Integrating Smart Roadside Initiative into the V2I Component of the Connected Vehicle Program

Task 3.2

www.its.dot.gov/index.htm
Final Report—January 2015
FHWA-JPO-14-188

U.S. Department of Transportation

Produced by DTFH61-11-D-00012
U.S. Department of Transportation
Intelligent Transportation Systems Joint Program Office

Notice

Quality Assurance Statement

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-14-188		

4. Title and Subtitle	5. Report Date
Integrating Smart Roadside Initiative into the V2I Component of the Connected Vehicle Program *Task 3.2*	January 2015
	6. Performing Organization Code
7. Author(s) Roy Sumner, Mark Jensen, Roger Schiller, Steve Capecci	8. Performing Organization Report No.
9. Performing Organization Name and Address FreeAhead Inc. P.O. Box 270 Orange, Virginia 22960 Cambridge Systematics, Inc. 100 CambridgePark Drive, Suite 400 Cambridge, MA 02140	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-11-D-00012
12. Sponsoring Agency Name and Address U.S. Department of Transportation ITS Joint Program Office–HOIT 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code HOIT

15. Supplementary Notes

16. Abstract

This document details an analysis that maps the current Connected Vehicle development effort to the SRI efforts currently underway. The document provides a mapping of how SRI incorporates into the Connected Vehicle program. This mapping is performed down to the data element level in the various message sets. The results inform how much of the current Connected Vehicle system design can be used to support the SRI applications (mainline electronic screening, virtual weigh station, commercial parking systems) that are central to this project.

17. Key Words	18. Distribution Statement
Smart Roadside Initiative, Connected Vehicle, Commercial Truck Technology, Virtual Weigh Station, Mainline Screening, Commercial Truck Parking	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	N/A

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO 51 UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
rt2	square feet	0.093	square meters	m2
yd2	square yard	0.836	square meters	m,
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kiometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
g?l	gallons	3.785	liters	L
W	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m"
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or"!")
		TEMPERATURE (exact degrees)		
0F	Fahrenhet	5 (F-32)/9 or (F-32)11.8	Celsius	•C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cdlm^2
		FORCEandPRESSUREorSTRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	fl
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m2	square meters	10.764	square feet	rt2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m'	cubic meters	35.314	cubic feet	fe
m'	cubic meters	1.307	cubic yards	yd"
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
•C	Celsius	1.8C+32	Fahrenheit	0F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

•SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Executive Summary

The Smart Roadside Initiative (SRI) was envisioned by the United States Department of Transportation (U.S. DOT) to extend and enhance the benefits associated with a myriad of Federal, State, and private-sector programs/technology deployments, including the Commercial Vehicle Information Systems and Networks (CVISN), truck size and weight enforcement technologies, Wireless Roadside Inspection, truck parking systems, Connected Vehicle Program, weather information, electronic toll collection systems, and carrier-based communication technologies. The U.S. DOT has undertaken the Smart Roadside Initiative (SRI) Gap Analysis to analyze the SRI concept, identify any gaps that may exist, and identify how the program can be advanced further. The project is designed to:

- Document the currently available and emerging roadside technologies for commercial vehicle operations (CVO);
- Analyze the functionality being developed as part of the Smart Roadside Prototype;
- Document the "target" SRI functionality; and
- Identify operational, institutional, and technical gaps that would hinder the deployment of the SRI "target" functionality.

This document details an analysis that maps the current Connected Vehicle development effort to the SRI efforts currently underway. The results inform how much of the current Connected Vehicle system design can be used to support the SRI applications (mainline electronic screening, virtual weigh station, commercial parking systems) that are central to this project.

Technical Approach

The following served as the primary reference documents for developing this study:

- **Connected Vehicle Reference Implementation Architecture (CVRIA)—**Provides a framework describing the various institutional entities and organizations and the systems they will implement to deploy the overall Connected Vehicle environment;
- **Connected Vehicle Standards—**This consists of several emerging connected vehicle standards associated with Dedicated Short-Range Communications (DSRC) and related technologies that form the common foundations that will allow the SRI elements to communicate with each other, vehicles, and the roadside;
- **SRI ConOps, System Requirements, and System Design—**This covers the U.S. DOT-sponsored test program being implemented by Leidos, that includes the SRI Concept of Operations documentation;
- **AASHTO's Connected Vehicle Footprint Analysis—**This provides an example operational scenario of how SRI operations could take place in a future vehicle-to-infrastructure DSRC-based commercial vehicle roadside screening environment;

- **NHTSA Interoperability Issues for Commercial Vehicle Safety Applications—** This provides some useful information on interoperability issues that can inform how systems can exchange info in a Connected Vehicle-SRI architecture.

Using these documents as the primary inputs, a basic methodology was implemented that focused on developing an integrated SRI flow diagram, conducting a comparison between the SRI functionality and the Connected Vehicle architecture, assessing the relevant standards and performance requirements of the technology elements, and developing a set of conclusions based on the assessments made.

Findings

Our analysis confirms that SRI functionality contained within the scope of this project (e.g., mainline electronic screening, virtual weigh stations, commercial parking systems) can function within the Connected Vehicle environment. The existing/emerging architecture and design for roadside safety applications support mainline screening and virtual weigh station functionality. The use of the Traveler Information Message (TIM), which was successfully demonstrated in Michigan, also indicates the potential for the Connected Vehicle infrastructure to support the commercial parking functionality.

The following present some highlights of the key outputs and conclusions from this report. Where appropriate, some associated recommendations are proffered for U.S. DOT's consideration:

- In developing this assessment, it was clear that both the existing CVRIA and SRI documentation had limitations in terms of defining the concept of what a connected vehicle SRI architecture would look like. Given this challenge, the study team's most important product of this effort was to develop a specific CVRIA SRI architecture diagram, which is shown in figure ES-1 below. Going forward, this provides a key input to U.S. DOT, the CVRIA team, and the Leidos SRI testing team concerning the basis for an all-encompassing SRI architecture that supports mainline screening and virtual weigh station operations.
- Initial calculations developed in this report show that it should be possible to conduct a SRI roadside screening in a connected vehicle/DSRC-standards environment, within a 10-second window, provided necessary and timely connectivity to credentialing systems/back-office systems exists to support the transaction. This highlights perhaps the most important technology-specific benefit provided to SRI by the Connected Vehicle environment.
- The current status of the Connected Vehicle design (based on the standards and the CVRIA documentation) can meet the needs of the existing SRI system functionality. However, there are data elements in the commercial vehicle data bus that are known to be not yet available. This circumstance also applies to the automobile fleet. Some new functionality would need to be added to the roadside and central applications to function most efficiently.
- Currently, the CVRIA architecture and associated documentation does not provide specific information on the data types as defined in the standards. Any implementer of the CVRIA architecture when developing a SRI system would need to map the data flows of CVRIA to the standards.

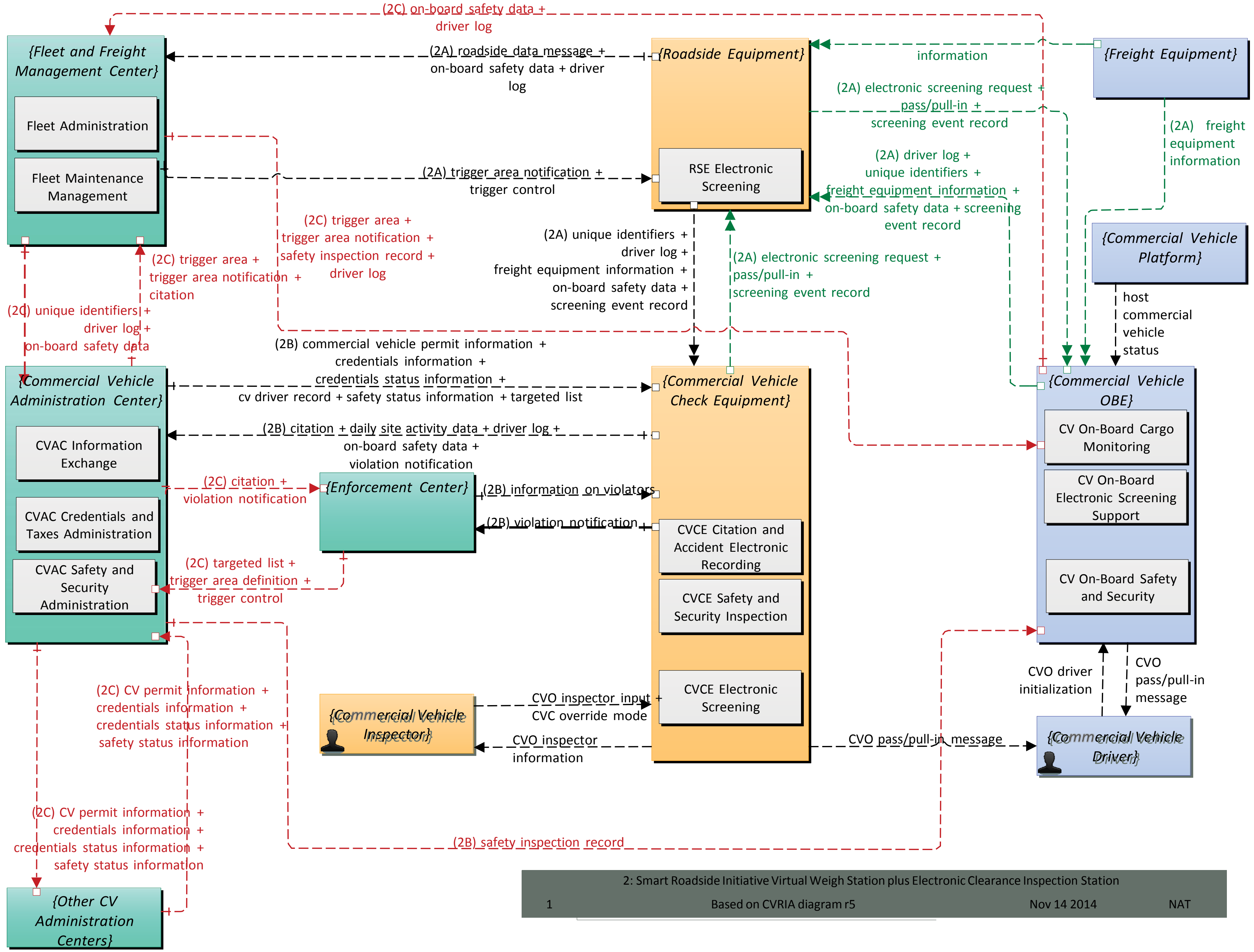

Figure ES-1. Flowchart. SRI architecture

(Source: Connected Vehicle Reference Implementation Architecture)

- In regards to Truck Parking systems SRI functionality, it is reasonable to assume that since Traveler Information Messages (TIM) can be used to transmit commercial vehicle parking that these tests could be considered to be fulfilled in the ongoing southeast Michigan projects where the TIM has been successfully demonstrated. In order to conduct such tests it is recommended that a detailed design be developed based around the CVRIA architecture and the SAE J3067 standard.
- The mainline screening and virtual weigh station applications should be implemented to conform as much as possible to the Safety and Fitness Electronic Records (SAFER) interface portion of the CVISN architecture because this architecture already provides a proven means for accessing safety and credentialing information in support of roadside enforcement activities.
- More visibility is required into the development on the SAE J3067 standard. Current information on the status and timing of this standards process is not definitive, and it is recommended that U.S. DOT and its CVRIA contractor establish a technical presence on the SAE standards committee that is moving forward with this process.
- The biggest impact on the performance requirements will occur on the infrastructure side. In the vehicle, the data can be kept current and ready to be transmitted with a very low latency. However, on the infrastructure side, equipment will need to determine the vehicle ID and then begin the relevant processing such as gathering records from databases and from the local hardware, etc.

1.0 Introduction

The Smart Roadside Initiative (SRI) was designed to break down information silos at the roadside in order to improve motor carrier safety and mobility, as well as the operational efficiency of motor carriers and the public-sector agencies that regulate them. Jointly conceived by the Federal Highway Administration (FHWA), the Federal Motor Carrier Safety Administration (FMCSA), and public- and private-sector stakeholders, SRI looks to build on the previous Intelligent Transportation Systems (ITS) research conducted by United States Department of Transportation (U.S. DOT), as well as the existing State and local ITS deployments.

SRI was envisioned to extend and enhance the benefits associated with a myriad of Federal, State, and private-sector programs/technology deployments (e.g., Commercial Vehicle Information Systems and Networks (CVISN), truck size and weight enforcement technologies, Wireless Roadside Inspection, truck parking systems, Connected Vehicle Program (e.g., "FRATIS"), weather information, electronic toll collection systems, carrier-based communication technologies) through additional collaboration, coordination, and data sharing. During the 2008 SRI workshop, stakeholders identified a total of 42 functional capabilities and 22 specific projects within 4 operational environments (urban, multistate/long haul, intermodal/port, and international border crossing) that could advance the Smart Roadside vision.

The U.S. DOT has undertaken the Smart Roadside Initiative (SRI) Gap Analysis to analyze the SRI concept, identify any gaps that may exist, and identify how the program can be advanced further. The project is designed to:

- Document the currently available and emerging roadside technologies for commercial vehicle operations (CVO);
- Analyze the functionality being developed as part of the Smart Roadside Prototype;
- Document the "target" SRI functionality; and
- Identify operational, institutional, and technical gaps that would hinder the deployment of the SRI "target" functionality.

1.1 Purpose of this Document

This document details an analysis that maps the current Connected Vehicle development effort to the SRI efforts currently underway. The document provides a mapping of how SRI incorporates into the Connected Vehicle program. This mapping is performed down to the data element level in the various message sets. The results inform how much of the current Connected Vehicle system design can be used to support the SRI applications (mainline electronic screening, virtual weigh station, commercial parking systems) that are central to this project.

This document does not address the requirements of the back-office systems beyond their impact on the Connected Vehicle mechanisms that are involved with communicating to and from vehicles. As documented during task 2 of this project, 46 States currently have deployed SRI safety systems and have existing back-office systems that support the existing SRI functionality. These systems have been deployed in accordance with the Commercial Vehicle Information Systems and Networks (CVISN) architecture. While the specific systems and overall concept of these systems (e.g., centralized State repository, centralized private-sector repository, distributed State systems) vary widely across the States, their adherence to the CVISN architecture ensures that the functionality required for SRI systems is in place. Our analysis assumes that future deployments of back-office systems also will be governed by the CVISN architecture and therefore will provide the necessary functionality.

This document also does not address privacy and information security, as these topics are covered under relevant Institute of Electrical and Electronics Engineers (IEEE) and Connected Vehicle Reference Information Architecture (CVRIA) standards to which U.S. DOT already adheres.

Finally, this document is "technology agnostic," meaning it does not prescribe or rely on a particular communication technology or medium. At the time of this writing, 5.9 GHz Dedicated Short-Range Communications (DSRC) is specifically designated and set aside for ITS applications; however, there is no reason other technologies such as cellular communication could not be used provided they meet the appropriate technical and performance requirements.

The structure of this document includes the following sections:

- Section 2 describes the methodology used in this report and introduces the background material;
- Section 3 describes the SRI functionality and its relationship with the Connected Vehicle Reference Implementation Architecture (CVRIA);
- Section 4 shows how the SRI could be supported within the CVRIA architecture and discusses elements that are missing when comparing the FMCSA requirements with the CVRIA functionality; and
- Section 5 discusses the performance requirements that are likely to be needed in order to verify that SRI will operate inside a Connected Vehicle environment.

2.0 Methodology

For the purpose of this analysis, the Connected Vehicle Program and its associated standards, functionality, and architecture were considered to be defined in the following foundational documents:

- Connected Vehicle Reference Implementation Architecture[1];
- Connected Vehicle Standards[2];
- SRI ConOps,[3] System Requirements,[4] and System Design[5];
- AASHTO's Connected Vehicle Footprint Analysis[6]; and
- National Highway Traffic Safety Administration (NHTSA) Interoperability Issues for Commercial Vehicle Safety Applications.[7]

In addition to these documents, the FMCSA SRI User Requirements were used as a resource for this assessment. Note that these User Requirements are unpublished since they were the product of a series of user needs interviews with FMCSA stakeholders that were conducted as part of the SAE J2735 standards development. Each of these sources is detailed below, with the exception of the FMCSA SRI User Requirements, since they are unpublished.

1 U.S. Department of Transportation, 'Connected Vehicle Reference Implementation Architecture,' http://www.iteris.com/cvria/. Accessed September 8, 2014.

2 Three standards were used in this assessment. They are: SAE J2735, 'Dedicated Short-Range Communications (DSRC) Message Set Dictionary™,' http://standards.sae.org/j2735_200911/; SAE J3067, 'Candidate Improvements to Dedicated Short-Range Communications (DSRC) Message Set Dictionary [SAE J2735] Using Systems Engineering Methods,' http://standards.sae.org/j3067_201408/; and SAE J2945, 'Dedicated Short-Range Communications (DSRC) Minimum Performance Requirements™,' http://standards.sae.org/wip/j2945/.

3 U.S. Department of Transportation, Smart Roadside Initiative Concept of Operations, May 2012.

4 U.S. Department of Transportation, Smart Roadside Initiative System Requirements Specifications, October 16, 2012.

5 U.S. Department of Transportation, Smart Roadside Initiative System Design Document, draft dated February 2013.

6 U.S. Department of Transportation, National Connected Vehicle Field Infrastructure Footprint Analysis Deployment Concepts, September 20, 2013. Available at http://stsmo.transportation.org/Documents/Deployment_Concepts.pdf. Accessed September 8, 2014.

7 National Highway Traffic Safety Administration, Interoperability Issues for Commercial Vehicle Safety Applications, September 2012. Available at http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2012/811674.pdf. Accessed September 8, 2014.

2.1 Data Sources

Connected Vehicle Reference Implementation Architecture

The current Connected Vehicle Reference Implementation Architecture (CVRIA), provides a framework describing the various institutional entities and organizations and the systems they will implement to deploy the overall Connected Vehicle environment. The CVRIA has four viewpoints to describe the architecture, including:

- **Enterprise—**Describes the relationships between organizations and the roles those organizations play within the Connected Vehicle environment;
- **Functional—**Describes abstract functional elements (processes) and their logical interactions (data flows) that satisfy the system requirements;
- **Physical—**Describes physical objects (systems and devices) and the application objects within the physical objects as well as the high-level information interfaces between those physical objects; and
- **Communications—**Describes the layered sets of communications protocols that are required to support communications among the physical objects that participate in the connected vehicle environment.

CVRIA has been developed to define the overall Connected Vehicle environment based on connected vehicle applications, and provides interface information needed for standards development analysis. The CVRIA provides a template for the deployment of Connected Vehicle applications, including SRI. Mapping the SRI effort to the CVRIA allows the SRI development to adhere to an architectural set of standards and to provide connectivity to a wide range of other ITS developments. Using the CVRIA also allows the definitions of physical objects and their connectivity and functional requirements to conform to the other parallel developments.

Connected Vehicle Standards

This analysis used the current published version of the SAE J2735 standard together with the candidate system engineering version, which currently is being renamed as SAE J3067. The third standard that was used for this analysis was SAE J2945, which provides the first working draft of performance requirements for the basic safety message. The use of J3067 is important as the published version of J2735 does not address the data elements and processes associated with commercial vehicle operations. Currently, J3067 is being published as an information report. It is assumed that the requirements developed for commercial vehicles as part of the J3067 will be eventually incorporated into the published standard. The requirements of commercial vehicles in J3067 were developed with significant input from Federal Motor Carrier Safety Administration (FMCSA), National Highway Traffic Safety Administration (NHTSA), U.S. DOT, and Volvo North America, which provided a trucking manufacturing perspective.

SRI ConOps, System Requirements, and System Design

The SRI Concept of Operations (ConOps) development and prototype is one of U.S. DOT's several research projects related to the usage of Connected Vehicles across the nation, the goal being to define a framework that will provide connectivity between commercial vehicles, fleet operators, enforcement personnel, and other State agencies and institutions involved with commercial vehicle operations. This concept of operations describes a set of operational scenarios, including the identification of commercial vehicles with a unique ID; making information available to the correct institution concerning the truck's safe and legal operation; and providing information on truck parking facilities in real time. The SRI system requirements specification describes a prototype to deliver the capabilities required for wireless roadside inspections, electronic screening with virtual weigh stations, a universal commercial vehicle identifier, and truck parking systems.

The SRI System Design Document (SDD) provides a basic prototype architecture that connects vehicles and roadside systems to two back-office systems over a communication network that supports the data flow needed to meet the SRI concept. The design goals for the new prototype include new capabilities such as providing mainline mobile enforcement compliance; verifying the use of common protocols and communication standards; demonstrating interoperable applications and verifying the speeds and performance requirements needed for data exchange. As noted in the task 3.1 memo associated with this project, some of the SRI functionalities associated with the SDD currently are not being implemented as part of the prototype effort. The two major SRI applications not being covered by the SRI ConOps and current Leidos test program include Wireless Roadside Inspection and Universal Driver ID.

AASHTO's Connected Vehicle Footprint Analysis

The *National Connected Vehicle Field Infrastructure Footprint Analysis Deployment Concepts*, one of several products of AASHTO's Footprint Analysis for U.S. DOT, describes a set of scenarios illustrating how State and local agencies might deploy Connected Vehicle technology and applications. The scenarios build upon the prior Applications Analysis and the Deployment Concepts developed as part of the Connected Vehicle Infrastructure Footprint Analysis. The convergence of these scenarios into an emerging national Connected Vehicle footprint will be the subject of the next activity in the Footprint Analysis. The deployment scenarios themselves describe the context and value proposition for Connected Vehicle infrastructure deployment; the system elements and steps by which deployment might proceed; funding strategies and other potential agency impacts; and some key challenges and limitations to deployment. Commercial Vehicle and Freight Systems was one of the individual scenarios investigated.

NHTSA Interoperability Issues for Commercial Vehicle Safety Applications

This document brings up a series of issues associated with the coding or lack thereof of some parameters in the SAE J2735 standard. The list of issues described by the various respondents, although important, is not of particular specific concern to the SRI program. The physical aspects of DSRC blockage; antenna issues such as multipath and ground nulls may be less important because trucks being monitored are often in the right-hand lane on freeways. Issues such as trailer length that have not been included into the basic safety message are of critical concern for safety applications but will not have an impact on SRI. Several of the other issues are institutional in nature and although important cannot be addressed here.

2.2 Methodology

Background

Work for the SRI Gap Analysis related to how SRI might function in a future Connected Vehicle environment started with the AASHTO Footprint Analysis that describes the conceptual level at which SRI will operate within the Connected Vehicle architecture. These concepts involve the installation of DSRC radios at the roadside and at key truck facilities, such as parking facilities, weigh stations, and tolling facilities. The DSRC equipment would form a roadside system that is connected with other appropriate equipment, such as weigh-in-motion (WIM) technology and connections to backhaul systems to support specific operational scenarios. The concept involves a string of facilities that will provide WIM information, e-screening services, and roadside inspections. These concepts were incorporated into the various SRI operational flow diagrams developed by Cambridge Systematics for task 2 of this project.

Methodology Steps

The following steps describe the methodology that was used to develop this report:

- The flow diagrams from task 2 (referenced above) were compared to the SRI diagrams that have been developed as part of the CVRIA architecture and modifications were made using the input from SAE J2735 and its associated standards;
- The FMCSA user needs were compared against the CVRIA and SRI approaches;
- The details of the data frames and data elements associated with enabling these processes were compared;
- The performance requirements were then studied to determine an estimate of the viability of the processes in terms of timing; and
- Appropriate conclusions and recommendations were developed based on what was learned in the above steps.

3.0 Architecture Analysis

This section draws connections between the SRI system as defined by the ConOps and system design documents and the CVRIA architecture and the current state-of-the-practice documentation that was prepared in task 2 of this project.[8] The physical viewpoint for SRI in CVRIA is described by two diagrams as discussed below.

Figure 3-1 illustrates the CVRIA architecture physical view for vehicle credentialing. The figure shows the back-office operations on the left side, the central column shows operations that occur on the roadside (both manual and electronic), and the right-hand side indicates the commercial vehicle equipment and the commercial driver.

Figure 3-2 illustrates the safety screening process with a similar layout. These two figures provide a physical view of the equipment, users, and the information flows between them. The CVRIA figures are configured to reflect a fully equipped Connected Vehicle system. That is, they reflect an end-state where SRI is assumed to be heading in a fairly distant future. The following section indicates the equipment and operations assumed in the CVRIA.

Note that not all of the data items in figures 3-1 and 3-2 are necessarily defined in the CVRIA and/or SAE J3067. The SAE standards do cover what occurs between the commercial motor vehicle (CMV) and the roadside equipment (RSE), but messages between the RSE and some back-office system are out of SAE's scope. The CVRIA, for its part, only states that there is supposed to be a message between the RSE and some central system, but it doesn't give technical specifics like message frequency, content, length, how many times it should attempt to send the message before giving up, etc. Such details would need to be formalized prior to large-scale deployment of SRI technologies. However, it should be noted that a "one-size-fits-all" approach may be difficult since system specifications and standards vary by State. As noted above, the CVISN architecture is envisioned to provide the necessary framework to guide the implementation of interfaces between roadside systems (e.g., mainline screening, virtual weigh stations) and back-office systems that contain the safety and credential information required to support enforcement activities.

The following list of definitions is from the CVRIA descriptions of the information flows from the physical view of vehicle credentialing. These definitions cover only the information that is flowing to and from the vehicle.[9]

- **freight equipment information—**Container trailer, or chassis information regarding identity, type, location, brake wear data, mileage, seal number, seal type, door open/close status, chassis bare/covered status, tethered/untethered status, temperature, humidity, power, battery levels, and bill of lading/information regarding the cargo/content.

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8 State of the Practice—Advanced Roadside Technologies for Commercial Vehicle Safety, February 2014.

9 Information flows are not capitalized here so they are consistent with the diagram.

- **electronic screening request—**Request for identification data to support electronic screening.
- **host commercial vehicle status—**Information provided to the Connected Vehicle on-board equipment from other systems on the Commercial Vehicle Platform.
- **CVO pass/pull-in message—**This flow represents the visual or auditory interface with ITS equipment containing a message sent to commercial vehicle driver indicating whether to bypass or requesting pull-in to inspection/verification stop along with inspection results (e.g., LED indicator on transponder or variable message sign).
- **CVO driver initialization—**This flow represents the tactile or auditory interface with ITS equipment containing the commercial vehicle driver and vehicle information. This flow contains inquiries to the commercial vehicle managing system, interaction with on-board equipment, including setup, configuration, and initiation of self-tests, and entry of carrier, driver, vehicle, and route information.
- **pass/pull-in—**Command to commercial vehicle to pull into or bypass inspection station.
- **unique identifiers—**Unique identifiers for the motor carrier, driver, and vehicle.
- **screening event record—**The results of a commercial vehicle screening transaction.
- **on-board safety data—**Safety-related data points collected by sensors on board the truck. This may include items like brake status, tire pressure, etc.
- **tag data—**Unique identifier for an in-vehicle transponder unit used for roadside screening.

In the CVRIA approach defined in the figures below, the data from the vehicle for credentialing includes the tech data, such as the freight equipment and the on-board safety data; this is essentially the same as the returning vehicle information in the safety screening approach in the second figure. The most efficient mechanism for interrogating commercial vehicle status is for the roadside equipment or the central administration center to make a request to the vehicle for all available information and for this to be returned to the requester and back-office systems which can then parse the data and distribute it according to the needs of the applications. This is the approach that is taken in the SAE J3067 dialogue descriptions shown in section 5.0.

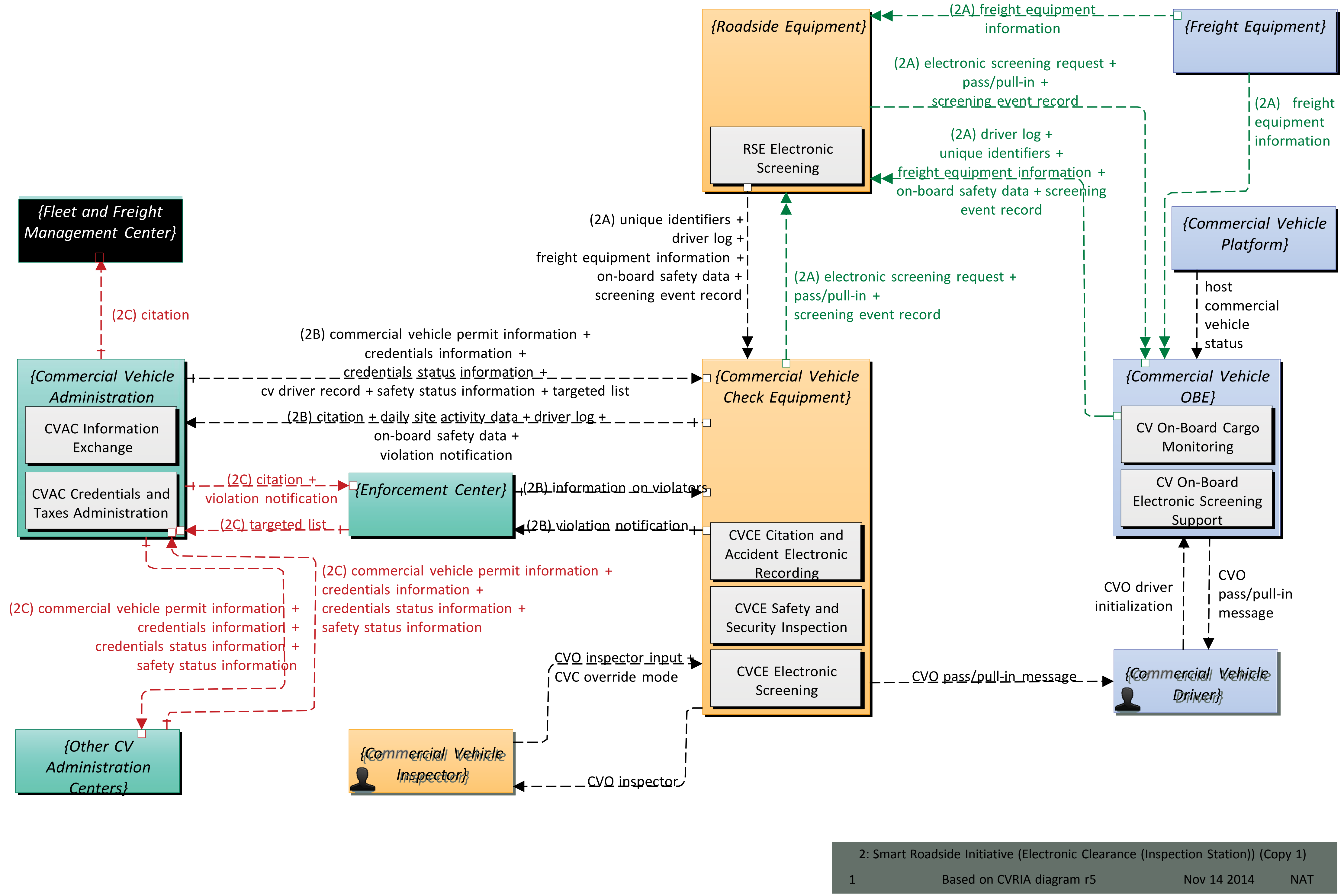

Figure 3-1. Flowchart. CVRIA physical view of vehicle credentialing
(Source: Connected Vehicle Reference Implementation Architecture)

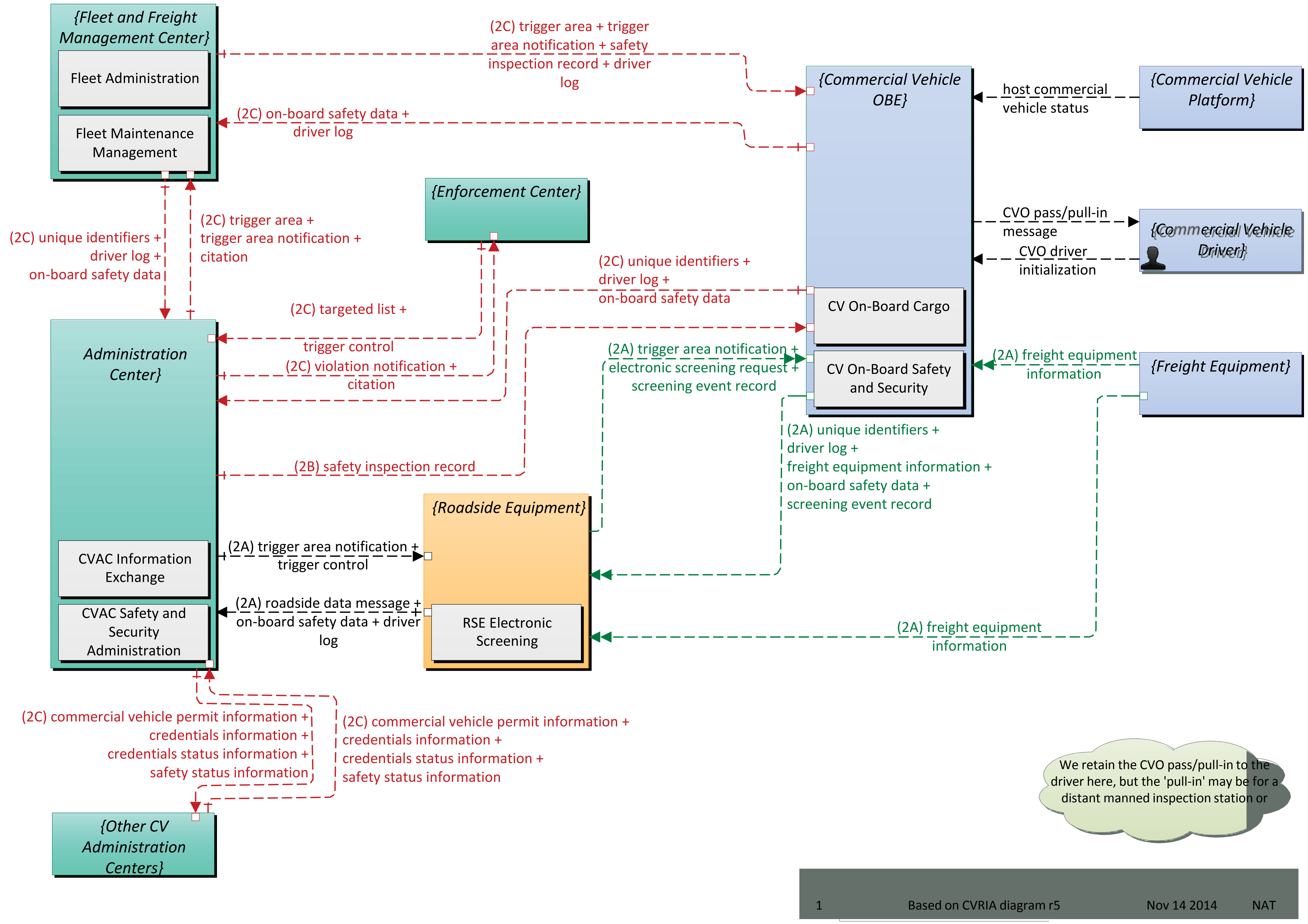

Figure 3-2. Flowchart. CVRIA physical view of safety screening
(Source: Connected Vehicle Reference Implementation Architecture)

3.1 SRI Functionality

There currently are multiple interpretations on how SRI can be formulated. AASHTO has a Footprint Analysis that provides a conceptual view. The SRI ConOps and SDD from Leidos provide more information and details of operation. Elements of the CVRIA also document how select SRI functionality (e.g., safety screening) could function. The Cambridge Systematics Memorandum Documenting SRI Prototype Functionality (prepared for task 3.1 of this Gap Analysis project) provides a view of how SRI will operate. The SAE J3067 document provides a precise definition of the data elements and data flow dialogs required when connecting with the commercial vehicle.

There also is much overlap and redundancy in the naming conventions concerning equipment and information flow. In trying to take all of these sources into account, our study team developed figure 3-3, which illustrates the SRI operational flow for mainline screening. The various steps in this diagram are discussed in their relationship to the CVRIA architecture, the FMCSA user needs, and the standards. This diagram is conceptual and provides one specific example of how the processing may be done.

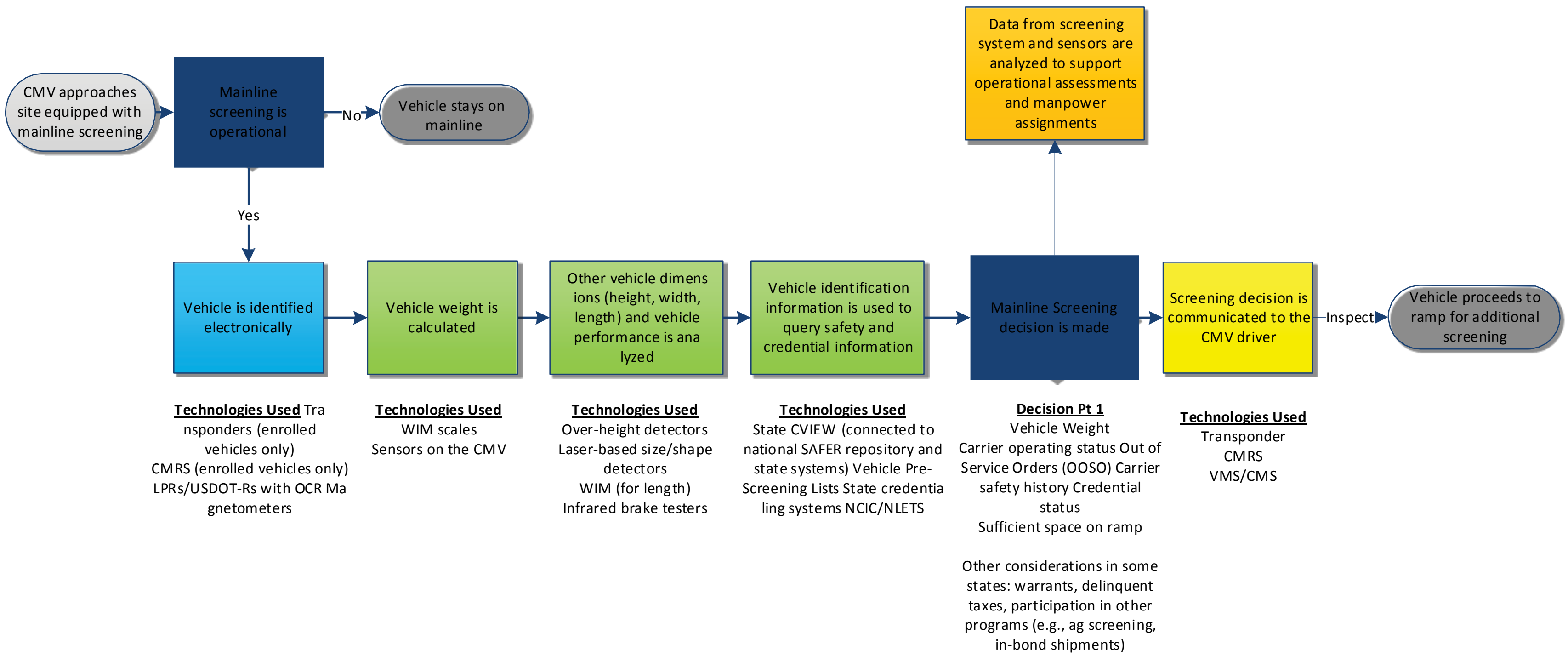

Figure 3-3. Flowchart. SRI operational concept for mainline electronic screening
(Source: Cambridge Systematics, Inc.)

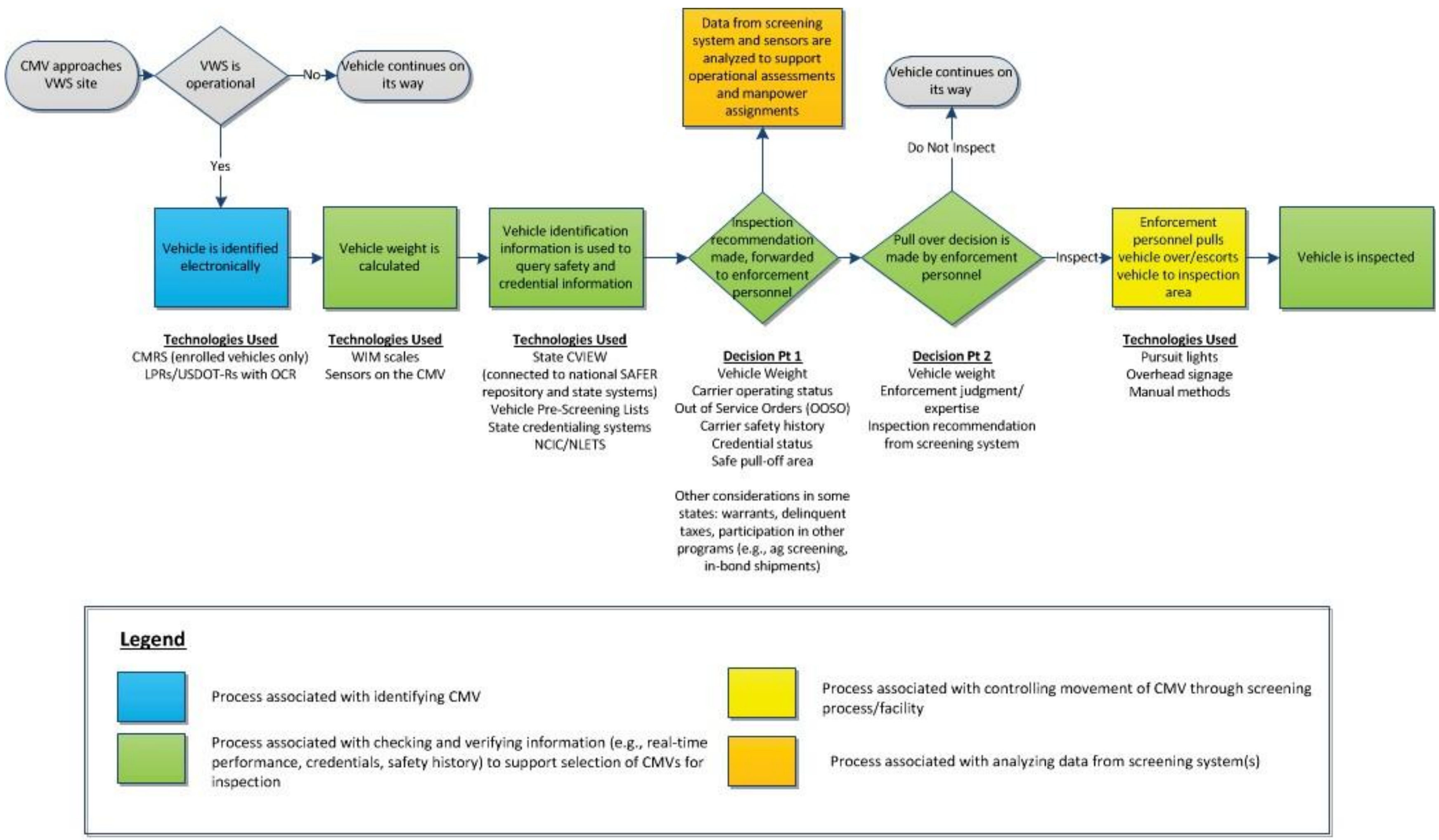

Figure 3-4. Flowchart. SRI operational concept for mainline electronic screening
(Source: Cambridge Systematics, Inc.)

Using the SRI operational flows (figures 3-3 and 3-4) as the point of reference, the following discussion describes how the information will flow to and from the vehicle in a manner that intends to meet the goals of the SRI and its wide range of stakeholders. The following range of processes assumes a layout of equipment as illustrated in the AASHTO Footprint Analysis and illustrated in figure 3-4. In this layout there is a linear collection of roadside equipment to support the Connected Vehicle Processes. These include a WIM system, which would be closely followed by a DSRC roadside unit that can interrogate the truck being weighed. Although there are other possible communication options, such as cellular, these have inherent technical difficulties such as inability currently to broadcast messages and architectural difficulties. Hence this report focuses on the use of 5.9 GHz DSRC.

Figure 3-4 is illustrative and shows separation between multiple roadside units. In practice it may be more efficient to combine some functions into one roadside location. For example, if the truck were to provide its own weight data then the WIM location would not be required. When configuring a SRI site it should be considered that the messages in the Connected Vehicle environment are not specific to applications. Although the authors of applications and architectures often describe the data transfers relating to a specific application, in practice this is not efficient and is typically not done during an implementation unless there are other reasons a commercial vehicle data request will be responded to by the on-board equipment (OBE) in the vehicle with all known data. The receiving applications can parse out the parts of the message they need for their particular purpose.

From the SRI perspective this means that the credentialing and safety application data and other applications will use different parts of the same message. This approach is efficient from a communication perspective; it also allows the message to expand readily when additional systems and newer technologies become available.

Prior to the CMV approaching a SRI site it will be necessary for the driver's identification to be present and electronically available within the vehicle. A unique vehicle code/identifier also will need to be kept electronically within the vehicle. The AASHTO deployment concept requires truck and driver credentials to be transmitted. It is assumed that the power unit weight and dimensions and other pertinent data have been entered into the vehicle's On-Board Equipment (OBE) during its installation or at the outset of a trip.

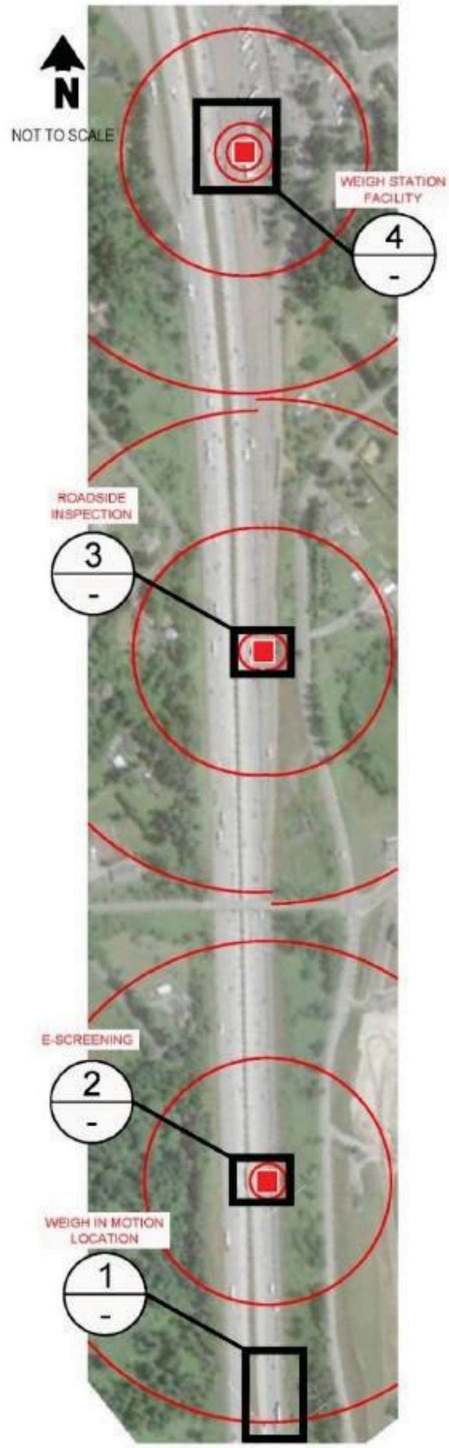

Figure 3-5. Graphic. Illustrative roadside configuration
(Source: AASHTO, *National Connected Vehicle Field Infrastructure Footprint Analysis, Deployment Concepts*. September 20, 2013.)

When a commercial vehicle approaches a SRI roadside installation the initial communication would be the advertisement message indicating what services were currently active at the SRI site (known as a WAVE service announcement). When the OBE in the vehicle receives an announcement that requires data it will typically send all known information. This can include the freight equipment information, tag data, on-board safety information, and a screening event record. In the SAE J3067 it is referred to as commercialVehicleData. The precise contents of commercialVehicleData are contained in appendix B. In a fully configured CV system there are likely to be three differing dialogs that are discussed in more detail later and are shown in the appendices. These three dialogs are:

- **(Roadside) Exchange Previous Commercial Vehicle Screening Results Dialog—**provides the information downloaded into the vehicle at the upstream SRI site.
- **(Site) Exchange Commercial Vehicle Credentials Dialog—**includes the transactions associated with this SRI site.
- **(Roadside) Exchange Commercial Vehicle Screening Results Dialog—**where the current data is downloaded into the vehicle for use at the next SRI site.

Some configurations may enable all of these dialogs from one roadside unit. However, more complex layouts will need to have multiple roadside units in order to direct the truck into a weigh station.

Applications such as e-screening and credentialing will be able to use the same data retrieved from the commercial vehicle. If the use of these applications will result in a decision to pull over a specific vehicle then there needs to be sufficient distance for the truck to safely exit the traffic stream. This may be greater than the range of the DSRC unit. Thus, the locations for each of the message deliveries need to be carefully considered when laying out a SRI site. In addition, in order to deliver the results dialog back to the vehicle this may necessitate the DSRC unit downstream from any inspection locations.

Thus with regard to the messages in exchanging of data the SRI would appear to be able to support this principal functionality. However, there are data elements specified in the CVRIA which include such items as status of the seals on trailers, length of trailers, and others that are not supported in the current standard. Should monitoring of these types of truck data be required, then additional system design and standard development will be needed.

The back-office applications associated with credentialing and safety data for use of the select/check/verify functionality described in the Cambridge Systematics report[10] can function at the messaging level as described above; however, currently there is no automated system that connects trucks to the commercial vehicle administration center as defined in the CVRIA architecture at the physical level as shown in figure 3-1.[11]

For the SRI process to utilize the functionality of Connected Vehicles there will be a need to revise the back-office component of the architecture in such a manner as to accommodate the requirements of individual State processes and procedures. For example, if the virtual weigh stations as outlined in the State of the Practice report are to be used then connectivity is required to a range of Federal and/or

[10] State of the Practice—Advanced Roadside Technologies For Commercial Vehicle Safety, February 2014.

[11] The connection in figure 3-1 refers to a theoretical side area wireless connection between the truck OBE and the commercial vehicle administration center.

State systems, such as Commercial Vehicle Information Exchange Window (CVIEW) and SAFER. Some States have elected to expand the data available in this CVIEW to include intrastate vehicle credentials thereby making this intrastate data available for screening purposes of the roadside. There are many potential combinations for back-office configurations that can provide the necessary requirements for a SRI deployment. These are likely to be different between States since the individual States currently have their own configurations and institutional and legal frameworks. It is likely that the introduction of Connected Vehicles will cause each State to design and implement its own solution. These different configurations are beyond the scope of this report but should be guided by the CVISN architecture.

FMCSA also currently is working on the Wireless Roadside Inspection (WRI) concept to provide real-time identification of commercial vehicles drivers and carriers in addition to information on the condition of the vehicle. Some of these concepts such as driver logs, axle weight, gross vehicle weight, brake status, etc., have been incorporated into the data frames and data elements of SAE J3067. However, this level of detail is not accommodated within current CVISN architectures at the State level.

The Connected Vehicle processes associated with mainline screening should follow the steps defined in SAE J3067. There are three dialogs here. The first relates to the exchange of commercial vehicle information, the second refers to providing the results of the first dialog back to the commercial vehicle, and the third dialog refers to a downstream roadside requesting the data collected upstream. This requirement which is embodied in the data element commercialScreeningResults was included in the draft standard at the request of U.S. DOT FMCSA staff.

3.2 Mainline Screening and Virtual Weigh Station Processes

The process outlined here is illustrated in figures 3-3 and 3-4. The dialog for the exchange of commercial vehicle messages to support mainline screening and virtual weigh station functionality consists primarily of two messages, the commercialVehicleRequest[12] message and the commercialVehicleData message. A third message, commercialVehicleClearance, is used to provide instructions to the commercial motor vehicle.

The exchanges are predicated on both the commercial vehicle and the roadside unit (RSU) at the roadside check station (which may be a fixed station or a mobile station) being in transmission range of each other, and that the driver and owner of the commercial vehicle has opted in. While the roadside check station is in operation, the RSU shall continuously advertise its support for freight management messages. A commercial motor vehicle, upon receiving the WSA or serviceAdvertisementMsg shall respond with commercialVehicleData message. The commercialVehicleData transmitted shall minimally contain the commercial motor vehicle's unique vehicle identification number. An application may include other data elements in the initial commercialVehicleData message as well. Upon receiving the commercialVehicleData message from the commercial vehicle, the roadside check station should process the information provided and determine if additional information is needed from the commercial vehicle.

[12] These naming conventions conform with the SAE J3067 nomenclature.

For example, the roadside check station may transmit a commercialVehicleRequest message to the commercial vehicle, with the target field set to the commercial vehicle's vehicle identification number, requesting additional information. Information that may be requested include additional information about the vehicle, driver identification, cargo data, trailer data, the duty logs of the driver(s), or the results of a previous screening event. The commercialVehicleRequest message also may contain valid area information such that the request for information is only valid if the commercial vehicle is within the intended geographical area or traveling in the intended direction. If the commercial vehicle is not within the valid area or traveling in the designated direction, it may ignore the request for additional information. Otherwise, the commercial vehicle will transmit a new commercialVehicleData message with the information requested.

If the roadside check station determines that no additional information is needed, it can then transmit a commercialVehicleClearance message with instructions to the commercial vehicle (by including the commercial vehicle's vehicle identification number). Those instructions may contain the location and name of a roadside check station for the commercial vehicle to pull into, or it may instruct the commercial vehicle to bypass the roadside check station.

When the commercial vehicle receives the commercialVehicleClearance message, it should respond to the RSU with a commercialVehicleAcknowledgment message. Note: A commercial vehicle should assume that if it does not receive a commercialVehicleClearance message from the RSU, the vehicle should pull into the roadside check station unless it receives some other indication that it does not have to.

The dialogs specific to the sharing of commercial vehicle information are contained in appendix A. These dialogs define the sequence of events and message exchanges between a RSU and a connected commercial motorized vehicle (CMV). The dialogs for commercial vehicle information exchanges consist of a series of requests and responses between the RSU and connected CMV. Note that for these dialogs, if a response is not received by the transmitting connected device, the transmitting connected device shall periodically retransmit a message for a fixed period of time until a valid response is received *or* an amount of time has elapsed since the first message was transmitted. The interval between transmissions and the period of time that the transmitting connected device will continue to transmit is defined in the performance requirements outlined in section 4.

The key to this process is the "commercialVehicle Data" message that includes all the detail associated with vehicle positioning, movement, vehicle and driver identification, heading, hazmat, shipper, etc. A detailed list of these messages and data elements is contained in appendix B. This message contains all the current information about the truck that can be used by multiple applications. The information includes position, vehicle, and driver ID and information concerning trailers. Both credentialing and safety inspections will be using this data message for their own applications.

3.3 Commercial Vehicle Parking

The SRI system requirements document includes the requirement to provide information regarding the availability of truck parking spaces at legal parking facilities. SAE J2735 contains a traveler information message (TIM) which is more than adequate to provide this information.

The traveler information message (TIM) makes use of the International Traveler Information Systems[13] (ITIS) encoding system to send well-known phrases, but allows limited text for local place names. The complete set of ITIS codes can be found in Volume Two of the SAE J2540 Standard. This is a set of nearly 1,500 items which are used to encode common events and list items in ITS. The implementation of commercial vehicle parking information should be relatively simple and can be performed at any suitably equipped roadside equipment. It does not necessarily have to be associated either physically or geographically with other SRI systems used for safety and credentialing. From a truck operation perspective it will be much more desirable to make use of the TIM as there likely will be many more locations where the DSRC equipment is available. In addition to the ITIS codes that can designate a parking spot, text can be used to send latitude, longitude, and elevation information should the vehicle's receiver wish to use it.

The CVRIA also covers truck parking under the Freight-Specific Dynamic Travel Planning application package. This application would include an electronic monitoring capability at truck parking facilities to monitor and update parking space availability in real time, and potentially support payment systems. An infrastructure-to-vehicle (I2V) link would permit electronic fee collection and disseminate space availability information to truck drivers and more broadly to ITS operational centers.[14]

It is likely to be logistically very difficult to provide parking advisory information that is sufficiently current at long distances from the parking facility. Although the number of available spaces is known they will diminish as drivers get towards the end of their working day. Truck drivers working days tend to avoid peak hour congestion as many of them are paid by the mile and working hours must be taken when congestion is minimal. This results in many drivers wishing to park at similar times. Therefore, the ability to provide parking information closer to the parking facilities will be desirable. It is therefore recommended that the parking requirement be expanded to cover all locations that are suitably located, including those from SRI sites.

[13] SAE J2540-2—ITIS Phrase Lists (International Traveler Information Systems), Revision 3, Adopted May 2005—and its successors.

[14] http://www.iteris.com/cvria/html/applications/app32.html#tab-3.

4.0 Comparison of SRI to CVRIA

4.1 SRI Functionality

Our team analyzed the ability of the CVRIA to support SRI both in terms of the previously identified SRI Concept of Operations (ConOps), as well as the SRI functionality that was identified as part of the SRI State of the Practice report (task 2) of this project.

The SRI ConOps[15] defines 14 user needs. Table 4-1 compares these user needs to the CVRIA architecture and associated standards. As shown in table 4-1, the SRI user needs are substantially met by the proposed Connected Vehicle capability, standard messages, and operational processes. Areas of concern include the ability to determine who the driver is in multiple-driver trucks and the need for a back-office architecture that supports differing State architectural configurations. These issues can be further explored in task 4 (Gap Analysis) of this project, if U.S. DOT elects to proceed with this effort.

The State of the Practice report developed as part of this project documented mainline screening and virtual weigh station operations as illustrated in figures 3-3 and 3-4. Table 4-2 compares these functional elements to the CVRIA and provides commentary on whether they can be supported by the Connected Vehicle architecture. As seen in table 4-2, the bulk of the current operations can be accommodated by the Connected Vehicle architecture.

The ability of the CVRIA to address the commercial vehicle parking component of SRI is addressed in section 3.5.

Table 4-1. Comparison of SRI user needs to CVRIA

ConOps User Needs	CVRIA Capability
UN01—The system must be able to identify CMV power units uniquely.	Yes
UN02—The system must support the exchange of data between the CMV and the roadside without requiring the vehicle to stop.	Yes
UN03—The system able must provide the ability to pass data collected from CMV to external systems.	Yes; this would require the enterprise and physical links as defined in the CVRIA. However, the architecture of these links would be on a State-by-State basis since they have different connections and requirements.

[15] Concept of Operations (ConOps) for Smart Roadside Initiative, May 21, 2012, Paul Belella, et al.

ConOps User Needs	CVRIA Capability
UN04—The system must provide the ability to receive data from external systems.	Yes. Since these data links exist in some State operations these would be possible
UN05—The system must provide the ability to efficiently and effectively exchange data between external systems and local users at the roadside or in the CMV.	Yes, although using cellular is an option it could be problematic due to lack of broadcasts capability.
UN06—The system must provide protection against unauthorized access to and use of data.	Unknown. The DSRC Connected Vehicle messaging applies security, other communication options would need to adopt some security standard.
UN07—The system must allow a vehicle operator to interact with it in a safe manner during vehicle operation.	Yes, the operator must do no more than current practice. The design incorporates no action by the driver beyond pulling in to a weigh station if asked.
UN08—The system must be consistent with the ITS National Architecture and standards.	Yes, as it is based on the SAE standards.
UN09—The system must facilitate the integration of data from multiple sources into one or more cohesive, reusable datasets.	Unknown. An implementation detail that may require additional standards. For example, since trucks now operate across various State and country boundaries this increases the need for national systems.
UN010—The system must include information capture and processing functionality that meets specific CMV operational needs (e.g., commercial vehicle parking and enforcement screening applications).	Yes/Unknown. Note that commercial vehicle parking is addressed below; however, on-board data currently is limited and some screening applications may not be possible until this is enhanced—the specific CMV functions will vary by State.
UN011—The system must provide applications data in sufficient time to support decision-making at the roadside.	Yes, up to highway operating speeds—see the performance requirements section.
UN012—The system must be able to identify, uniquely and reliably, which CMV driver is actually operating a CMV.	CVRIA does not provide enough detail in its information flow definition to know if this would be addressed. Additionally, to accomplish this would require additional technology for commercial vehicles with multiple drivers.
UN013—The system must be able to support the identification of trailing equipment pulled by uniquely identifiable CMV power units.	Yes, CVRIA does include data from freight equipment that includes the power units. However, from a standards perspective, although the data sets support trailer data currently there is no mechanism by which the length and weight of trailers is transmitted to the tractor.
UN014—The system must operate in a V2X cooperative systems environment.	Yes, CVRIA describes that V2X environment.

Table 4-2. SRI operational flow compared to CVRIA

SRI Functions	CVRIA Functionality
	Upstream data sent from roadside to vehicle (Process 2.3.3.5: Carry-out Commercial Vehicle Roadside Inspection).
Vehicle identified electronically.	Commercial Vehicle Check Equipment (Physical Object).
Vehicle weight is calculated.	Process 2.3.4: Detect and Classify Commercial Vehicles and Freight Equipment.
Other vehicle characteristics such as height, width, and length are required.	All sensor data is sent in one message to the roadside unit. This is the commercialVehicleData defined in appendix B (CVCE Electronic Screening Application Object).
Vehicle ID is used to query safety and credentialing information.	Process 2.3.4: Detect and Classify Commercial Vehicles and Freight Equipment.
Mainline screening decision is made.	Process Screening Transactions (CVCE Electronic Screening Application Object).
Data is sent to State systems.	Administer Commercial Vehicle Roadside Credentials Database (CVCE Electronic Screening, Citation and Accident Electronic Recording, and Safety and Security Inspection Application Objects).
Pull over for screening decision sent back to the driver.	Process Screening Transactions (CVCE Electronic Screening Application Object).
Inspection may be performed at the roadside.	Carry-out Commercial Vehicle Roadside Inspection.
	Data summary sent back to the vehicle (Process 2.3.3.5: Carry-out Commercial Vehicle Roadside Inspection).

4.2 An Initial CVRIA-Based SRI Architecture

The CVRIA SRI architecture diagrams shown in figures 3-1 and 3-2 have been combined (see figure 4-1) to provide the basis for an all-encompassing SRI architecture that supports mainline screening and virtual weigh station operations. The large boxes shown in figure 4-1 represent physical objects that are defined in the architecture's database. The small boxes within the large boxes represent application objects that indicate which applications at those locations are using the data flows that are indicated by the arrows.

The specific definitions of these objects are available from the CVRIA reference site.[16] For example, the upper left physical object is the Fleet and Freight Management Center which contains two application objects: Fleet Administration and Fleet Maintenance Management. The data flows between the various objects and applications are indicated by the arrows, which also are defined in detail on the CVRIA reference site. This diagram does not include the parking information as this has been addressed in a separate section above (and is addressed in a separate CVRIA application).

[16] http://www.iteris.com/cvria/html/applications/app94.html#tab-3.

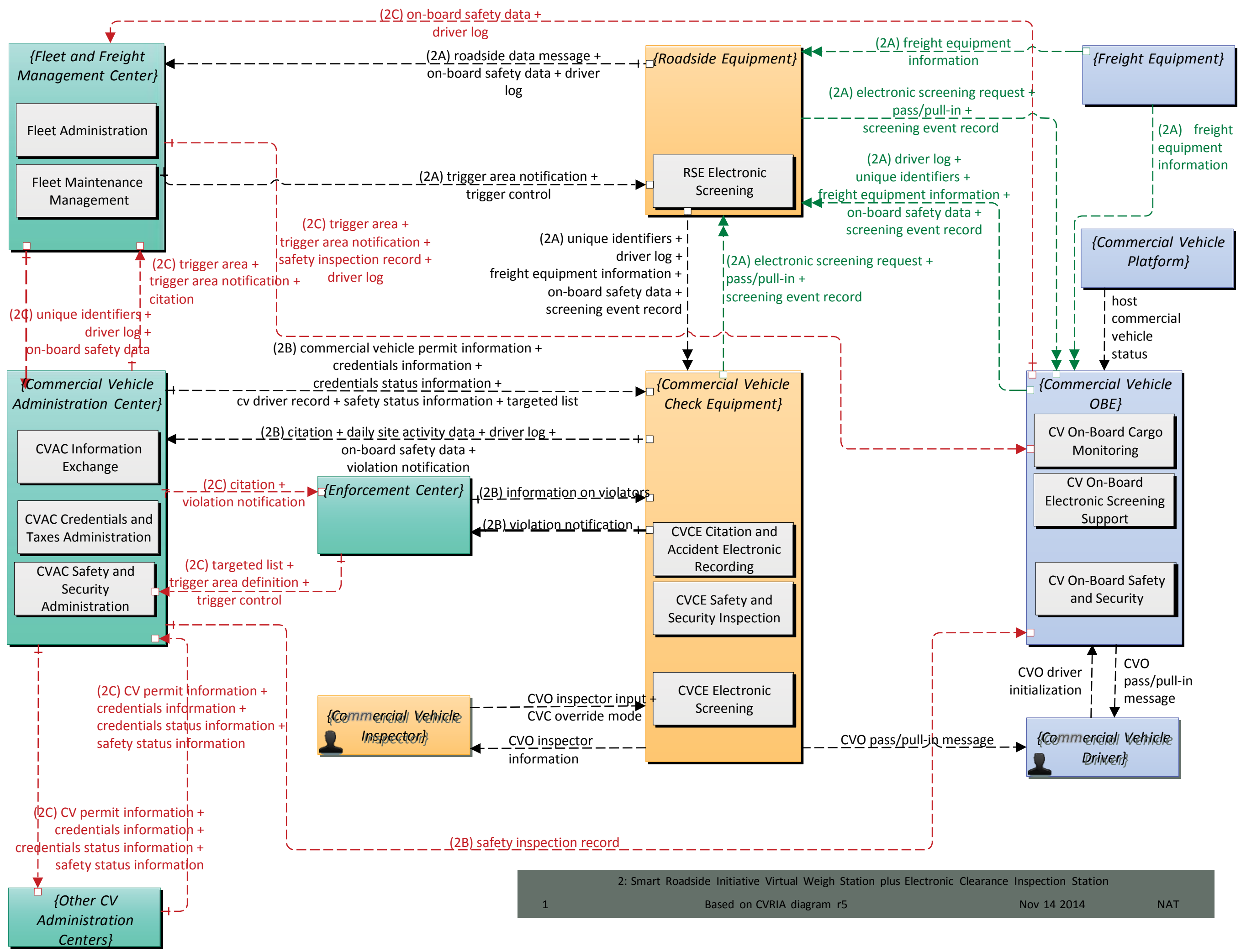

Figure 4-1. Flowchart. SRI architecture
(Source: FreeAhead Inc. based on CVRIA)

5.0 Performance Requirements

The performance requirements will need to specify transmission rates and message latency for all of the elements within a specific dialog. Both DSRC and cellular systems are proposed for use in SRI. The use of cellular is of concern since the dialogs between the roadside in the vehicle have not been clearly identified. Current cellular systems do not support broadcast mechanisms and therefore a SRI-equipped site would not be able to advertise its presence. In order for data to be transferred from a commercial vehicle to an SRI the call would initiate in the vehicle. Therefore, a geofencing application in the vehicle is necessary to determine when a commercial vehicle is approaching an SRI site. Following this call, a connection over the same readers and Internet systems would be made to an SRI site. Following this, the dialog for data transfer would occur. There is an inherent latency inside cellular systems that would mean that such a transfer would need to be initiated a reasonable distance upstream of the SRI site. This process is made more complex by the requirement of FMCSA to provide upstream SRI results to the downstream sites which necessitate three separate dialogs, see figure 5-1.

The use of DSRC is likely to be a more feasible option for this interchange and the performance requirements for DSRC are investigated below.

SAE J3067 has developed performance requirements. A series of typical requirements were developed by the various DSRC subcommittees. These have not been developed during testing but are a result of engineering judgment based on what little information was available from the initial pilot proof of concept study in Detroit. That project did not include commercial vehicles nor does the currently published SAE J2735 specifically address commercial vehicles. The times and intervals included here are at best preliminary and will need to be verified in the field. However, developers will need some starting point in order to develop the software and these caveats need to be borne in mind when using this data.

It also should be considered that the overall requirement of the U.S. DOT is to increase by an order of magnitude the rate at which commercial vehicle inspections and credentialing is performed. In order to achieve this it is likely that these operations will take place at many more locations than currently are used. Therefore, the future will probably not be limited to existing designated enforcement facilities but could likely utilize other locations, such as toll booths, where the roadside hardware could receive the required communication and power. The implication of being able to locate SRI sites in multiple locations will require the implementer to ensure that the performance requirements can be met. For example where traffic is slow, such as toll booths or border crossings, there is unlikely to be an issue as there is sufficient time to transfer the data. However, locations where the traffic is very heavy and at high speed (for example, leaving a port and moving on to a freeway) there may be a requirement for multiple RSUs to support the data exchanges.

5.1 Transmission Rate Requirements—Commercial Vehicle

The detailed transmission rate requirements for an RSU to exchange commercial vehicle information with connected commercial motor vehicles (CMV) follows.[17]

- **Maximum Broadcast Rate—**An RSU shall broadcast the same commercial vehicle message to connected commercial motor vehicles no more than once per 100 milliseconds.
- **Default Broadcast Rate—**If the specification does not indicate a default transmission rate, the suggested default transmission rate for an RSU to broadcast the same commercial vehicle message to connected commercial motor vehicles shall be once per second.
- **Maximum Response Time—**A commercial connected vehicle shall process all commercial vehicle messages from a RSU within the maximum response time. If the commercial vehicle responds to the message, the response time is measured as the time between the receiving of the last byte of the request and the transmission of the first byte of the response. If the specification does not indicate the response time, the suggested default maximum response time shall be two seconds.
- **Default Retransmission Rate (RSU)—**If a RSU transmits a message to a specific CMV, and does not receive an expected response or acknowledgment from the CMV, the RSU shall retransmit the same message to the CMV at a fixed time interval until it receives a valid response or acknowledgment, or an amount of time has elapsed since the RSU first transmitted the message to the CMV. The retransmission is needed in case the initial transmission of the message by the RSU is not properly received by connected CMV, or the response from the connected CMV is not properly received by the RSU. Improper reception can be due to channel noise or bandwidth issues. Without this retransmission, the dialog for the sharing of commercial vehicle information between the RSU and the connected CMV cannot be completed. If the specification does not indicate the time interval between retransmission, the suggested retransmission time shall be three seconds. A three-second interval between transmissions provides the CMV with sufficient time to respond to the RSU's message and for the RSU to receive the response.
- **Default Retransmission Rate (CMV)—**If the CMV transmits a message to the RSU, and does not receive an expected response or acknowledgment from the RSU, the CMV shall transmit the same message to the CMV at a fixed time interval until it receives a valid response or acknowledgment; or an amount of time has elapsed since the CMV first transmitted the message to the RSU. The retransmission is needed in case the initial transmission of the message by the connected CMV is not properly received by RSU, or the response from the RSU is not properly received by the connected CMV. Improper reception can be due to channel noise or bandwidth issues. Without this retransmission, the dialog for the sharing of commercial vehicle information between the RSU and the connected CMV cannot be completed. If the specification does not indicate the time interval between retransmission, the

[17] Data from SAE J3069 derived from the various SAE DSRC subcommittees.

suggested retransmission time shall be three seconds. A three-second interval between transmissions provides the RSU with sufficient time to respond to the connected CMV's message and for the CMV to receive the response.

- **Maximum Retransmission Time—**If one of the connected devices transmits a message to the other connected device, and does not receive an expected response or acknowledgment from the receiving connected device, the transmitting connected device shall retransmit the same message to that specific receiving connected device until it receives a valid response or acknowledgment, or an amount of time has elapsed since the RSU first transmitted the message to the CMV. If the specification does not specify a maximum transmission time, the connected device shall retransmit a message to another connected device for no more than 15 seconds. This maximum time interval is needed so that a CMV or an RSU does not continuously retransmit a message indefinitely, adding to any congestion on the communications channel. The 15 seconds provide sufficient time for a connected CMV traveling at the expected 95th percentile speed would be within the transmission zone for at least three or four transmissions.

5.2 Performance Impact

Using an estimate for the range of the DSRC transmitter of 300 meters and assuming a commercial vehicle speed of 40 meters per second this leaves the window of about 15 seconds for the entire transaction. The most complex interaction that could occur would include:

- Commercial vehicle receiving the advertisement of services;
- Commercial vehicle uploading its upstream information to the RSU;
- Roadside equipment reviewing this information and determining that it is satisfactory;
- Roadside equipment then creating a new batch of data to transmit to the commercial vehicle for later download at the next site; and
- Commercial vehicle receiving this new data and continuing on without stopping.

Interactions that involve instructing the commercial vehicle to pull over would be shorter. Therefore, the process defined above would be most appropriate for determining the performance requirements. The following assumptions have been made:

- For geographical locations that include a pull-over facility, all the interactions need to be made sufficiently far upstream to enable the commercial vehicle to safely receive the pull-over message and enter the facility;
- The timing of the actual transmissions can be considered very short and are not considered in the development of performance requirements;
- It is assumed that at least two transmissions from the vehicle are needed to initiate communications. This is to allow for transmission errors or occlusion by other vehicles;
- The 300-meter assumed valid range is available in both directions; and
- The system should be designed to accommodate high-speed traffic operating on both sides of an Interstate.

In order to develop the performance requirements, the longest likely dialogue that could occur is illustrated in figure 5-1. In this example, data from an upstream SRI site is on board the vehicle as it comes into range of the system. The upstream data is then transferred to the roadside. The commercial vehicle system then is interrogated by the roadside unit. The previous data is then inspected to determine whether or not more information is needed. In this example the current data is then retrieved from the vehicle. This is processed by the roadside and infrastructure systems. Then a recommendation is sent to the vehicle to bypass or pull over. In this example the vehicle bypasses and then the roadside equipment sends its data to the vehicle ready to be downloaded at the next RSU it encounters.

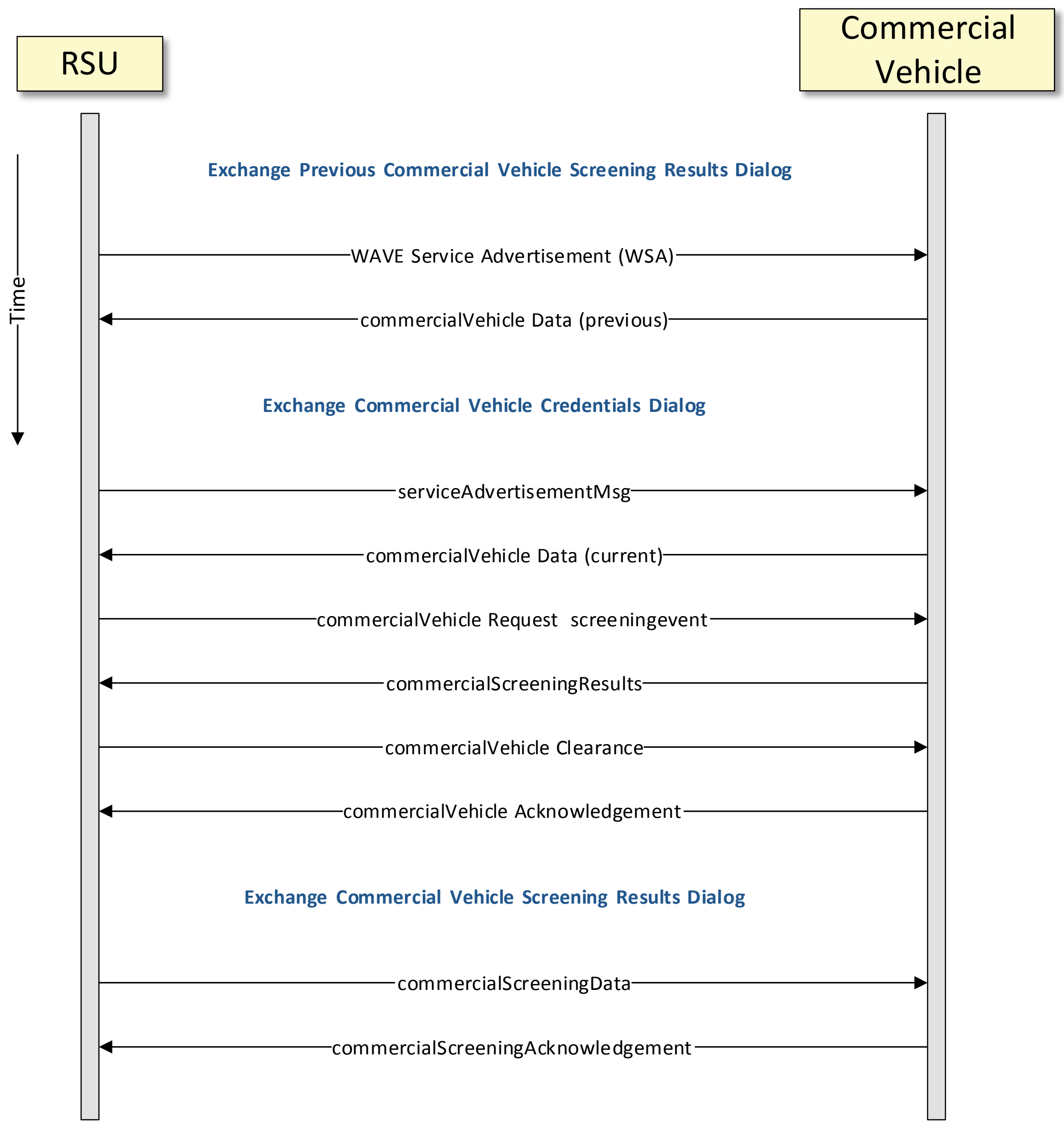

Figure 5-1. Diagram. Longest possible dialog
(Source: FreeAhead Inc.)

The biggest impact on the performance requirements will occur on the infrastructure side. In the vehicle, the data can be kept current and ready to be transmitted with a very low latency. However, on the infrastructure side, equipment will need to determine the vehicle ID and then begin the relevant processing such as gathering records from databases and from the local hardware, etc. Typically inquiries will be made using the Safety and Fitness Electronic Records (SAFER).[18] Requests for information from the system maintainers indicate that when using this SAFER web service the response times between one and three seconds. However, some States query their own local database that is populated with the same information. This is likely to be quicker and more reliable as it is less dependent on the communications infrastructure.

It is likely that the same techniques that are used in tolling systems may be needed here. In the tolling case, the relevant data is kept in memory in the device of the roadside in order that a fast response can be achieved (in order to determine if the account of the toll being read is satisfactory). Distributed databases are a common mechanism in software system design and should be a relatively easy mechanism to ensure that State databases are regularly and frequently kept synchronized with the central systems.

Using the J3067 default transmission rates and the longest dialog figure shown above, it is possible to roughly estimate how long any transmission is likely to be. Assuming that the default broadcast rate for other advertising services is once per second, only 50 percent go through, and the vehicle takes no time to prepare a message because it is always ready, then transmitting the previous commercial screening results could take about 2.5 to 3 seconds. Assuming that the RSU immediately asks for the current exchange commercial vehicle credentials then this message should return within approximately 1 second, then the roadside and infrastructure has 2 seconds to send a screening event. Allowing 1 second for the vehicle to respond, the results would be back at the roadside in perhaps 5 to 6 seconds. Then allowing 1 second for the roadside to send a clearance message and for the vehicle to respond brings the total time for delivery of credentials and an action message to the vehicle to about 7 seconds. The exchange of commercial vehicle screening results dialog would take the same amount of time as the initial request, i.e., perhaps 2.5 seconds. Thus the total screening process may be done in approximately 10 seconds. This calculation is obviously very rough and would need to be verified in the field. It also has sufficient contingency for the entire process to happen twice which might be desirable from a design perspective. During this transaction most of time is spent with the roadside equipment making back-office inquiries and waiting to retransmit. This means a SRI site could utilize dual DSRC transmitters in order to increase the capture rate in both directions if this were desired.

[18] Safety and Fitness Electronic Records (SAFER) Safer Software version 9.3 Interface Control Document.

6.0 Conclusions

The following conclusions have been developed from conducting this study. Where appropriate, some associated recommendations are proffered for U.S. DOT's consideration:

- In developing this assessment, it was clear that both the existing CVRIA and SRI documentation had limitations in terms of defining the concept of what a connected vehicle SRI architecture would look like. Given this challenge, the study team's most important product of this effort was to develop a specific CVRIA SRI architecture diagram, which is shown in figure 6-1 below. Going forward, this provides a key input to U.S. DOT, the CVRIA team, and the Leidos SRI testing team concerning the basis for an all-encompassing SRI architecture that supports mainline screening and virtual weigh station operations.
- The current status of the Connected Vehicle design (based on the standards and the CVRIA documentation) can meet the needs of the existing SRI system functionality. However, there are data elements in the commercial vehicle data bus that are known to be not yet available. This circumstance also applies to the automobile fleet. Some new functionality would need to be added to the roadside and central applications to function most efficiently.
- Currently, the CVRIA architecture and associated documentation does not provide specific information on the data types as defined in the standards. Any implementer of the CVRIA architecture when developing a SRI system would need to map the data flows of CVRIA to the standards.
- In regards to Truck Parking systems SRI functionality, it is reasonable to assume that since Traveler Information Messages (TIM) can be used to transmit commercial vehicle parking that these tests could be considered to be fulfilled in the ongoing southeast Michigan projects where the TIM has been successfully demonstrated. In order to conduct such tests it is recommended that a detailed design be developed based around the CVRIA architecture and the SAE J3067 standard.
- The mainline screening and virtual weigh station applications should be implemented to conform as much as possible to the Safety and Fitness Electronic Records (SAFER) interface portion of the CVISN architecture because this architecture already provides a proven means for accessing safety and credentialing information in support of roadside enforcement activities.
- More visibility is required into the development on the SAE J3067 standard. Current information on the status and timing of this standards process is not definitive, and it is recommended that U.S. DOT and its CVRIA contractor establish a technical presence on the SAE standards committee that is moving forward with this process.
- The biggest impact on the performance requirements will occur on the infrastructure side. In the vehicle, the data can be kept current and ready to be transmitted with a very low latency. However, on the infrastructure side, equipment will need to determine the vehicle ID and then begin the relevant processing such as gathering records from databases and from the local hardware, etc.

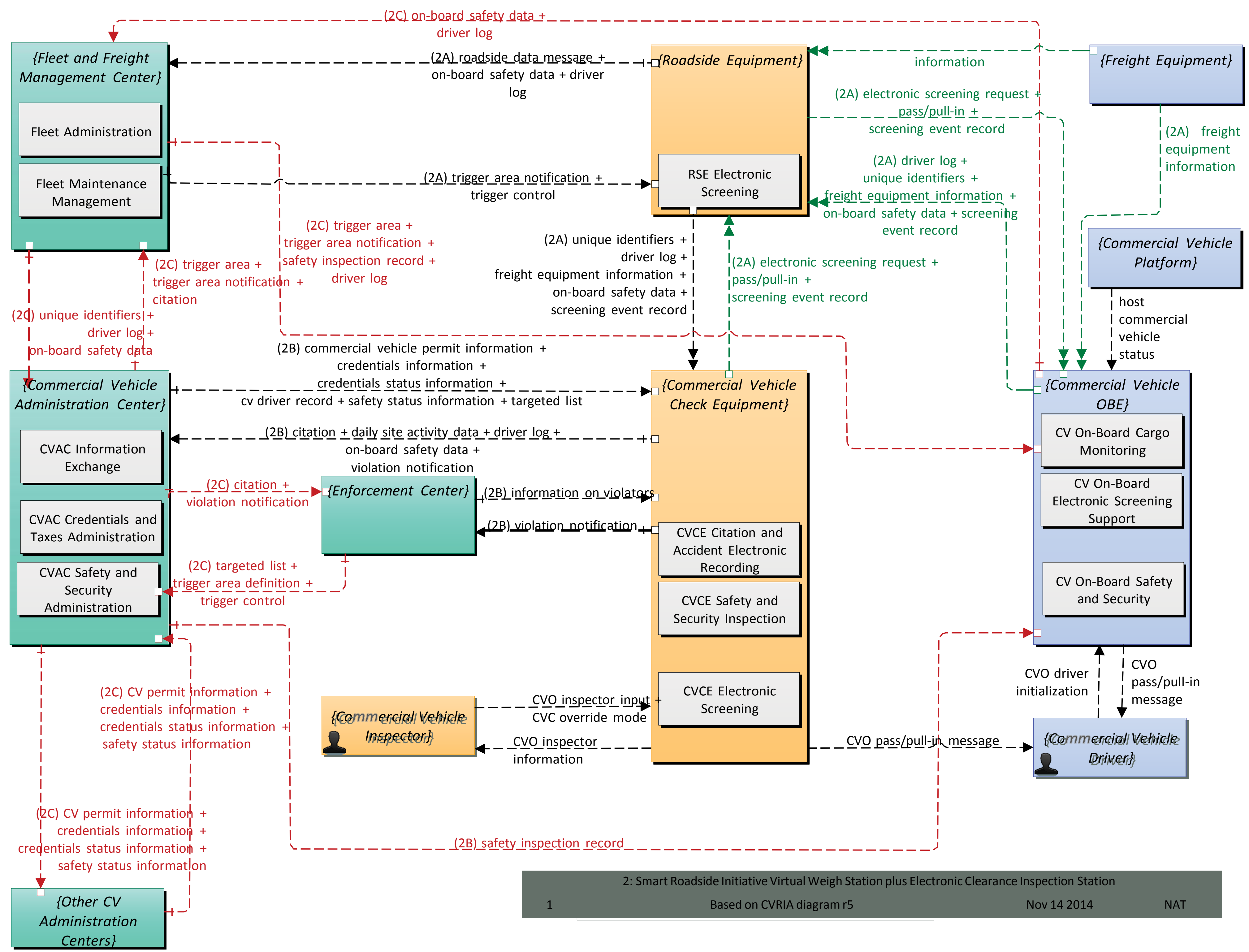

Figure 6-1. Flowchart. SRI architecture
(Source: FreeAhead Inc. based on CVRIA)

APPENDIX A. Commercial Vehicle Message Dialogs

The nomenclature used in this appendix is from the system engineering version of J2735 which was developed using the ISO 14817 standard. This requires all objects to have a unique name and start with lowercase letter for example commercialVehicleRequest. ISO 14817:2002 specifies the framework, formats, and procedures used to define information exchanges within the Intelligent Transport System/Transport Information and Control Systems (ITS/TICS) sector.

Exchange Commercial Vehicle Credentials Dialog

The standardized dialog for an RSU to exchange credentialing information with a connected CMV shall be as follows:

1. (Precondition) Both the connected CMV and the RSU transmitting commercialVehicleRequest messages shall be in transmission range of each other.
2. (Precondition) The connected CMV shall identify itself as a commercial vehicle.
3. (Precondition) The driver of the connected CMV has opted in to provide its vehicle identification information.
4. If the RSU is using IEEE 1609 for communications, go to step 5, otherwise go to step 7.
5. The RSU shall broadcast a WAVE Service Advertisement (WSA) indicating its support for receiving freight fleet management messages (with a PSID as determined by IEEE Standard 1609), and the service channel (SCH) the connected CMV shall transmit its response on the channel directed.
6. The connected CMV, upon receiving the WSA message indicating support for freight fleet management messages, shall transmit a commercialVehicleData message on the SCH indicated by the RSU. Go to step 9.
7. The RSU shall broadcast a serviceAdvertisementMsg message, indicating its support for receiving freight fleet management messages.
8. The connected CMV, upon receiving a message indicating support for freight fleet management messages, shall transmit a commercialVehicleData message to the RSU.
9. The RSU, upon receiving a commercialVehicleData message from a connected CMV, shall respond with either a commercialVehicleRequest message, requesting additional information from the connected CMV, or a commercialVehicleClearance message, providing instructions to the connected CMV. The commercialVehicleRequest message and the commercialVehicleClearance message are addressed to a specific connected CMV, by setting the target field equal to the connected CMV's VIN.
10. The connected CMV, upon receiving a commercialVehicleRequest message or a commercialVehicleClearance message from the RSU, shall check if the target field is equal to the connected CMV's VIN. If yes, continue to step 11, otherwise remain in step 10.
11. If the connected CMV receives a commercialVehicleClearance message, go to section 4.3.7.4, step 5.[19]

[19] Note reference denoted a 4.3.7.x refer to the Exchange Previous Commercial Vehicle Screening Results Dialog shown below.

12. The connected CMV, upon receiving a commercialVehicleRequest message from the RSU, shall check if the connected CMV is within the valid region (regions field) and is traveling in the designated direction (direction field). If yes, continue to step 13, otherwise exit the process.
13. The connected CMV shall transmit a commercialVehicleData message to the RSU:
    a. If the requestItem field in the commercialVehicleRequest message includes 'driveridentification (5)', the commercialVehicleData message shall include the contents of the drivers data frame.
    b. If the requestItem field in the commercialVehicleRequest message includes 'driverdutylog (4)', see section 4.3.7.3.
    c. If the requestItem field in the commercialVehicleRequest message includes 'trailerdata (3)', the commercialVehicleData message shall include the contents of the trailers data frame.
    d. If the requestItem field in the commercialVehicleRequest message includes 'cargodata (2)', the commercialVehicleData message shall include the contents of the currentTrip data frame.
    e. If the requestItem field in the commercialVehicleRequest message includes 'screeningevent (1)', see section 4.3.7.3.
14. Go to step 9.

After the completion of a roadside check, a connected CMV would like to receive and store the results of the roadside check so it may bypass similar roadside checks downstream. To accomplish this, the roadside check station needs to transmit the results of the screening event to the connected CMV. The connected CMV then confirms its receipt of the roadside check results.

The standardized dialog for exchanging the results of the commercial vehicle screening between an RSU and a connected CMV shall be as follows:

1. (Precondition) Both the connected CMV and the RSU transmitting commercialScreeningData messages shall be in transmission range of each other.
2. (Precondition) The connected CMV shall identify itself as a commercial vehicle.
3. (Precondition) The driver of the connected CMV has opted in to provide its vehicle identification information.
4. The RSU, upon completion of the roadside check, shall transmit a commercialScreeningData message to a connected CMV with the results of its screening.
5. The connected CMV, upon receiving a commercialScreeningData message from the RSU, shall check if the target is equal to the connected CMV's VIN. If yes, continue to step 6, otherwise remain in step 5.
6. The connected CMV shall transmit a commercialScreeningAcknowledgment message to the RSU, with the encounterCrc field equal to the crc field in the commercialScreeningData message it has just received.
7. The RSU, upon receiving a commercialScreeningAcknowledgment message from the connected CMV, shall check if the commercialScreeningAcknowledgment message is valid. A commercialScreeningAcknowledgment message is valid if the encounterCrc field is equal to the crc field in the commercialScreeningData message the RSU previously sent to the connected CMV. If the commercialScreeningAcknowledgment is valid, go to section 4.3.7.4. Otherwise, go to step 4.

Prior to arriving at a roadside check station, a commercial vehicle agency may request a connected CMV's previous screening results. If the commercial vehicle's screening results are in order, the commercial vehicle agency may elect to allow the connected CMV to bypass the roadside check station. This capability allows a roadside check station to only inspect those connected CMVs for which no data is available or whose screening results are suspect while allowing connected CMVs that have already been screened to bypass additional screening.

The standardized dialog for exchanging a connected CMV's previous screening results with an RSU shall be as follows:

1. (Precondition) Both the connected CMV and the RSU transmitting commercialVehicleRequest messages shall be in transmission range of each other.
2. (Precondition) The connected CMV shall identify itself as a commercial vehicle.
3. (Precondition) The driver of the connected CMV has opted in to provide its vehicle identification information.
4. If the RSU is using IEEE 1609 for communications, go to step 5, otherwise go to step 7.
5. The RSU shall broadcast a WAVE Service Advertisement (WSA) indicating its support for receiving freight fleet management messages (with a PSID as determined by IEEE Standard 1609), and the service channel (SCH) the connected CMV should transmit its commercial vehicle messages on the channel directed.
6. The connected CMV, upon receiving a WSA indicating support for freight fleet management messages, shall transmit a commercialVehicleData message on the SCH indicated by the RSU. Go to step 9.
7. The RSU shall broadcast a serviceAdvertisementMsg message, indicating its support for receiving freight fleet management messages.
8. The connected CMV, upon receiving a message indicating support for freight fleet management messages, shall transmit a commercialVehicleData message to the RSU.
9. The RSU, upon receiving a commercialVehicleData from a connected CMV, shall transmit a commercialVehicleRequest message to the connected CMV with the requestItem field to include 'screeningevent (1)'.
10. The connected CMV, upon receiving a commercialVehicleRequest message from the RSU, shall check if the target is equal to the connected CMV's VIN. If yes, continue to step 11, otherwise remain in step 10.
11. The connected CMV shall transmit a commercialScreeningResults message with the screening results from its previous screening events on its current run.

If the RSU receives a commercialScreeningResults from the connected CMV, go to section 4.3.7.4, otherwise remain in step 12.

The data elements in the above dialogs are defined below, note that much of the overhead and descriptive parts of the standards have been removed to make this more readable. Also the reader should be aware that the ISO 14817 standard used to develop J3067 requires the first letter of the data elements be lowercase. To obtain the full text of the candidate standard the reader is referred to SAE J3067.

APPENDIX B. Commercial Vehicle Messages and Data Elements from SAE J3067

commercialVehicleData

DEFINITION: “A data frame used by commercial motor vehicles to provide its credentialing and sensor measurement information. This data frame typically shall be contained within a dSRCMessage. This data frame contains a commercial vehicle’s identification information, its position, information about the trip and cargo, trailer data, and driver identification. If a commercial motor vehicle receives a request for a data element it does not understand or support, then the request for that item is simply ignored.”

{ j2735DataFrames 175 },—VehiclePositionMark
{ j2735DataFrames 73 },—LocationAccuracy
{ j2735DataFrames 167 },—VehicleLicenseInformation
{ j2735DataFrames 153 },—Trailers
{ j2735DataFrames 44 }—Drivers }

REFERENCED-DATA-ELEMENTS {
{ j2735DataElements 241 },—Vehicle-vin
{ j2735DataElements 242 },—Vehicle-vin-source
{ j2735DataElements 225 },—Vehicle-movement-per
{ j2735DataElements 213 },—Vehicle-heading
{ j2735DataElements 12 }—Cmv-current-trip-oer }

Note: Expressions such as { j2735DataFrames XXX } are part of the ISO standard requirement that each data element and data frame is required to have a unique number. These data frames include the following data elements:

vehicleLicenseInformation

DEFINITION: “A data frame that provides identification information about the motorized vehicle. This includes identification information about the vehicle itself, such as its vehicle identification number (VIN) and license plate number; and the owner of the vehicle, and the lessee, if applicable.”

REFERENCED-DATA-FRAMES {
{ j2735DataFrames 168 }—VehicleLicensePlate }

REFERENCED-DATA-ELEMENTS {
{ j2735DataElements 227 },—Vehicle-owner-oer
{ j2735DataElements 218 }—Vehicle-lessee-oer }

DATA-TYPE “
VehicleLicenseInformation::= SEQUENCE {
owner Vehicle-owner-oer,
licensePlate VehicleLicensePlate,
lessee Vehicle-lessee-oer,... } ”}

vehicleLicensePlate

DEFINITION: "A data frame providing information about a vehicle's license plate, including country and jurisdiction of issue, and the license plate number. Intended for commercial vehicles."

DESCRIPTIVE-NAME-CONTEXT {""}

DATA-CONCEPT-TYPE data-frame

REMARKS ""

STANDARD "SAE J2735"

REFERENCED-DATA-ELEMENTS {
{ j2735DataElements 129 }—Registration-oer }

DATA-TYPE "
VehicleLicensePlate::= Registration-oer "}

vehicleDriver

DEFINITION: "A data frame containing identifying information for a driver. Typically used only for commercial vehicle drivers who opt in, this information is used for driver safety inspections and for security purposes."

REFERENCED-DATA-FRAMES {
{ j2735DataFrames 36 }—DriverLicense }

REFERENCED-DATA-ELEMENTS {
{ j2735DataElements 113 },—Person-name-last
{ j2735DataElements 112 },—Person-name-first
{ j2735DataElements 31 },—Driver-pin
{ j2735DataElements 111 }—Person-date-of-birth-oer }

The SAE J3067 standard also includes the following Commercial Vehicle Class Data Elements. As can be seen these elements include an encounter that provides the opportunity for both safety screening and credentialing. Such an approach in the standard allows for more flexibility as technology changes and new data elements are available on the vehicle.

cmv-current-trip-oer—This data element is the OER encoding of the cmvTrip data frame. This data element is used by commercial motor vehicles to provide its bill of lading and hazardous materials information.

cmv-hazmat-identifier—The CFR Title 49 hazardous material code for any observed or detected hazardous materials (reference 49 CFR 172.336 and 172.101 Hazardous Materials Table).

cmv-instructions—This data element indicates if a commercial vehicle is cleared to bypass or if the commercial vehicle is required to pull into a roadside check station. Typically used with commercial vehicle operations.

cmv-placard-identifier—This data element is the numerical code representing the U.S. DOT placard code that is observed on the commercial motor vehicle.

cmvEncounter—Class Data Elements.

cmvEncounter-identifier—This data element is an identifier assigned to each commercial vehicle encounter. An encounter may include screening events or safety inspections. It is discretion of the individual commercial vehicle agencies on how this identifier is assigned.

cmvEncounter-location-description—This data element is a text string providing a description of the roadside check station. This description may include directions to the roadside check station. Typically, this data element is associated with commercial vehicle operations.

cmvEncounter-station—This data element is a text string name of the roadside check station.

cmvEncounter-type—This data element identifies the types of roadside checks that were performed during the encounter. The type(s) is determined by what data was electronically requested from the commercial vehicle. The types of roadside checks include vehicle identification, driver identification, trailer data, cargo data, and driver duty logs.

CmvRequest—Class Data Elements. This data element represents the default allowed direction of travel on a street lane or path described by shape points. This data element is used to indicate the direction of travel along the series of offset points defined for all shape point sets, unless specified otherwise. Valid values are forward (direction of travel follows node ordering), reverse (direction of travel is the reverse of node ordering), or both (direction of travel allowed in both directions).

cmvRequest-default-width—A data element representing the default width of a geographic area in units of 1 centimeter. This width is used as part of the definition of geographic regions where the commercial vehicle request is valid for, unless specified otherwise.

cmvRequest-encounter-identifier—This data element is the identifier assigned to the commercial vehicle encounter for which an RSU is requesting information for, from a commercial motor vehicle. An encounter includes screening events, safety inspections, or other roadside checks.

cmvRequest-item—This data element is used to specify what item (or items) are being requested from a connected commercial motor vehicle. The requested item is typically transmitted from a connected device to a commercial motor vehicle as part of commercial vehicle roadside checks.

```
DATA-TYPE
 CmvRequest-item::= BIT STRING {
 reserved0 (0),
 reserved1 (1),
 screeningevent (2),
 cargodata (3),
 trailerdata (4),
 driverdutylog (5),
 driveridentification (6),
 vehicleidentification 7) } (SIZE(8))
```

CmvScreening Class Data Elements

cmvScreeningAck-encounter-crc—A two-byte data element equal to the dSRCMessage-crc data element previously transmitted in the commercialScreeningData message. This data element is used as a check to confirm the receiving connected device has properly received the message, that is, the integrity of the message is intact.

cmvTrip-shipping-identifier—A data element containing the shipping document number or bill of lading number assigned by the carrier. This data element is typically used for commercial vehicle credentialing.

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