection

2.2.2.1.13 Presence of Unexpected Objects

The presence of unexpected objects (e.g., slower moving preceding vehicles, a stalled vehicle, an accident or short-term construction blocking one or multiple lanes upstream or downstream of an intersection) affects vehicle movement through the intersection, impacting queues in the vicinity of the intersection. If the unexpected object is capable of broadcasting V2X OTA messages, determination of the presence/location of the object is done either on board the vehicle or by the infrastructure. If done by the infrastructure, the presence/location of the object is broadcast to approaching vehicles. The response of Eco A/D equipped vehicles to unexpected objects is defined according to the ACC function on board the vehicle and the actions of the driver to maneuver around the object.

Knowledge Gaps:

- Methods for detecting the presence of unexpected objects in the intersection approaches
- Methods for estimating effects of turning vehicles on time to clear queue predictions
- Method of transmission, message format and content of object presence / location messages broadcast by the infrastructure
- Optimal Human Machine Interface (HMI) for communicating eco-driving info to the driver in cases both where automation is employed and where automation in not employed

2.2.2.1.14 Vehicle System

The vehicle accomplishes the following:

- Either generates or receives optimal speed profile for eco-driving strategies
- Either generates or receives traffic conditions data, such as such as queue formation and discharge rates, for input to eco-driving strategies

- Collects SPaT data as the vehicle approaches a signalized intersection as well as receives MAP data from the approaching intersection
- Senses other vehicles in front of the vehicle in order to adjust speed trajectory planning; this sensor data can be fused with BSM communications
- Collects vehicle status data contained in V2X OTA messages from the infrastructure as well as other vehicles
- Collects diagnostics data from on-board systems and sensors to obtain vehicle status and vehicle emissions data
- Determines driving recommendations with the objective of promoting a time- and energy-efficient driving style that lowers vehicle emissions and fuel consumption
- Uses V2X OTA messages (including SPaT and MAP message data, traffic data, vehicle sensor data, and vehicle status data from other vehicles) to encourage "green" approaches to and departures from signalized intersections
- Broadcasts vehicle status data that is currently included in the BSM
- Provides a driver interface through which eco-driving information can be provided to the driver to encourage them to drive in a more environmentally efficient manner. A snapshot of individual driver performance in terms of eco-driving on the route could serve as an encouragement to use the technology more often in order to perform better.
- Provides a switch to activate or turn off the function
- Can provide engine start-stop capabilities allowing the vehicle's engine to be automatically shut down and restarted as an optional feature
- Receives an efficiency and / or "Green" number in order to calculate an Eco-route and ETA

2.2.2.2 Scope Limitations

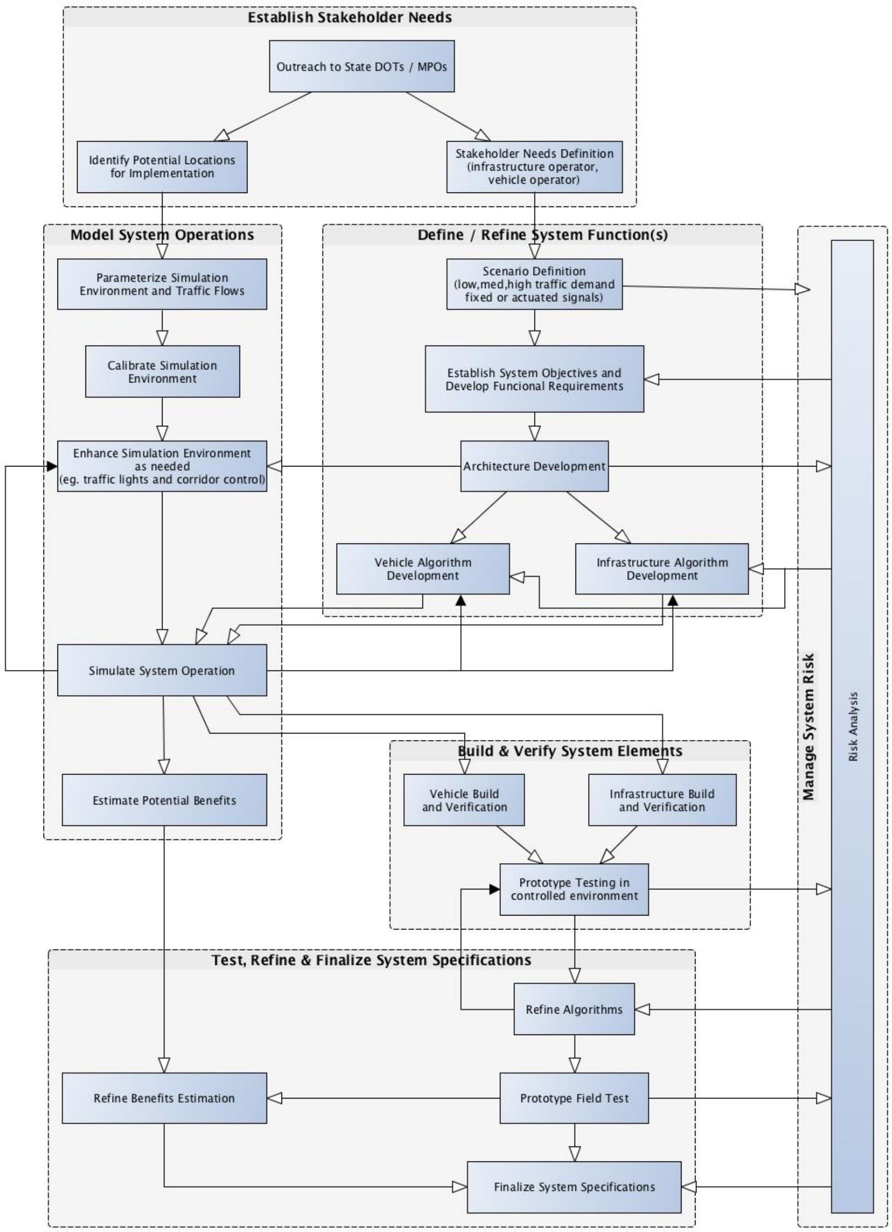
The following issues are considered outside the scope of Eco A/D research:

- Although implementing secure communications is important, it would be best to study the issue of what level / type of security is appropriate in a separate activity geared specifically toward security
- Ensuring interoperability and compatibility for various levels of infrastructure (acknowledged as critical to deployment)
- Roadway changes in order to maximize the benefits of Eco A/D, such as dedicating new or existing lanes for specific purposes (e.g., turn lanes)
- Inductive charging capability for electric vehicles waiting in a queue at an intersection
- Broadcast of environmental data messages based on data collected from sensors located on-board the vehicle

- Criteria used to generate and grant signal priority requests

2.2.3 Subtask 2.3: Roadmap to Address Eco-Signal Research Needs

In order to generate a high-level roadmap for future Eco A/D research, the set of knowledge gaps associated with the Refined Eco A/D Operational Concept from Subtask 2.2 were partitioned into near term, mid-term and long term time research needs and used to create an Eco A/D Research Process Work Flow. This workflow (Figure 1) illustrates the activities and interrelationships necessary to explore in each time bin. The result of partitioning the research needs into time bins provides the high-level roadmap recommended for future Eco A/D research



Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Figure 1: Eco A/D Research Process Work Flow

2.2.3.1 Research Process Work Flow

2.2.3.1.1 Establish Stakeholder Needs

Applying the Refined Eco A/D Operational Concept to a real-world traffic corridor is key to pursuing a research and development plan targeting potential deployment of an Eco A/D system. Thus the first step in the workflow is to conduct outreach to potential infrastructure partners to identify candidate traffic corridors and establish a consensus set of stakeholder needs reflecting the interests and objectives of both the vehicle and infrastructure operators implementing an Eco A/D system. The stakeholder needs documented in this step will assist in addressing the knowledge gap concerning the “decision criteria / parameters which are used to determine the optimization” identified in the Overall Objective of the Refined Eco A/D Operational Concept (Section 3.2.2.1.1). This effort drives the remainder of the workflow to design, develop and implement an Eco A/D system.

2.2.3.1.2 Model System Operations

Once candidate traffic corridor(s) have been identified, a simulation environment can be created (or potentially adapted from prior AERIS research) which includes suitable traffic, infrastructure and vehicle models to explore overall system operation and the interaction of the various system elements. The basic elements of the model are parameterized to reflect the real-world operating characteristics of the traffic corridors, signal control systems and vehicles in which the system will be implemented. This modeling environment will facilitate iterative development and evaluation of the system architecture, including both vehicle and infrastructure algorithm development, and provide preliminary estimates of potential system benefits.

2.2.3.1.3 Design / Refine System Function(s)

The stakeholder needs and objectives identified drive the development of functional requirements for both the infrastructure and vehicle elements of the Eco A/D system as well as the architecture supporting their interaction. Developing the vehicle and infrastructure algorithms and overall system architecture first in software, and subsequently using Hardware-in-the-Loop (HIL) simulation, in a modeling environment reflecting real-world conditions enables the iterative refinement of system elements. This process explores the parameters and policies needed to implement stakeholder objectives and the tradeoffs needed to balance potentially conflicting objectives.

2.2.3.1.4 Build and Verify System Elements

Using the overall system architecture, vehicle / infrastructure algorithms and hardware subsystems developed and refined in the modeling environment, the vehicle and infrastructure elements of the Eco A/D system must first be built and verified independently and then interactively as prototype systems operating in a controlled environment (i.e., test track / proving grounds). This step in the workflow provides the opportunities needed to debug and refine the system elements and overall operation.

2.2.3.1.5 Test, Refine and Finalize System Specifications

Once verified, the prototype system is implemented in the real-world traffic environments originally selected to assess performance, using first a pilot then full-scale field operational test (FOT) techniques. The performance data collected is used to refine benefits estimates using the modeling environment to project to wider-scale deployment as appropriate. Performance data also will be used to understand how the system can be refined to increase the benefit as well as how the driver interface can be utilized to further optimize the actual and perceived benefit. The resulting refined system design and its components are documented in the final Eco A/D system specifications.

2.2.3.1.6 Manage System Risk

Developing a risk model for Eco A/D system operation and using it to guide design choices is an iterative process that proceeds throughout the research workflow. It begins with the creation of a risk assessment framework using initial scenario definitions and guides the creation of functional requirements. Review of the resulting system architecture leads to refinements in vehicle / infrastructure algorithms which are evaluated using the simulation environment in an iterative fashion until risk management objectives have been met. Once system elements have been built and verified, the results of prototype testing in a controlled environment are used to further refine risk assessments and algorithm implementations for use in FOT. Test results from real-world evaluations provide the final refinement of system risk assessment and guides finalization of Eco A/D system specifications.

2.2.3.2 Eco A/D Research Progression

In order to consider the logical research progression of Eco A/D functionality the Key Issues and Knowledge Gaps identified were grouped into sets by system component as shown in Table 1 The team then considered the timeline associated with resolving the complexities within each set as well as the interrelationship between the sets that would lead to potential deployment of the refined operational concept. The operating environment and recommended progression of research is described in the following sections. Note that after the description of research components in the near term (Section 3.2.3.2.3), only the changes to the component sets are identified moving into the mid- and long-terms (Sections 3.2.3.2.4 and 3.2.3.2.5).

Table 1: Overall Eco A/D Research Plan Components

System Component	Research Need
Vehicle	• Single / Coordinated Ad-hoc String / Platoon (internally or remotely controlled) • Automation Level 0 / 1 / 2
Signal	• Single Intersection / Corridor of Eco -Independent Intersections / Corridor of Eco-Coordinated Intersections
Roadway	• Single Lane / Multi Lane • Dedicated Lane / Mixed Flow
Driver	• Intention: Straight / Turn / Lane Change • Compliance with System Guidance • Knowledge of Other Vehicle State • Driver Vehicle Interface (e.g. for optimizing performance, communicating benefit)
Function(s)	• Eco Approach • Eco-Departure (Coordinated Launch) • Speed Harmonization • Queue Estimation / Spillback / Balancing • Preemption / Exception Handling • Unexpected Objects / Obstacles

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

2.2.3.2.1 Operating Environment

The operating environment for any instantiation of an Eco A/D system is presumed to contain signals, which operate either independently or in a coordinated fashion along a corridor. However, this coordination does not yet involve consideration of Eco A/D functionality. Signals are connected via some form of backhaul network that facilitates signal-to-signal communications either directly or through a traffic management center. Intersections have been mapped and are broadcasting SPaT and MAP in accordance with existing standards. Eco A/D equipped vehicles transmit and receive BSM Parts 1 & 2 in accordance with existing standards and participate in an appropriate Security and Credential Management System (SCMS).

2.2.3.2.2 Recently Completed Research

The FHWA recently completed a series of Eco A/D studies under the Glide Path project [2]. This work was examined as part of the broader literature review in Subtask 2.1. The Glide Path project demonstrated the basic Eco A/D functionality of a single vehicle approaching a single intersection with no additional traffic present and explored both Level 0 (driver information) and Level 1 (longitudinal control) automation based Eco-Approach functionality. The results of this effort lead to the conclusion that while the basic benefit(s) of Eco A/D functionality appear realizable, Level 0 automation systems are potentially difficult to execute successfully. The CAMP Project Team feels this work successfully addresses the research needs associated with implementing the basic Eco A/D concept.

2.2.3.2.3 Near Term Research

Building on the Glide Path work, near-term research needs are considered as the next logical set of Key Issues and Knowledge Gaps to address over the next four years, potentially leading to an Eco A/D system concept that could be transitioned into an FOT, first as a small pilot exercise and then, if successful, as a larger FOT. If FOT results are promising then consideration of possible commercialization of the system design could begin, perhaps even overlapping with the completion of full FOT evaluation. The components of the research plan that the CAMP Project Team believes fit into this time frame are:

Table 2: Near-Term Eco A/D Research Plan Components

System Component	Research Need

Vehicle	• Coordinated Ad-hoc String
	• Automation Level 1 (longitudinal)
	  o Adaptive Cruise Control
	  o Cooperative Adaptive Cruise Control

Signal	• Single Intersection / Corridor of Eco-Independent Intersections
Roadway	• Single Lane • Mixed Flow
Driver	• Knowledge of Other Vehicle State
Function(s)	• Eco-Approach • Eco-Departure (Coordinated Launch) • Queue Estimation • Preemption / Exception Handling

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Note that under the Vehicle heading the team thinks it is important to explore the capabilities of basic ACC to perform at least a portion of the Eco A/D functionality being explored and the role communications plays in completing the function set using CACC.

2.2.3.2.4 Mid Term Research

Building on the near-term results, mid-term research needs are those Key Issues and Knowledge Gaps that might be addressable in the four- to six-year time frame. The additional components of the research plan that the CAMP Project Team feels fit into this time frame are:

Table 3: Mid-Term Eco A/D Research Plan Components

System Component	Research Need
Signal	• Corridor of Eco-Coordinated Intersections
Function(s)	• Speed Harmonization • Queue Spillback • Unexpected Objects / Obstacles

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

2.2.3.2.5 Long Term Research

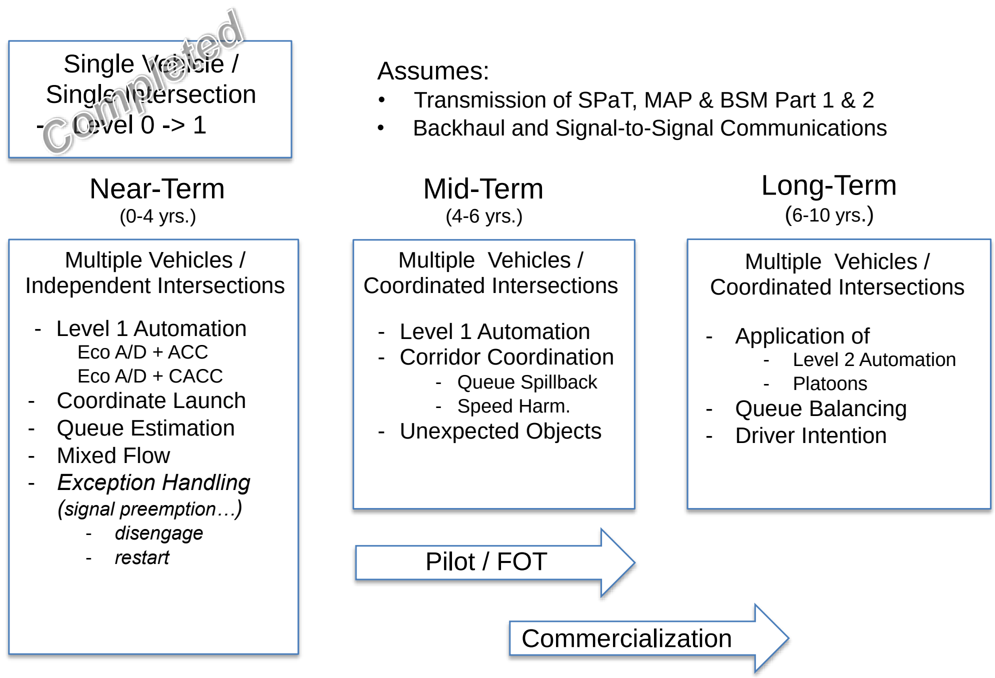
Finally, those elements of the Eco A/D Key Issues and Knowledge Gaps that the CAMP Project Team feels should be deferred to the long-term time frame of six to ten years are:

Table 4: Long-Term Eco A/D Research Plan Components

System Component	Research Need
Vehicle	• Platoon (internally or remotely controlled) • Automation Level 2 (longitudinal and lateral)
Roadway	• Multi Lane
Driver	• Intention: Straight / Turn / Lane Change • Driver Vehicle Interface (e.g. for optimizing performance, communicating benefit)
Function(s)	• Queue Balancing

Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

The overall recommended partitioning of Eco A/D research into a logical progression of steps addressing the Key Issues and Knowledge Gaps identified is shown as a combined ‘roadmap’ in Figure 2



Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium

Figure 2: Eco A/D Research Progression

2.2.4 Subtask 2.4: Assessment of Transportation Data Sharing

The analysis investigated how the need to share transportation-related data will have policy-related impacts in the future, particularly with respect to data ownership, data security, what is acceptable for sharing from a privacy perspective, and liability issues related to data sharing. The research identified the various forms of data, both current and anticipated, that agencies may need to share across jurisdictions, and investigated shortcomings that may limit sharing to facilitate advanced operations, including real-time data that will enable CV/AV operations. Issues of particular interest include intrastate cross-jurisdictional sharing, state-to-state sharing, public-private sector sharing, data-sharing agreements, data exchanges, internal agreements, privacy, security, and liability. The research did not include limitations related to sharing data across international borders.

2.2.4.1 Data Elements

Technology-supported traffic management strategies have become fairly standard and commonplace across the U.S. These strategies include traffic signal coordination, road weather information systems, display of travel times on electronic message signs and electronic tolling. More recently, Active Traffic Management (ATM) has emerged as the evolutionary offshoot of more traditional strategies that exploit technology to manage traffic flow. Furthermore, as connected and automated vehicles emerge in the future traffic stream, agencies will need to adapt their operational strategies to accommodate these vehicles and the data they may provide. All of these strategies use integrated systems with advanced technology, including comprehensive sensor systems, real-time data analysis, and automated dynamic deployment of necessary actions, which rely on a variety of data elements. Appendix D1 provides a list of transportation data elements that are critical to these operational strategies and which are subject to sharing under a variety of scenarios.

2.2.4.2 Current and Best Practices in Data Sharing

For nearly half of a century, transportation agencies have recognized the need to share transportation data, with formal documented policy statements dating back to the 1970's [4]. While the availability and robustness of data has improved with the introduction of new technologies, the overarching motivation consistently has been to improve the overall travel conditions. For several decades, various researchers have studied data sharing from both a public- and private-sector perspective. Combined with information obtained from various agencies, six of the most recent reports [4,5,6,7,8,9] provide the basis for the following best practices in data sharing.

2.2.4.2.1 Types of Agreements

The research suggests that the type of agreement utilized varies depending upon case-specific circumstances, often dictated by agency-specific policy and relationships between parties rather than the specific type or intended usage of the data being shared. In general, data sharing falls into one of the following four categories

- <u>Open Access</u> - This category generally applies to Federal and State agencies which have "open access" policies for their operations data, such as the data available through agency websites. No formal, written agreement is required and typically the only applicable and enforceable conditions are those associated with Federal copyrights.
- <u>Handshake Agreements</u> - This category applies when agencies form a mutual, good faith agreement for sharing data but don't formalize it through documentation. Examples include mutually beneficial data being shared between local, regional and state agencies.
- <u>Memorandums of Understanding (MOU)</u> - This category applies when the parties have similar policy goals that can be attained by sharing data and a mutual desire to document their intent to collaboratively share operations data through a non-binding, signed acknowledgement.
- <u>Data Usage Agreements (DUA)</u> - This category applies to legally binding, signed documents that govern the terms and conditions placed on data being shared between two or more parties. These agreements are categorically the most restrictive and often include legal considerations such as privacy, liability or financial obligations. DUAs can be associated with contracts, cooperative agreements, collaboration agreements, inter-governmental / inter-agency agreements, inter-local agreements and Public-Private Partnerships.

2.2.4.2.2 Current Sharing Practices

In a 2014 study [5], State Departments of Transportation (DOTs), bus transit providers, transportation / transit / port authorities, and local agencies were polled on various aspects of sharing transportation data. The goal was to collect data from different jurisdictions, districts, divisions, and organizational groups to determine if there are differences in the way larger or more decentralized organizations share operations data. Relevant to AERIS Eco A/D, the survey indicated city and local agencies were the most frequent suppliers of traffic signal system data (i.e., signal status and timing plans), followed by county and state DOTs. The primary recipients of this data were Metropolitan Planning Organizations (MPOs) and bus transit providers. 89 of 198 respondents provided data through real-time or near real-time feeds. The majority of data-sharing agreements were fairly informal, with most organizations sharing data either without formal agreements, in good faith, or through MOUs. 6 of 12 county DOTs and 18 of 40 bus transit providers required formal data use agreements.

In a 2011 workshop that included 21 individuals from 17 MPOs and regional transportation authorities throughout the U.S., the participants were asked to indicate what types of institutional agreements were used. [11] Over half of the 17 responding agencies indicated that they did not use any formal agreement. 3 indicated that they used interagency or project agreements to fund individual upgrades or synchronization projects within their programs and 2 agencies mentioned that they used MOUs.

And finally, in a 2002 survey of public agency policies and practices for sharing traveler information data [4], 17 of 33 responding agencies indicated that written data sharing agreements are required. Another 12 said agreements are typically needed when data are shared with a private organization, when sharing video, and when there is a fee for the data. 4 of the agencies reported never requiring a formal agreement. The responses from the 7 private sector entities followed the same general trend.

The private sector and public agency respondent demographics were not publically disclosed.

2.2.4.2.3 Key Elements of Successful Sharing

Many factors can influence the manner in which data sharing initiatives are structured or whether data sharing even occurs. Those most commonly cited in the literature are listed below.

- Data ownership – agencies should proactively include data sharing rights in the terms and conditions of their vendor contracts to ensure the ability to share data generated by their systems with third parties
- Data access – Traffic Management Center (TMC) systems and traffic signal systems vendors often use proprietary data formats and application programming interfaces that are not publicly available, making it difficult for agencies to share the data. Agencies should consider standardized data formats and Application Program Interfaces (APIs), or sourcing common systems as neighboring jurisdictions to mitigate this issue.
- Data rights – when purchasing data, agencies should include standard data rights language in their proposal requests to ensure the ability to the use and share the data as needed
- Data usage – when sharing data, agencies should include necessary conditions on the data usage. Typical conditions include acknowledgement of the data source (particularly if copyrighted), restrictions to protect Personally Identifiable Information (PII) (for video and other data types), restrictions on usage for law enforcement, restrictions on data modification and prohibition on reselling the data
- Data value – agencies that are pressured to monetize their data to offset operational costs associated with providing data should consider reciprocal agreements with other jurisdictions, providing data for in-kind services, such as receipt of the other jurisdiction’s data.

Additionally, a number of technical challenges exist that might be impediments to implementing successful data sharing initiatives. They include:

- Data availability – often local agencies lack electronic data to share
- Data reliability – data can be low quality, intermittent or missing
- Bandwidth issues – agencies may not have the bandwidth to transmit or receive data
- Network – direct point-to-point connections are more commonly used than Internet connections.
- Security – security concerns may deter agencies from sharing data
- Costs – costs associated with creating data feeds or integrating data from other agencies may prohibit sharing

2.2.4.3 Statutory Policy and Regulations Related to Data Sharing

For decades, agencies have used a diverse array of data sources to operate their transportation networks. These data sources typically include field-related real-time data along with archived data to determine operational strategies.

As CV technologies are introduced into the data stream used by agencies to operate the transportation system, they reinforce the need to have clear approaches to data sharing and archiving. Agencies will likely want to develop policies and procedures related to data sharing and archiving, including the need for interagency agreements or data usage agreements to facilitate multi-agency cooperation and operations [17]. Furthermore, agencies need to determine the policies that need to be in place when sharing transportation data (e.g., video, networks) with other agencies. They will need to assess how to coordinate efforts to develop data management tools across agencies and identify any applicable standards necessary for data exchange. Laws and policies governing data privacy, confidentiality, data security, and data sharing might be necessary especially when data access may be granted. Given that the evolutionary Eco A/D concept begins with Level 1 longitudinal control and V2X connectivity, a CV and Automated Vehicle (AV) legislative review was conducted for this task.

2.2.4.3.1 Data Privacy

It is imperative that the privacy of individuals be maintained within the CV / AV environment for successful implementation. Privacy protection is important to individuals and the drivers who will operate Eco A/D vehicles will need assurance from both the manufacturers and transportation operating agencies that their privacy will remain intact. Some considerations noted in the literature are:

- Drivers need to be aware of what information is gathered and how it may be used within the Eco A/D environment
- Public agencies that collect and archive the Eco A/D data need to understand and mitigate potential risks to individuals' privacy, particularly when combining these data with other data sets, such as traffic video
- Privacy by design should remain a guiding principal to preserve the integrity of the V2V system

Appendix D2 provides some examples of current laws, many of which could be related to CV / AV technology. These laws could be revised to include specific restrictions on PII related to this new operational reality. Although not comprehensive across all states, the list illustrates a prevailing awareness of data privacy concerns. Specifically, existing laws related to administrative policy, commerce, health and human services, and insurance are seemingly logical places to start in order to expand the existing legal framework to include CV / AV technology.

The protection of PII is directly related to data security. The USDOT has determined that appropriate protections on user privacy must be ensured by any security system that is part of the CV / AV environment [10]. Laws governing data security are discussed in the next section.

2.2.4.3.2 Data Security

Security for CV / AV technologies involves the following elements:

- In-vehicle cybersecurity – includes physical security, electrical hardware / software security and vehicle network security countermeasures, including telematics, DSRC, cellular and other communications interfaces
- OTA communications security – includes the SCMS, back-end system and its physical / operational security, device credentialing, and the vehicle and infrastructure functions related to signing and verifying messages. Misbehavior detection and revocation processes are included in this category.
- Infrastructure device cybersecurity – includes all physical and hardware / software security aspects of infrastructure devices, such as traffic signal controllers or other road-side devices
- TMC cybersecurity – includes physical security, electrical hardware / software security and the security of networks or point-to-point connections to field devices or other TMCs for centralized processing of real-time traffic and operations data

A breach of security could involve intentional or unintentional violations to either privacy or OTA message trust. A review of state and local legislation and policy indicated that no specific laws are in place to address the data security issues related to CV / AV technology, although most states have some laws governing the manner in which sensitive data are to be stored, secured, and protected from unauthorized use. Appendix D3 provides a sampling of laws that could be appropriate for modification to address CV and AV data.

Beyond whatever Federal guidance or regulations are released, each state or region may need to develop its own principles, guidance, and/or regulations according to its particular needs, goals, and policy framework to protect its systems and secure privacy for its citizens. Clearly, policy and legislation cannot be developed in contradiction to technical designs and requirements of CV / AV systems, but rather the technical designs should support policy requirements, and vice versa. Furthermore, there is no pre-set requirement for states to develop additional levels of security, beyond what the federal regulations imply or what commercial or private organizations implement. Nonetheless, because states have distinct privacy and security approaches or goals, one can reasonably expect that some states may choose to enact additional security regulations or guidelines with which they could require organizations retaining CV / AV data to comply.

2.2.4.3.3 Data Sharing

A review of current state legislation and local ordinances that govern data sharing indicated that none of the laws currently in place specifically address data sharing. However, some states have laws related to how specific types of data can be shared (e.g., private networks, only with specific partner entities). The sharing of these data is directly related to data security and data privacy issues. Appendix D4 provides examples of state laws that might be extensible to user-specific CV and AV data rather than anonymous transportation data. For example, any PII that might be related to health, minors, finances, or public safety may be subject to legal governance. The laws noted highlight specific instances where laws might need to be changed to accommodate the specific data elements that are part of CV/AV technologies that may require specific handling or have privacy implications.

2.2.4.3.4 Liability

Product liability law, one area of law relevant to CV/AV technology, is diverse and complex. Appendix

D5 provides some examples of current CV / AV policies addressing liability issues. Beyond these specific examples, most states are silent on liability related to CVs and automated transportation. The specific laws and policies across the 50 states need to be reviewed to identify the extent to which they can be modified to incorporate changes that address the CV and automated transportation landscape. Specifically, product liability laws for original and converted vehicles and equipment, motor vehicle laws governing legal responsibility over controlling a vehicle, and motor vehicle insurance laws governing liability all provide ample opportunities to set the stage for future deployment of CVs and automated transportation and reduce the likelihood of barriers to success.

3 Conclusions and Recommendations

Establishing a research roadmap focused on developing and potentially deploying a commercially feasible Eco A/D system requires partitioning the key issues and research needs into a sequential set of phases. The result of this planning study is an evolutionary three-phase plan for Eco A/D system research spanning a ten-year time frame. The near-term phase focuses on leveraging existing commercial deployment of Level 1 longitudinal control systems combined with emerging V2X communications capabilities to equip eco-independent intersections to operate Eco A/D functionality interacting with ad-hoc strings of equipped vehicles in mixed flow conditions.

Significant challenges will need to be overcome to achieve this objective. Engaging the vehicle and infrastructure stakeholders in executing the initial four-year near-term research plan with a focus on application to specific real-world traffic corridors is viewed as a critical first step in executing this plan. Exploring the near-term time frame using a two-phase approach is recommended. The first phase of research would select specific existing traffic corridors as potential deployment sites, model the overall operating environment and develop an Eco A/D system design in a simulation environment to evaluate potential benefits and risks. If the estimated potential benefits are promising and system risks manageable then a second phase of near-term research would build and evaluate the system under controlled conditions. To preserve Eco A/D system integrity, an ongoing assessment of data privacy and security will be part of the risk management process, particularly when creating / modifying OTA messages, combining data from multiple sources and sharing / archiving data.

A detailed research process flow is proposed for this work which serves as the outline for potential follow-on research. Successful execution of proposed near-term research could lead to a system design feasible for use in field operation testing leading to potential commercial implementation. Beyond the technical challenges involved, managing the data sharing, privacy, security and liability issues associated with implementing Eco A/D functionality will be critical to successful deployment.

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4 References

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[18] State of Nevada Code of Revised Statutes, Chapter 482A, https://www.leg.state.nv.us/nrs/NRS-482A.html, accessed September 7, 2015

APPENDIX A. List of Acronyms

ACC	Adaptive Cruise Control
AERIS	Applications for the Environment: Real-Time Information Synthesis
API	Application Program Interface
ATM	Active Traffic Management
AV	Automated Vehicle
BSM	SAE J2735 Basic Safety Message
CAMP	Crash Avoidance Metrics Partners
CACC	Cooperative Adaptive Cruise Control
CV	Connected Vehicle
DOT	Department of Transportation
DUA	Data Usage Agreement
DSRC	Dedicated Short Range Communication
Eco A/D	Eco-Approach / Eco-Departure
ETA	Estimated Time of Arrval
FHWA	Federal Highway Administration
FOT	Field Operational Test
GPS	Global Positioning System
MIL	Hardware-in-the-Loop
HMI	Human Machine Interface
HOV	High Occupancy Vehicle
ITS	Intelligent Transportation System
JPO	Joint Program Office
MAP	SAE J2735 Map Message
MOU	Memorandum of Understanding
MPO	Metropolitan Planning Organization
OEM	Original Equipment Manufacturer

OTA	Over the Air
PI	Principal Investigator
PII	Personally Identifiable Information
RTCM	SAE J2735 Radio Technical Commission for Maritime Services Correction Messages
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
SPaT	SAE J2735 Signal Phase and Timing Message
TMC	Traffic Management Center
TMT	Technical Management Team
TTI	Texas A&M Transportation Institute
UCR	University of California - Riverside
UMTRI	University of Michigan Transportation Institute
USDOT	United States Department of Transportation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Vehicle / Infrastructure
WAAS	Wide Area Augmentation System

APPENDIX B. List of Reviewed Publications

The reference number shown at the top of each column identifies the report in the list that follows. General technical references are highlighted in yellow, OEM suggested reports in green, additional USDOT information in red and other documents which were identified from the reference sections of the general technical references are highlighted in blue.

REFERENCES

Category Coverage	3	4	5	6	7	8	13	14	18	24	28	29	32	33	47	48	52
1) ECO Concept (ECO)	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
2) Vehicle Technical Issues (VEH)	x		x		x	x				x	x	x	x		x		x
3) Infrastructure Technical Issues (INF)		x	x	x	x	x	x		x				x	x		x	
4) Communications/Standards (COM)										x							x
5) Human Factors (HF)								x					x				
6) Performance Measures (PM)	x	x	x	x			x	x	x		x	x	x	x	x	x	x

REFERENCES

1) ECO Concept (ECO)	59	61	81	82	85	90	91	100	113	116	127	128	130	133	137	139
2) Vehicle Technical Issues (VEH)	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
3) Infrastructure Technical Issues (INF)	x			x						x				x		
4) Communications/Standards (COM)		x	x			x	x	x	x	x		x	x			x
5) Human Factors (HF)			x										x		x	
6) Performance Measures (PM)	x				x				x			x		x		
		x				x	x	x	x	x	x	x				x

OEM

	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155
1) ECO Concept (ECO)	x	x	x	x						x	x				x	
2) Vehicle Technical Issues (VEH)		x		x	x							x	x	x		
3) Infrastructure Technical Issues (INF)	x					x	x	x	x					x	x	
4) Communications/Standards (COM)		x			x											
5) Human Factors (HF)																
6) Performance Measures (PM)	x		x		x	x	x					x				x

USDOT

	156	157
1) ECO Concept (ECO)		x
2) Vehicle Technical Issues (VEH)		
3) Infrastructure Technical Issues (INF)	x	
4) Communications/Standards (COM)		
5) Human Factors (HF)		
6) Performance Measures (PM)		

OTHER

	158	159	160	161	162	163	164	165	166	167	168	169	Category Total
1) ECO Concept (ECO)	x			x				x				x	43
2) Vehicle Technical Issues (VEH)													20
3) Infrastructure Technical Issues (INF)	x				x				x	x	x		33
4) Communications/Standards (COM)				x									8
5) Human Factors (HF)													7
6) Performance Measures (PM)		x	x			x	x						34

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2. Park, Sangjun et al., Real-Time Emission Modeling with EPA MOVES: Framework Development and Preliminary Investigation, TRB 94th Annual Meeting Compendium of Papers, 2015, http://docs.trb.org/prp/15-2604.pdf

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APPENDIX C. Eco A/D Key Research Needs

C.1 ConOps Research Needs

- Identification of failure modes should be undertaken but countermeasures are out of current scope; system level risks (vehicle & Infrastructure) should be assessed but hardware / software is implementation specific
- Is DSRC sufficient / is it realistic to rely on other vehicles?
- Is obstacle detection capability required in the vehicle?
- Should there be RSEs at each intersection or can a corridor be serviced by a single RSE?
- Deciding whether speed profile generation occurs on board vehicles or in the infrastructure needs to be assessed - local or TMC?
- Investigate data content and transmission protocols needs as well as minimum performance requirements
    - E.g., frequency, latency and accuracy requirements, needed to support Eco A/D
    - Develop necessary data content, protocols and performance requirements especially as they pertain to vehicle strings
- How signal priority affects overall traffic flow should be addressed in follow-on research
- Management of infrastructure-side information is seen as important and should be addressed in follow-on research
- Includes both information collected by the infrastructure, as well as information the infrastructure generates
- Communicating the right data at the right time and right place must be assured
- Research needed to ensure seamless performance of all sub-networks under a central Eco A/D system
- Need to assess the significance of how a failure in one sub-network affects the region or corridor
- Accurate positioning information is seen as critical to Eco A/D operation, although the required level of accuracy and whether map data is required, needs to be assessed
- The need for vehicles to possess automated driving capabilities in order to be Eco A/D enabled is an important research topic
- Assess other issues such as the effect of launch delays when the signal transitions from red to green
- Sensor fusion that allows, among other things, the ability to detect the location of other vehicles that are not equipped with DSRC radios, is seen as an important research topic

- How a request for signal priority affects overall Eco A/D functionality is seen as an important research topic
- Who sends the request and what information is contained in the request is immaterial to the research question
- An assessment of level of effectiveness vs. penetration rate should be a part of follow-on research

C.2 Vehicle Technical Issues

- The In-Vehicle System may benefit from receiving environmental condition data, including road weather conditions but this is a longer range research issue
- Timing issues related to control lag (e.g., as present in Glide Path) and the impact on control and communication lag are a concern and should be studied further
- The research should explore vehicle and environmental variables
    - E.g., powertrain types, body types, vehicle classification for the vehicle
    - E.g., road grade, coefficient of friction, weather condition, visibility for the environment
- The assumption that Eco A/D will require longitudinal control needs to be further assessed
    - In the case of automated driving, it is assumed that automated driving shall also follow Eco A/D advisory signals
    - The degree of difficulty for drivers to adjust vehicle speed in response to instructions from the in-vehicle system needs to be studied
- Is it necessary / useful to communicate Eco A/D mode with other vehicles?
- Follow-on research should address in an evolutionary manner:
    - Single vehicle(s) under driver or automated system control
    - Multiple individual vehicles in a single lane under driver or individual vehicle system control
    - A CACC string of vehicles (e.g., single lanes)
    - A wave of individual vehicles traveling in multiple adjacent lanes under driver or individual vehicle system control
    - Two or more adjacent lanes of CACC strings of vehicles; a multi-lane wave of vehicles under coordinated automated control
- The need for the In-Vehicle System to provide drivers with eco-driving information that encourages them to drive in a more environmentally efficient manner is seen as a research topic

C.3 Infrastructure Technical Issues

- Developing Eco A/D algorithms that can accurately estimate traffic flow and queues is considered important
    - Accurate estimations of the back of a queue, queue length and the time required to clear the queue are necessary to effectively determine velocity profile
    - It is important accurately estimate the time to stop bar in conjunction with the SPaT
- Investigating the benefits of communicating both strategic (e.g., where is the green band supposed to be) and tactical (queue clearance, etc.) information related to downstream signal timing and traffic conditions to upstream vehicles and intersections is considered important. In doing this, consider:
    - What information needs to be communicated to whom (vehicles and/or intersections), from whom, by when and how
    - Both corridors in which traffic signal controllers are controlled by a TMC and those which aren't
    - New technologies, such as those that might emulate BSMs for unequipped vehicles or send other messages or data
- Assessing whether the Eco-Traffic Signal System requires historical and current traffic data in order predict traffic conditions aggregated at different levels (e.g., intersection, corridor, and regional levels) is an important research topic
- Vehicle locational accuracy and MAP accuracy are critical to EAD application performance
    - Understand and address the impacts of GPS outages
    - Investigate the current positioning capabilities relative to the EAD system requirements
    - Assess methods of improving the accuracy for the vehicles and infrastructure, such as dead reckoning improvements, GPS repeaters, benefits from other sensors, differential corrections, and future GPS improvements
- Establishing a "green number" for intersections based upon travel demand, geometry, the type of signal controller, driver incentives, and historical data that could enhance Eco A/D and is viewed as useful research
- It is important to define the corridor characteristics that provide the highest Eco A/D benefits
- It is important to understand whether the current standards and technologies support the concept and identify / address existing gaps in:
    - SAE J2735 SPaT and MAP standards relative to evolutionary Eco A/D application needs
    - The current signal controller technology and the National Transportation Communications for ITS Protocol standard relative to evolutionary Eco A/D application needs

- Research related to the Eco-Traffic Signal System calling a different traffic signal timing plan or manipulating the existing plan (e.g., through holds and force-offs, traffic signal priority) using processed traffic data, predicted traffic data, and environmental data is seen as an important research topic
- Understanding the current features in the signal controller (e.g., Phase Holds, Phase Omits, Force Offs) and how these features contribute to Eco A/D timing plans is seen as important for the Eco A/D research
- Understanding the current traffic controller priority feature and whether the Eco-Traffic Signal System needs to provide traffic signal priority action data (e.g., time to extend the green or advance the green for priority) to the traffic signal controller(s) is considered an important research topic
- Research related to the Eco-Traffic Signal System disseminating traffic data and traffic signal timing plans to other jurisdictions to enable coordination of timing plans and other operational strategies for a corridor or a region is part of the research plan, including what elements and how to communicate them
- Assess what traffic data the Eco-Traffic Signal System needs to collect, such as traffic volume, speed, occupancy, vehicle classification, turning movements, incidents, pedestrian calls or presence at traffic signals, vehicle type, and vehicle position to support Eco A/D
- Follow-on research focused on the development, simulation, testing and performance analysis of potential Eco A/D algorithms is necessary and should include:
    - An analysis of vehicle-based, infrastructure-based and hybrid queue estimation
    - Investigation of the feasibility of queue balancing
    - Consideration of in-vehicle and infrastructure-based sensing
    - Existing and new OTA messages, data accuracy and timeliness
    - Various market penetration levels and traffic scenarios, including the impact of vehicles making turns
- Future research should consider real-time road and traffic conditions and incorporating traffic prediction models
- Research related to the Eco-Traffic Signal System providing traffic signal timing plans (e.g., cycle lengths, phases, offsets and other parameters) to the traffic signal controller(s) is not viewed as important for the long-range research plan
- Research related to the Eco-Traffic Signal System collecting and archiving traffic data, signal operations data, event logs, operational status and other performance data, as well as providing traffic condition messages to vehicles is considered important follow-up research
    - Logging activities and decisions are important to public agencies, particularly for testing and evaluation, but also for legal reasons
    - It will be important to agencies to illustrate benefits to users and decisions makers
- Research related to the Eco-Traffic Signal System collecting and disseminating descriptions about the static physical geometry at intersections and arterial roadway segments is part of the research plan, since this data will impact the performance of the Eco A/D applications

C.4 System Integration Technical Issues

- Research related to understanding and predicting driver intent with respect to vehicle operation (e.g., turn signal and other BSM elements) is important to the concept and should be undertaken as mid- to long-term research
    - Algorithms could reside in the infrastructure, the vehicles or a combination of both
    - Initial solutions should focus on the simple and practical solutions, such as an algorithm based upon the standard BSM data available rather than more complex approaches, such as an algorithm based upon statistical behavior patterns
    - Explore the role of signal intent aiding driver intent using data provided by the signal system to vehicles
- The research will investigate whether the eco-approach and eco-departure algorithms can be common or if they should be treated as separate research areas (or algorithms)
- The research should explore all configurations of vehicles and intersections in simulation, and then in field testing as applicable
- As part of this plan, quantify the benefits of the application at various market penetration levels for these configurations
- The research plan should consider:
    - Single Eco A/D vehicle or multiple Eco A/D-equipped vehicles
    - Single intersection for various intersection configurations (e.g., number of lanes in each direction, with or without turn lanes)
    - Multiple intersections for various intersection configurations
    - Traffic volume levels
- As noted in the Infrastructure "next steps," follow-on research focused on the development, simulation, testing and performance analysis of potential Eco A/D algorithms is important and should include:
    - Estimation of the time to stop bar in conjunction with the SPaT
    - An analysis of vehicle-based, infrastructure-based and hybrid queue estimation
    - Investigation of the feasibility of queue balancing
    - Consideration of in-vehicle and infrastructure based sensing
    - Existing and new OTA messages, data accuracy and timeliness
    - Various market penetration levels and traffic scenarios, including the impact of vehicles making turns

C.5 Human Factors

- End-user requirements must drive application design in order to deliver perceived value. Basic consideration of desired functionality and usability are important during the Eco A/D system design phase, while details of the in-vehicle interface may be left for future development.

- Research is required to understand if driver perception of benefit will require tangible reductions in travel time, or if there is a perceived comfort benefit in smoother flow with fewer stops even if mobility remains constant
- Research should explore the ability of Eco A/D systems to achieve improved mobility benefits for equipped drivers focusing first on Eco-Approach with Level 0 systems, then considering Level 1 augmentation to achieve Eco-Departure. In both cases the implications for surrounding traffic will need to be evaluated including the effect of penetration rate and infrastructure needs to support deployment (e.g., while Eco-Approach may function in free flowing traffic, improvements may be possible using restricted lanes. In addition, Eco-Departure may require implementation of dedicated infrastructure similar to automated tolling lanes with fault tolerant vehicle control system designs.)

C.6 Performance Measures

- Look at historical intersection automation research for driver acceptance and workload
- Start with mobility. Consider emissions and fuel economy effects, including the role of powertrain in the fleet mix, later in the research timeline.
- Hazard analysis is inextricably related to system design. A preliminary hazard analysis should be performed on the system design(s) chosen for initial exploration.
- The feasibility of employing a generic interface between Eco A/D modeling architecture and specific traffic models should be explored.

C.7 Communications and Standards

- Need to explore communication of partial MAP messages or high level corridor MAPs to communicate downstream intersection information to approaching vehicles
- Is there a need to share information such as obstacle detection or GPS drop outs with other vehicles and will communications standards support it?
- Initial research efforts focusing on individual vehicles / cooperative strings of vehicles interacting with individual intersections / coordinated corridors should be assessed. This can be evaluated by extending the Glide Path research to corridor operation and incorporating CACC research to explore the sufficiency of existing modes of communication.
- The additional / different needs of platoons of vehicles under (partially) automated control interacting with a progressively more sophisticated and possibly more restrictive infrastructure should be a long-range research focus if justified by potential benefits
- Investigate BSM 1 and 2 for data elements that can be used to facilitate Eco A/D and determine if elements not available are needed in the future

APPENDIX D. Transportation Data Sharing

D.1 Transportation Data Elements

<table>
<tr><th></th><th>Traditional Operational Strategies</th><th>ITS Enabled Operational Strategies</th></tr>
<tr><td>Field Data</td><td>• Video camera feed
• Loop detector feed
• Bluetooth device feed
• Acoustic sensors
• Microwave sensors
• Radar
• Probe-based systems such as:
    • License plate recognition
    • Toll tag transponders
    • GPS system data
    • Cell phone tracking data</td><td rowspan="3">• Active traffic demand
• Adaptive ramp metering signal status
• Active traffic management strategy information
• Adaptive signal control status
• Arterial management
• Congestion management
• Congestion pricing and managed lanes
• Dynamic junction control status
• Dynamic lane reversal status
• Dynamic lane use control signal status
• Dynamic shoulder use status
• Freight management/commercial vehicle operations
• Freeway service patrols/emergency response units
• High occupancy vehicle or high occupancy tolling lane development
• Origin-destination data
• Parking (traffic) management
• Queue warning status and algorithms
• Real-time transit location data
• Routing data for emergency response and general traveler information
• Regional signal systems coordination
• Regional transit coordination
• Road weather management
• Special events management
• Traffic incident management
• Traffic volume data
• Traffic speed data
• Traveler information dissemination`
• Travel time data
• Variable speed limit status
• Vehicle class data
• Vehicle occupancy data
• Work zone management
• Variable speed limit algorithms</td></tr>
<tr><td>Traffic Management Center Data and Computer Aided Dispatch Data</td><td>• Archived field data
• Intersection signal timing plans
• Dynamic message sign messages
• Highway advisory radio messages
• Field device operational status data
• Intersection/metering signal status data (operational, flashing, offline, maintenance mode, current timing plan)
• Decision support response plans
• Event data
• Work zone data
• Emergency data
• Fire, medical and law enforcement dispatch information
• Incident location
• Incident type and severity
• Status and info on vehicles involved
• Responder requests
• Emergency and other lane closure and detour data</td></tr>
<tr><td>Transit Data and Other Service Vehicle</td><td>• Transit alerts
• Disruptions</td></tr>
</table>

	Traditional Operational Strategies	ITS Enabled Operational Strategies
Data	• Transit schedules, routes and stops • Location and status of transit and other service vehicles with locating devices	
Freight Data	• Origin/destination of shipments • Types of goods • Value • Quantity • Container types • Safety data • Historical data	
Static, Descriptive Information	• Number of lanes • Speed limits • Weight restrictions • Height restrictions • Transit and rail network information • Evacuation routes • Business location • ITS device and other fixed asset locations • Evacuation routes	
Weather Data	• National Weather Service radar and alerts • Media and other third parties • Roadway weather information system data • Pavement surface condition	
Connected and Automated Vehicle Data	• BSM information (vehicle broadcast) • SPaT and intersection MAP message information (infrastructure broadcast) • Basic Mobility Message information (under development by SAE) • Personal Safety Message Information (under development by SAE for broadcast by pedestrians and other vulnerable road users) • Future Cooperative Vehicle	Enabled CV and AV Application Categories • V2I Light Vehicle and Heavy Vehicle Safety • V2V Light Vehicle and Heavy Vehicle Safety • V2I Transit Safety • V2V Transit Safety • AERIS • Road Weather • Mobility

	Traditional Operational Strategies	ITS Enabled Operational Strategies
	Messages (under development by SAE for automated vehicles) • Future Public Safety Messages (under development by SAE) • Future safety, mobility, and environmental messages	

D.2 Sample Data Privacy Laws [12]

State	Legislation/Policy	Regulatory Departments/Topics									
		Administrative Services	Attorney General	Commerce, Banking, Finance	Education	Environmental Quality	Family Resources, Human Services	Health, Aging	Insurance	Professional Licensing and Regulation	Telecommunications and Technology Commission
AZ	Arizona Admin. Code R6-6-104			X							
AR	Arkansas Admin. Code 054.00.74								X		
IL	Illinois Admin. Code 130.849 50 Ill. Admin. Code 4002								X		
IN	Indiana Admin. Code 410 IAC 34-9-1 Indiana Admin. Code 470 IAC-3.1 Indiana Admin. Code 511 IAC 7-32-73				X		X	X			
IA	Iowa Administrative Code 187-7.14 (17A,22) Iowa Administrative Code 17-19.14 (17A,22) Iowa Administrative Code 11-4.14 (8A, 22) Iowa Administrative Code 61-2.14 (17A,22) Iowa Administrative Code 193-13.13 (17A,22) Iowa Administrative Code 281-5.14 (256) Iowa Administrative Code 751-2.14 (17A,22)	X	X		X			X		X	X
LA	LAC tit. 28, pt. XLIII, § 123 LAC tit. 33, pt. I, § 601				X	X					
MN	Minnesota Rules 4731.0240 Minnesota 9500.1458						X	X			
NB	Nebraska Administrative Code Tit. 92, Ch. 6, Appendix A				X						

ND	North Dakota Administrative Code 69-02-09	X									
OH	OAC 4765-4-05							X			
OK	OAC 90:1-3-6 OAC 105:1-3-4			X							
OR	Oregon Administrative Rules 407-014-0000 Oregon Administrative Rules 943-014-0000						X	X			
SC	South Carolina Code of State Regulations R. 126-171							X			
SD	Administrative Rules of South Dakota 24:05:29:20				X						
TX	Texas Administrative Code 28 TAC Part 1 § 22								X		

D.3 Sample Data Security Laws [12]

State	Policy/Regulation/Security Topic							
	Written Security Program to Protect Information Required; Specifics to Be Determined by Each State	Program Must Protect Against Unauthorized Access or Use	Holder Shall Not Allow Any Other Individual to Have Access to Information Unless Permitted by Regulation	Personnel Using Systems Are Required to Have Information Technology Security Training	Criminal Offender Records May Be Released on a Need-to-Know Basis	Before Use of Information and Tracking Network, Law Enforcement Must Go Through Training	Data Submitted to the DMV Is to Be Encrypted	Enquiries of Vehicle Registration or Driver's License Registration Limited to Law Enforcement, Criminal Justice, and DMV
AL	X	X						
AR	X	X		X				
CA	X				X			
AK, CO, CT, DE, FL, IL, IN, IA, ME, MT, NE, NH, NJ, ND, OK, PA, TX, VT, WA, WV, WY	X							
MA	X							
MI	X	X	X			X		
OR	X	X						
SC							X	

D.4 Sample Data Sharing Laws [12]

State	Legislation / Policy	Topic						
		Health, Human Services	Children and Families	Revenue, Tax, Banking	Public Utilities	Insurance	Public Safety	Criminal Justice
CO	6 CCR 1009-1:6 – Rules and regulations pertaining to epidemic and communicable disease control, information sharing	X						
DC	29 DCMR § 3000 – Rules that apply to the sharing of health and human services information	X						
FL	RAC 12-22.007 – Rules covering the confidentiality and disclosure of tax information			X				
IL	77 IAC 690.1405 – Rules covering information sharing related to the control of communicable diseases 83 IAC 550.85 – Prevents a gas utility from directly or indirectly providing preferential access to information related to its interests	X			X			
ME	02-031 CMR Ch. 790 – Governs the Bureau of Insurance and the disclosure of investigative records of licensing boards during pending investigations					X		
MA	110 CMR 4.45 – Governs the information shared by the Department of Children and Families related to specific cases 803 CMR 7.06 – Establishes requirements for a global public safety information sharing agreement related to the department of criminal justice		X				X	
NC	14B NCAC 11A.0301 – Designates agencies authorized to share information within the Department of Public Safety, Division of Juvenile Justice						X	
ND	NDAC 110-01-02-02 – Establishes the organization of the criminal justice information sharing board and that board's duty to set policy related to sharing information							X
OH	OAC 4501:2-10 – Establishes guidelines and policy related to an international justice and public safety information sharing network within the Highway Patrol, Public Safety Department						X	
TX	7 TAC § 131.1 – Establishes guidelines for the confidentiality of information as part of the State Securities Board			X				
WA	WAC 182-557-0300 – Sets policies for confidentiality and data sharing with home health service contractors as part of the Department of Social and Health Services WAC 388-76-10174 – Within the Department of Social and Health Services, governs the disclosure of information sharing related to background information by health care facilities	X	X					

D.5 CV / AV Policies Addressing Data Sharing Issues [12]

Jurisdiction	Legislation / Policy	Date	Description / Summary
DC	DC Act 19-643 (Autonomous Vehicle Act of 2012) [12]	1/23/2013	The DMV must establish safe operating protocols for AVs (an AV is defined as a car that can navigate the road without a driver); liability on a converted car is on the party that converted the car unless a problem existed before conversion
FL	CS 1207 [13]	4/16/2012	Limits the liability of the OEM of a vehicle converted to an AV
MI	SB 169 [14]	3/27/2014	A manufacturer of automated technology is immune from civil liability for damages that arise out of any modification made by another person to a motor vehicle or an AV, or to any automated technology
	SB 663 [15]	12/27/2013	A subcomponent system producer is not liable in a product liability action for damages resulting from the modification of equipment installed by the subcomponent system producer to convert a vehicle to an AV, unless the defect from which the damages resulted was present in the equipment when it was installed by the subcomponent system producer
NV	SB 313 [16]	6/2/2011	The manufacturer of a motor vehicle that has been converted to an AV by a third party is immune from liability for certain injuries in certain circumstances
	Nevada Register of Administrative Regulations, Volume 174, Number 2 [17]	2/29/2012	An AV is defined as a car that can carry out driving without active control from a natural person; regarding enforcement of traffic laws, the driver will be deemed responsible even if not present; an AV requires separate insurance policies from normal liability insurance; operators must have a special endorsement on the driver's license
	Nevada Administrative Code NAC 482A.050—Autonomous Vehicles [17]	2/15/2012	An AV must contain a mechanism to store data for 30 seconds prior to a collision and store data for up to three years

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