Concept of Operations for Virtual Weigh Station






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Concept of Operations for Virtual Weigh Station

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1.0 Introduction

1.1 STATEMENT OF PROBLEM

With commercial vehicle inspection resources stretched thin due to increasing traffic volumes, staffing cuts, and expansion of roles and activities, states are seeking new ways to monitor and enforce truck size and weight regulations. Limitations of fixed weigh station-based screening and enforcement activities (e.g., ability of overweight vehicles to use routes around the fixed sites to bypass enforcement resources) provide strong motivation for states to consider new approaches to roadside compliance verification and enforcement. These bypass routes are among many locations where violators are likely to travel that are monitored only by mobile enforcement officers whose presence may be sporadic and random. In many other locations, such as urban areas, a weigh station cannot be built due to environmental or cost reasons, but violators are likely to travel these roadways. A number of the "bad actors" purposely avoid detection. Many of these operators are habitual offenders.

Resources for roadside safety inspections are especially scarce. According to the United States Department of Transportation (USDOT), approximately 177 million truck weight inspections are conducted annually, versus only three million truck safety inspections.[1] Of these three million inspections, 73 percent result in violations, whereas only 0.29 percent of weight inspections result in violations. Overall, truck safety compliance is problematic, but the low percentage of weight violations belies the numbers of overweight commercial vehicles that travel on roadways not monitored by traditional enforcement operations.

In an effort to address these and other issues, states are deploying "virtual weigh stations." Compared to a traditional weigh station, a virtual weigh station "mimics" the capabilities of the weigh station but do not require continuous human staffing and can be deployed more cheaply than fixed sites. No fewer than 14 jurisdictions received Federal Commercial Vehicle Information Systems and Networks (CVISN) Deployment Grants in Fiscal Years 2006 – 2008 to deploy "virtual weigh stations." States also are using other Federal, or State, funds to deploy virtual weigh stations. An in-depth study conducted by the Federal Highway Administration (FHWA) in 2008 – 2009 documented the current State of the practice regarding "virtual weigh station" deployments and revealed a

[1] IntelliDrive℠ website, sponsored by the United States Department of Transportation, Research and Innovative Technology Administration, June 18, 2009.

wide range of capabilities and little consensus on what constitutes a virtual weigh station.[2]

In fact, the term "virtual weigh station" is ubiquitous and often is used to describe any deployment of roadside technologies that occurs away from a fixed inspection site. If virtual weigh stations are to become an integral element of states' commercial motor vehicle enforcement strategies – and indications are that they will – it is imperative that all stakeholders have a comparable understanding of the virtual weigh station concept.

1.2 SCOPE OF THIS DOCUMENT

This document describes the concept of operations (ConOps) for the virtual weigh station (VWS). The ConOps describes the goals, functions, key concepts, architecture, operational scenarios, operational policies, and impacts of virtual weigh stations. A summary of benefits and costs follows the ConOps description.

This ConOps will provide technical guidance to jurisdictions regarding their implementations of the virtual weigh station concept. The ConOps will be a tool that can be used to plan roadside programs, support states' funding requests, obtain buy-in from public and private stakeholders, and communicate information among State, Federal, and private sector parties.

Sections 4.0, 5.0, and 6.0 of this document describe the opportunities afforded by virtual weigh stations to address roadside compliance verification and enforcement challenges summarized above.

1.3 ORGANIZATION OF THIS DOCUMENT

This document contains six sections. The sections are the following:

1. **Section 1.0, Introduction –** Provides the context for developing a concept of operations for the virtual weigh station.
2. **Section 2.0, Current Situation –** Reviews current roadside enforcement operations and existing virtual weigh station deployments.
3. **Section 3.0, Motivation for Virtual Weigh Station –** Describes the challenges and needs underlying states' virtual weigh station deployments and the operations that will address the challenges.

[2] *State of the Practice of Roadside Technologies*, submitted by Cambridge Systematics to the Federal Highway Administration, May 2009, as part of the Truck Size and Weight Enforcement Technology Project.

4. **Section 4.0, Concept of Operations –** Presents the operational scenarios, information needs, and functionality associated with virtual weigh stations.
5. **Section 5.0, Summary of Benefits and Costs –** Relates the expected benefits and costs of deploying virtual weigh stations.
6. **Section 6.0, Conclusions –** Summarizes the enforcement improvements gained from virtual weigh stations, as well as limitations and next steps.

An **Appendix** also is included, which presents a list of acronyms used in this document.

2.0 Current Situation

2.1 BACKGROUND

Unstaffed and remotely monitored roadside enforcement facilities – commonly called virtual weigh stations – are deployed to address some of the deficiencies in states' traditional roadside enforcement programs. These facilities can expand the geographic scope and effectiveness of a State's truck size and weight enforcement program by monitoring and screening commercial vehicles on routes that bypass fixed inspection stations and on secondary roadways, as well as in heavily populated urban or geographically remote locations where it may be difficult to deploy traditional enforcement operations. Data from virtual weigh station sites also can effectively target enforcement resources on roadways where overweight trucks are known or are suspected to operate.

2.2 OVERVIEW OF FIXED ROADSIDE ENFORCEMENT OPERATIONS

Fixed weigh or inspection stations are the backbone of most states' truck size and weight enforcement programs. In many states, the majority of weight inspections are conducted at weigh stations. These facilities intercept commercial vehicles entering or passing through a State on major highways. Currently, approximately 680 weigh stations are in operation in the United States.[3] Customarily, signs on the highway direct commercial vehicles to pull into the stations where they are weighed by static scales to ensure that they are within Federal and State regulations. Both total gross weight and individual axle weights are measured and displayed to station operators. The primary purpose of these stations is to enforce truck weight regulations, in order to protect the infrastructure from excessive wear and tear caused by overweight trucks.

It is efficient to screen trucks for safety, credentials, and logbook violations at the same time they are weighed. At the static scale, the truck is checked for obvious safety problems and for proper credentials, including the driver's medical examination certificate and commercial driver license. In case of a problem, the truck is directed to an inspection area within the station for a closer examination. Some trucks may be selected for closer inspection in a random manner or because of the officer's experience with the carrier, in addition to visual clues seen by the officer. In many cases, officers will use identifying information on

[3] *2009 Rand McNally Motor Carriers' Road Atlas*, 2009. Massachusetts and New York are the only states that indicate there are no permanent weigh stations used in the State.

the truck to query safety and credentialing data repositories (e.g., State Commercial Vehicle Information Exchange Window [CVIEW], national Safety and Fitness Electronic Records [SAFER]) to determine if the carrier has a history of poor safety performance and/or to verify the current status of motor carrier and commercial vehicle credentials. For example, the USDOT or license plate number can be used in a manual or automated check of a carrier or vehicle database (e.g., CVIEW), yielding an Inspection Selection System (ISS) inspection value and recommendation or registration or tax payment status. The ISS is a decision-aid for commercial vehicle/driver inspections, which guides inspectors in selecting vehicles for inspection; the ISS value or score is based on a motor carrier's safety performance data.

The effectiveness of fixed weigh stations is affected by:

- Limited physical and processing capacity that can be regularly overwhelmed, resulting in commercial vehicles backing up onto the highway and requiring closure of the station so that public safety is not impacted by the lengthening queue;
- Limited geographic coverage (i.e., each facility supports enforcement monitoring over a limited portion of a roadway);
- Limited hours of operation, which largely are driven by availability of staffing and financial resources;
- Inability to deploy fixed sites in some areas (e.g., remote, urban) that are in need of commercial vehicle enforcement; and
- Expenses associated with the acquisition, development, operation, and maintenance of the sites.

These stations also can cause motor carrier delays that range from a few minutes to extended queue times for trucks waiting to be weighed. Unnecessary delays and prolonged transit times adversely impact a carrier's ability to bid competitively on delivery contracts.

In order to address some of these limitations, the vast majority of states currently support electronic screening at many of their fixed facilities. Electronic screening is the automated screening of vehicles that pass a roadside check station, determining whether further inspection or verification of credentials is required, and taking appropriate actions. Electronic screening requires a change in the traditional concept of pulling in every truck for weighing and inspection. In electronic screening, commercial vehicle traffic is sorted to distinguish between known or likely safe and legal vehicles and potential violators before they stop at an inspection facility. The intent of electronic screening is to allow safe and legal trucks to pass the station while enforcement resources are focused on high-risk carriers and vehicles. Mainline weigh-in-motion (WIM) is frequently used as part of an electronic screening system, providing real-time weight verification concurrent with automated safety and credentials verification for bypass

eligibility. Vehicles cleared for bypass are not generally directed to pull into the weigh station.

States with electronic screening have reported a reduction of 15 to 20 percent in the volume of truck traffic passing through weigh stations that are instrumented with the capability. The reduction is directly related to the level of participation in electronic screening by motor carriers. Clearly, the greater the participation of carriers in electronic screening programs, the less likely it is for queuing to close weigh stations and legal trucks to need to pull into weigh stations. The benefit to the carrier is the ability to travel past the weigh station without stopping. For the State, electronic screening allows enforcement resources to be focused on high-risk carriers and vehicles.

Electronic screening cannot address all of the limitations associated with fixed weigh stations. Even with electronic screening, noncompliant vehicles can attempt to bypass the enforcement station by using a route that goes around the site. Weigh stations also may have restricted and often predictable hours of operations. As a result, overweight trucks may travel when weigh stations are closed, at night, and on weekends. Electronic screening also does not address the costs and the physical space that are required to deploy a weigh station.

Because weigh stations often are bypassed or otherwise avoided by overweight trucks, significant effort is expended on compliant carriers, providing incentive for states to implement tools and methods to better target high-risk carriers and vehicles.

2.3 OVERVIEW OF MOBILE ROADSIDE ENFORCEMENT OPERATIONS

Mobile enforcement consists of enforcement activities that do not take place at fixed weigh or inspection stations. States' mobile enforcement programs usually encompass temporary roadside locations (e.g., rest areas, modified shoulders, abandoned weigh stations), roving patrols, or both. These activities typically are conducted on routes without fixed weigh stations, on secondary roadways, and in remote areas. Mobile enforcement allows states to expand their enforcement efforts away from the Interstate and major highways and onto secondary and smaller roads that are known bypass routes around fixed stations.

During mobile enforcement details, commercial vehicles are stopped and weighed on portable scales. States also may opt to conduct a safety inspection, and/or credentials verification based on random selection, visual clues, or experience (or inexperience) with a particular carrier. At the roadside, common visual clues are an appearance of being overweight and observed safety problems. Enforcement officers may stop a vehicle after an automated (using a laptop computer capable of accessing a database or the Internet) or radio check of the driver's license number, vehicle license plate number and/or vehicle identification number (VIN), or USDOT number. If a temporary roadside

location is being used, officers may attempt to stop all approaching trucks, depending on traffic conditions. Note that in some states, probable cause is required to stop a vehicle.

Compared to weigh stations, mobile weight enforcement operations process a smaller volume of trucks, although the percentage of violators is arguably higher. Similarly, most safety inspections are conducted at weigh stations (where it is a safe place to put a truck out-of-service), but indications are that the number of inspections is growing at mobile locations.

Incorporating WIM systems into mobile operations provides the State with the potential to weigh a greater number of trucks. WIM equipment can be installed in the pavement or it can be portable. Mobile teams can set up in vans and move equipment around as needed, or they can set up in the area of a permanently installed WIM system. Real-time WIM data can be viewed by roadside enforcement personnel on laptop computers, who visually identify the potential violators. Automatic identification of violators (relieving the need for manual visual recognition of suspect vehicles) is possible with the incorporation of advanced roadside-based technologies (e.g., license plate readers).

The importance of mobile operations in states' overall commercial vehicle enforcement programs is increasing as many states "deemphasize" weigh stations that are expensive to build and maintain. However, the effectiveness of mobile units is limited by the number of roadside personnel that can be deployed by a State. Furthermore, with dwindling resources, it is difficult for states to expand mobile enforcement coverage. Under such conditions, just as weigh stations equipped with electronic screening attempt to focus on high-risk operators, states are pursuing new ways to effectively target their resources on high-risk carriers, drivers, and vehicles during mobile operations.

2.4 OVERVIEW OF EXISTING VIRTUAL WEIGH STATION DEPLOYMENTS

At least 10 states across the United States have deployed a virtual weigh station to date. States deploy virtual weigh stations in order to enforce legal truck weights and to protect the State's investment in the infrastructure. These states' deployments vary in terms of their operational focus (e.g., screening commercial vehicles, supporting planning for the deployment of enforcement resources) and technologies used (e.g., WIM, license plate reader, USDOT number reader). These deployments are documented in a FHWA study of the state of the practice regarding virtual weigh station deployments.[4] What all of these deployments

[4] *State of the Practice of Roadside Technologies*, submitted by Cambridge Systematics to the Federal Highway Administration, May 2009, as part of the Truck Size and Weight Enforcement Technology Project.

have in common is a WIM system that supports real-time screening activities at locations that are unstaffed and away from weigh stations.

In Fiscal Years 2006 – 2008 a total of 14 jurisdictions received Federal CVISN Deployment Grants for virtual weigh station deployments (a few of these states have completed their deployments and are counted in the 10 states mentioned above). These states' virtual weigh station deployments may include – in addition to WIM scales or sensors – cameras, optical character recognition (OCR) technology, system electronics, screening software, system integration, and/or expanded communication networks to support the timely and secure transmission of data to users, as well as integration of safety data/screening algorithms into roadside operations.

Some states have deployed VWS technology as part of a mobile screening system in which an officer at the roadside with a laptop computer receives individual axle weights and gross vehicle weights that are wirelessly transmitted from the WIM device on the mainline that is being monitored to the mobile officer's laptop. The officer physically monitors the real-time WIM data on the laptop and visually identifies the trucks that are overweight according to the data received. The potentially overweight trucks are then intercepted for inspection after traveling past the WIM site. Having quantifiable performance measurements avoids stopping vehicles that are legal according to weight thresholds established by the State.

A few states have added a roadside digital camera system to the mobile screening system to facilitate the identification of suspect commercial vehicles. In these operations, an enforcement officer views the real-time WIM data linked with a vehicle photo on a laptop computer in the patrol vehicle located downstream of the WIM site. Multiple photos also may be displayed in thumbnail form so the officer can easily select from different views of the vehicle of interest. Suspect vehicles are identified on the laptop, facilitated by visual and/or sound alerts. In one scenario, the officer monitors the data and images and intercepts the violators. The same data and images may be viewed by enforcement personnel in a fixed facility. In a different scenario that is deployed by states, instead of an officer located downstream performing monitoring and weighing functions, personnel viewing the WIM data and images at a nearby weigh station will dispatch nearby enforcement units to intercept and weigh suspect vehicles identified on the monitor.

As part of the "2006 Commercial Motor Vehicle Size and Weight Enforcement in Europe" scan sponsored by FHWA in cooperation with the American Association of State Highway and Transportation Officials (AASHTO) and the National Cooperative Highway Research Program (NCHRP), the scan team observed the use of high-speed weigh-in-motion (HSWIM) and vehicle image capture using digital cameras as a common enforcement site layout. The COST (Cooperation in Science and Technology) 323 truck weight enforcement protocol used throughout Europe since the late 1990s, entitled WIM/VID, calls for WIM/visual identification capability for screening at the roadside. The

simultaneously captured picture of the motor vehicle and its associated axle and gross vehicle weight values are used immediately by enforcement officials who are preselecting certain trucks for more extensive inspections, or the data are processed and stored for further analysis and use at a later time.

This system configuration (i.e., "bundled" WIM and digital imaging functions) is not currently deployed in the United States; however, it is now readily available in North America. "Off-the-shelf" virtual weigh station technology packages including digital image capture coupled with HSWIM telemetry are offered by several vendors at this time.

Several states have deployed a license plate reader (LPR) or USDOT number reader to provide automatic vehicle identification (AVI). These technologies use a digital camera or cameras augmented with specialized OCR software to isolate and identify specific characters and numbers making up a license plate number and/or USDOT number. AVI relieves the need for any kind of manual visual recognition, whether it is based on direct observation of the vehicle itself or examining a photo of the vehicle.

The concepts of operations for basic and expanded virtual weigh stations are provided in Section 4.0.

3.0 Motivation for Virtual Weigh Station

3.1 ROADSIDE ENFORCEMENT CHALLENGES

The increasing numbers of commercial motor vehicles traveling on the nation's roadways is the preeminent challenge faced by enforcement personnel. At the same time, the enforcement workforce is not increasing to keep pace with the growing volumes; in many states, commercial vehicle enforcement personnel levels are less than their full complement. This disparity between truck volumes and enforcement staffing – which is expected to widen – makes it difficult for State governments to ensure the safe, secure, and legal movement of commercial vehicles.

FHWA and the Federal Motor Carrier Safety Administration (FMCSA) report the following dramatic statistics concerning the commercial motor vehicle industry:

- Commercial vehicles may move 100 percent more freight tonnage in 2035 compared to 2004, assuming moderate economic growth of three percent. The tonnage could total over 30 billion tons in 2035.
- To accommodate this increase in freight volume, commercial vehicle miles traveled (VMT) will need to increase. It is estimated that truck VMT will increase 60 percent from 2005 to 2020, approaching 100 billion miles annually.
- The large projected increases in truck VMT could result in a significant increase in the number of fatalities associated with large truck crashes.

In addition, this growth in truck VMT has the potential to increase the frequency between inspections of a commercial vehicle; increase congestion, delay, and the variability of transit times; increase freight transportation costs; degrade bridges and pavement more rapidly; and worsen air quality.

In this environment, states require new ways to work "smart." States are looking for systems that:

- Automatically process large numbers of commercial vehicles while delaying only those that pose a safety risk or exceed weight regulations;
- Expand the enforcement net to reach roadways and areas not adequately covered by existing enforcement operations while conserving enforcement resources; and
- Augment current enforcement processes to help mitigate the growth of unsafe commercial vehicle traffic.

3.2 STAKEHOLDER NEEDS

Stakeholders include institutions, groups, companies, or individuals who:

- Directly generate benefits realized by other stakeholders (e.g., data sharing, information exchange);
- Have an interest in the short and long term success of the program in question;
- Contribute to or are affected by some part of the program; or
- Can influence the real or perceived success of the program.

Virtual weigh station stakeholders include State Departments of Transportation (DOTs), State and local enforcement agencies, other State agencies, Federal agencies, motor carriers, technology manufacturers and vendors, highway and commercial vehicle safety organizations, and the driving public.

The Technology Implementation Group (TIG) of AASHTO selected "virtual weigh-in-motion" (i.e., virtual weigh station) as a focus technology. According to the group, "the application of 'virtual technologies' demonstrates an innovative approach to solving size and weight enforcement issues that ranges beyond the WIM traditional role in data collection and vehicle classification."[5] AASHTO is the leading source of technical information on design, construction, and maintenance of highways and other transportation facilities. The TIG promotes technological advancements in transportation, sponsors technology transfer efforts, and encourages implementation.

The group identified the following list of virtual weigh station stakeholders:[6]

- Driving public;
- American Trucking Associations;
- American Association of State Highway and Transportation Officials (AASHTO);
- State Departments of Transportation;
- State Departments of Revenue;

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[5] American Association of State Highway and Transportation Officials (AASHTO), *Virtual Weigh-in-Motion: A "WIM-win" for transportation agencies,* http://www.transportation.org/sites/aashtotig/docs/VWIM%20Brochure%20Final%2010-27-06.pdf, October 2006.

[6] American Association of State Highway and Transportation Officials (AASHTO), *Virtual Weigh-in-Motion: A "WIM-win" for transportation agencies,* http://www.transportation.org/sites/aashtotig/docs/021907%20Short%20Version.pdf , February 2007.

- USDOT;
- Federal Highway Administration (FHWA);
- Federal Motor Carrier Safety Administration (FMCSA);
- Commercial Vehicle Information Systems and Networks (CVISN) program partners;
- State Highway Patrols/State Police and enforcement agencies; and
- Motor carriers.

The operations of some of these stakeholders will be directly impacted by the deployment of virtual weigh stations. These impacts will be clarified in the remaining sections of this document.

All stakeholders have the following high-level needs with respect to virtual weigh stations:

- Reduce the numbers of highway fatalities and injuries;
- Reduce the numbers of commercial vehicle crashes;
- Reduce congestion and delay on highways;
- Reduce diesel fuel consumption by commercial vehicles;
- Decrease transportation costs for freight;
- Preserve the highway infrastructure; and
- Improve air quality.

Public agency stakeholders have the following additional needs:

- Improve the efficiency and effectiveness of roadside enforcement operations;
- Improve motor carrier compliance with Federal and State truck size and weight regulations;
- Reduce infrastructure and enforcement costs; and
- Provide data for traffic monitoring, pavement monitoring, and resource planning.

Motor carriers have the following specific needs:

- Improve the reliability of scheduling highway-based freight deliveries;
- Improve the efficiency of trips;
- Increase productivity;
- Level the playing field for safe and legal carriers;
- Improve confidence levels in meeting transport contracting requirements;
- Enhance company monitoring of driver performance and compliance; and

- Enhance vehicle fleet tracking and goods tracking capabilities.

3.3 ASSUMPTIONS AND CONSTRAINTS

Virtual weigh station deployment will be affected by existing or anticipated conditions that facilitate deployment (assumptions) and by limitations that potentially constrain deployment (constraints).

The following assumptions can be expected to facilitate virtual weigh station deployment:

- Commercial vehicle traffic will increase according to current estimates (Section 3.1);
- Enforcement resources available to conduct weight and safety inspections are limited and will become increasingly strained;
- Funds available to support construction of traditional weigh or inspection stations are limited and will not appreciably increase;
- Technologies exist to automatically identify commercial motor vehicles traveling at normal highway speeds;
- Technologies exist to automatically weigh commercial motor vehicles traveling at normal highway speeds;
- Potential violators according to weight, safety, credentials, and other factors can be identified and their data delivered to enforcement officials in real-time;
- Costs of deploying a virtual weigh station are low compared to a fixed weigh or inspection station, regardless of the technology that is deployed at the virtual weigh station;
- Many commercial vehicles avoid weighing by traveling on bypass routes or secondary roads, or during times when weigh stations are closed;
- An even greater number of commercial vehicles are rarely subject to a safety inspection because they operate in areas without a roadside enforcement presence or the enforcement assets are limited;
- Weight compliance is generally improved when enforcement operations are expanded;
- Many State agencies are responsible for enforcing both weight and safety regulations; and
- Safety inspections contribute to safer motor carrier operations.

The following constraints have the potential to inhibit virtual weigh station deployment:

- Human resources are required to monitor real-time information from virtual weigh stations and intercept violators at the roadside for weighing and/or inspection, as long as the virtual weigh station is used as a screening tool. In a study conducted by FHWA of challenges faced by states in deploying roadside enforcement technologies, participating states were quick to point out that during staffing shortages, systems that are not "permanently" staffed but require continuous human monitoring such as virtual weigh stations are of limited value.[7]
- Although considerable strides have been made recently in automatically identifying vehicles traveling at highway speeds through optical character recognition (OCR) technologies, which are the most frequently deployed automatic vehicle identification (AVI) technologies deployed at virtual weigh stations, 100 percent accuracy in identifying all carriers (through their USDOT number) or vehicles (through their license plate) is not currently possible, and it is unclear whether 100 percent accuracy will be attainable with these technologies. Most experts believe that accuracy will never approach 100 percent with these technologies because license plates and displayed USDOT numbers are not standardized and not optimized for automated reading.
- Costs of deploying a virtual weigh station, despite being considerably lower than a traditional weigh station, can range from $300,000 to $1 million, based on a survey of State applications for Federal CVISN Deployment Grants, Fiscal Years 2006 - 2008. Because costs depend on a large number of factors, such as whether a new WIM system is purchased and installed, the number of lanes, the number of other systems that are deployed (OCR, height detection, etc.), communications requirements, and integration needs, actual costs can be considerably less, or possibly greater, than these figures. For states that are experiencing budget cuts and/or shortfalls, funding for additional costs such as virtual weigh stations may be difficult or impossible.

3.4 DESCRIPTION OF DESIRED VIRTUAL WEIGH STATION OPERATIONS AND PROCESSES

A virtual weigh station should support the following operations and processes in order to address the challenges described in Section 3.1 and meet the stakeholder needs described in Section 3.2:

- Use technology to automatically identify carriers, drivers, and/or vehicles;

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[7] *Technology Deployment Challenges and Guidelines on the Use of Weigh-in-Motion in Roadside Enforcement*, submitted by Cambridge Systematics to the Federal Highway Administration, April 2009, as part of the Truck Size and Weight Enforcement Technology Project, page 4.

- Distinguish potential weight violators from the real-time traffic stream based on automatic weight measurements that exceed established thresholds;
- Distinguish high safety risk motor carriers, drivers, and vehicles from the real-time traffic stream based on an automatic screening algorithm that indicates the presence of safety risks, credentials violations, or other criteria established by the State;
- Intercept potential weight violators for weighing on scales that produce enforceable weights;
- Intercept high-risk carriers and vehicles for safety inspection and/or other close examination;
- Allow safe and legal carriers/vehicles to travel unimpeded;
- Conduct screening (weight, safety, credentials, and/or other criteria) on routes that do not generally capture traffic traveling past existing weigh stations, including bypass routes, secondary roads, highways in heavily populated urban areas, and remote highways;
- Conduct screening operations to maximize available enforcement resources, e.g., coordinate operations with nearby weigh station operations;
- Collect continuous data for planning purposes and make the data available electronically to stakeholders. Planning purposes may include deployment of enforcement resources, as well as pavement and bridge monitoring, analysis of travel and weight trends, and development of emissions models;
- Verify compliance with tax payment requirements (e.g., Heavy Vehicle Use Tax, International Fuel Tax Agreement) and vehicle registration requirements (e.g., International Registration Plan, intrastate vehicle registration); and
- Verify, as applicable to the specific load movement, State-issued permitting procurement and compliance.

It is important to keep in mind that the concept of "virtual weigh stations" is to develop and deploy automated tools at the roadside capable of conducting measurements, verifications, and certifications traditionally conducted manually at fixed weigh stations. Enforcement activities conducted at fixed weigh stations include:

- Truck size and weight compliance measurements;
- State-issued oversize/overweight permit availability and compliance;
- Verification of registrations and payment of taxes and fees;
- Driver credentialing and "hours-of-service" compliance; and
- Carrier safety performance checks and vehicle and driver inspections.

In addition, there is a growing recognition of the need to integrate services beneficial to the private sector at the roadside. As compliance checks are conducted at highway speed, the "digital enforcement cloud" must be designed so as not to cause interference or interruption to company telecommunication and satellite-based fleet and goods tracking systems. The high speed nature of "just-in-time" supply chain models requires advanced communication and identification systems; these capabilities have been in deployment in the private sector for several years now. Interference with these systems by introducing non-compatible electronic data-heavy enforcement events at the roadside can be avoided through open communication and coordination with State trucking associations and large carriers. Communication is vital to success.

Services available in an electronic format that support efficient movement of highway-based goods can be integrated into the roadside information exchange model as well. Traffic operating conditions, construction zone awareness, road/ weather information services, and truck parking availability and reservation systems are examples of areas emerging as candidates for integration into roadside enforcement platforms. At some point, State toll authorities offering e-tolling services may be integrated into the roadside data model to further enhance highway-based freight movement performance. While these considerations and concepts each introduce added layers of complexity to an already complex enforcement model, the potential for integration and compatible system constructs will become more evident in the discussion and through the diagrams offered in the section that follows.

4.0 Concept of Operations

A virtual weigh station (VWS) is an enforcement facility that does not require continuous staffing and is monitored from another location.[8] The virtual weigh station concept is very flexible. While there is a minimum set of functionality/technology that must be deployed in association with a VWS, states can customize their VWS deployments to meet their specific functional needs (e.g., focus exclusively on truck size and weight issues, expand focus to include safety and credentialing regulations), operational environment (e.g., typical weather conditions, physical space, terrain), and communication infrastructure (e.g., presence of communication infrastructure at site, presence of power at site). This section documents the basic VWS concept, as well as additional functionality that can be associated with an expanded VWS.

4.1 VIRTUAL WEIGH STATION GOALS

Virtual weigh stations are employed to meet a wide range of operational objectives. States typically deploy virtual weigh stations in order to:

- Increase compliance with Federal and State size and weight standards through augmented enforcement operations (e.g., screening commercial vehicles; persistent enforcement operations on known bypass routes around fixed facilities; persistent enforcement operations on routes that are not regularly patrolled by mobile enforcement assets due to remoteness/geography/topography);
- Improve commercial vehicle safety through targeted enforcement at commercial vehicles that are known to be overweight, are improperly credentialed, or are operated by high-risk motor carriers;
- Improve the efficiency and effectiveness of roadside enforcement assets;
- Improve resource allocation and staffing decisions through the use of information; and
- Reduce costs associated with the expansion of commercial vehicle size and weight/safety enforcement programs through the use of technology.

As states consider the next generation of roadside technologies, VWS sites also may be designed to serve as conduits for two-way communication between the

[8] *Technology Deployment Challenges and Guidelines on the Use of Weigh-in-Motion in Roadside Enforcement*, submitted by Cambridge Systematics to the Federal Highway Administration, April 2009, as part of the Truck Size and Weight Enforcement Technology Project, page 12.

roadside and a vehicle in motion and therefore may support a broader range of safety, security, mobility, and systems management objectives.

4.2 FUNCTIONS OF VIRTUAL WEIGH STATIONS

As noted above, virtual weigh stations can be designed and implemented to support a wide variety of roadside enforcement functions. At a minimum, a VWS must support the following functionality:

- **Real-time weighing of a commercial vehicle**—Determine a commercial vehicle's approximate axle weights as the vehicle moves across sensors, and calculate the gross vehicle weight and classification based on the number of axles, as well as axle weights and spacings;
- **Real-time identification of a commercial vehicle**—Identify accurately all commercial vehicles that pass the site;
- **Integration of real-time data for screening decisions**—Integrate commercial vehicle identification and weight data in real-time/near real-time, in order to support manual (i.e., decisions made by roadside enforcement personnel) or automated (i.e., decisions calculated by the system and then forwarded to a human) targeting of specific commercial vehicles for further enforcement action; and
- **Communication of data to enforcement personnel in real-time**—Communicate VWS data (e.g., vehicle photo, weight data) to authorized users (e.g., mobile enforcement personnel stationed downstream from the VWS, enforcement personnel stationed at a fixed inspection site that could be dispatched to intercept an overweight vehicle) in a timely and secure manner.

States also use their current VWS deployments to support the following expanded functionality:

- **Real-time identification of the motor carrier responsible for the operations of a commercial vehicle**—Identify the motor carrier that is responsible for the safe operation of the vehicle;
- **Implementation of an expanded screening algorithm**—Integrate additional criteria (e.g., motor carrier history of safety performance, motor carrier history of compliance with size and weight standards, current commercial vehicle credential status, current motor carrier credential/operating authority status, driver's license status) into the screening decision;
- **Real-time verification of vehicle dimensions**—Integrate additional sensors (e.g., gantry-mounted laser overheight detectors) to determine if a commercial vehicle exceeds legal height, width, and length regulations and therefore would require an oversize/overweight permit; and

- **Availability of data to support resource planning**—Provide commercial vehicle average daily trip data (e.g., volume, weight, vehicle classification) in order to support the scheduling of mobile enforcement activities, as well as to identify locations in need of fixed enforcement facilities.

During recent stakeholder discussions about the future uses of roadside technologies, stakeholders also identified a series of additional functionality that could be supported by a VWS. This additional functionality includes:

- **Real-time identification of the commercial driver operating a commercial vehicle and inclusion of driver information in the screening decision**—Identify the individual driving a commercial vehicle and determine if that individual can legally operate the vehicle at that time (i.e., commercial driver's license is not revoked or suspended);
- **Direct enforcement**—Write a citation or take other enforcement action (e.g., prevent a commercial vehicle from being started) based on data from a VWS;
- **Communication of real-time operational data to system managers**—Serve as a conduit for onboard vehicle data (e.g., speed, windshield wipers on/off, air temperature) to be sent to traffic management centers in support of traffic/congestion monitoring and development of travel advisories;
- **Communication of real-time traveler information to commercial drivers**—Serve as the means by which real-time traffic (e.g., incident warning, congestion, weather advisories) and truck parking (e.g., location, availability) information could be delivered to commercial vehicle drivers operating within a specific geographic area/corridor; and
- **Communication of commercial vehicle location data to authorized users**—Accurately capture vehicle location data (i.e., date and time that it passed a VWS) in order to support private sector (i.e., asset tracking, estimated time of arrival [ETA] updates to vehicle's motor carrier/shipper/receiver) and public sector (i.e., tracking of hazardous material by Department of Homeland Security, tracking of in-bond agricultural shipments by the United States Department of Agriculture) applications.

4.3 KEY CONCEPTS

The basic virtual weigh station functionality is based on the following concepts:

- Use roadside technology to augment human enforcement resources;
- Deploy scarce enforcement resources as effectively and efficiently as possible;
- Accurately identify all commercial vehicles in real-time;
- Determine a commercial vehicle's weight to a degree of accuracy that is sufficient for its functional purpose (e.g., 10 - 15 percent error tolerance for system monitoring while building knowledge on system-level loadings; 3 - 5

percent error tolerance for mainline WIM systems for screening; 1 - 2 percent error tolerance for ramp WIM for sorting at weigh stations);

- Deliver the vehicle identification and weight data to enforcement personnel in real-time;
- Leverage other safety and credentialing data in screening criteria;
- Focus enforcement on commercial vehicles that pose the highest risk; and
- Deploy VWS technology in an open and expandable way so that future technologies (e.g., enhanced vehicle identification systems, driver identification systems, Smart Roadside, IntelliDrive/Commercial Vehicle Infrastructure Integration) can be integrated easily and cost effectively.

4.4 OPERATIONAL SCENARIOS

Varying technology is required to support the different types of VWS functionality (documented in Section 4.2). The minimum VWS functionality requires deployment of:

- **WIM scales or sensors**, which weigh the commercial vehicle;
- **Camera (digital imaging) system**, which captures real-time images of a commercial vehicle crossing the WIM system to support its immediate identification by enforcement personnel;
- **Screening software**, which integrates the data from the WIM and imaging systems; and
- **Communication infrastructure**, which makes the VWS data (e.g., vehicle photo, weight data) available to authorized users (e.g., mobile enforcement personnel stationed downstream from the VWS, enforcement personnel stationed at a fixed inspection site that could be dispatched to intercept an overweight vehicle) in a timely and secure manner. The VWS allows for the use of a variety of communication technologies. Depending on what is available at the site, authorized personnel may use a wireless connection (e.g., cellular, satellite) or a wired connection (e.g., fiber optics, T-1 line) to a secure Internet site to access the information.

The following types of technology also may be deployed in order to support additional VWS functionality:

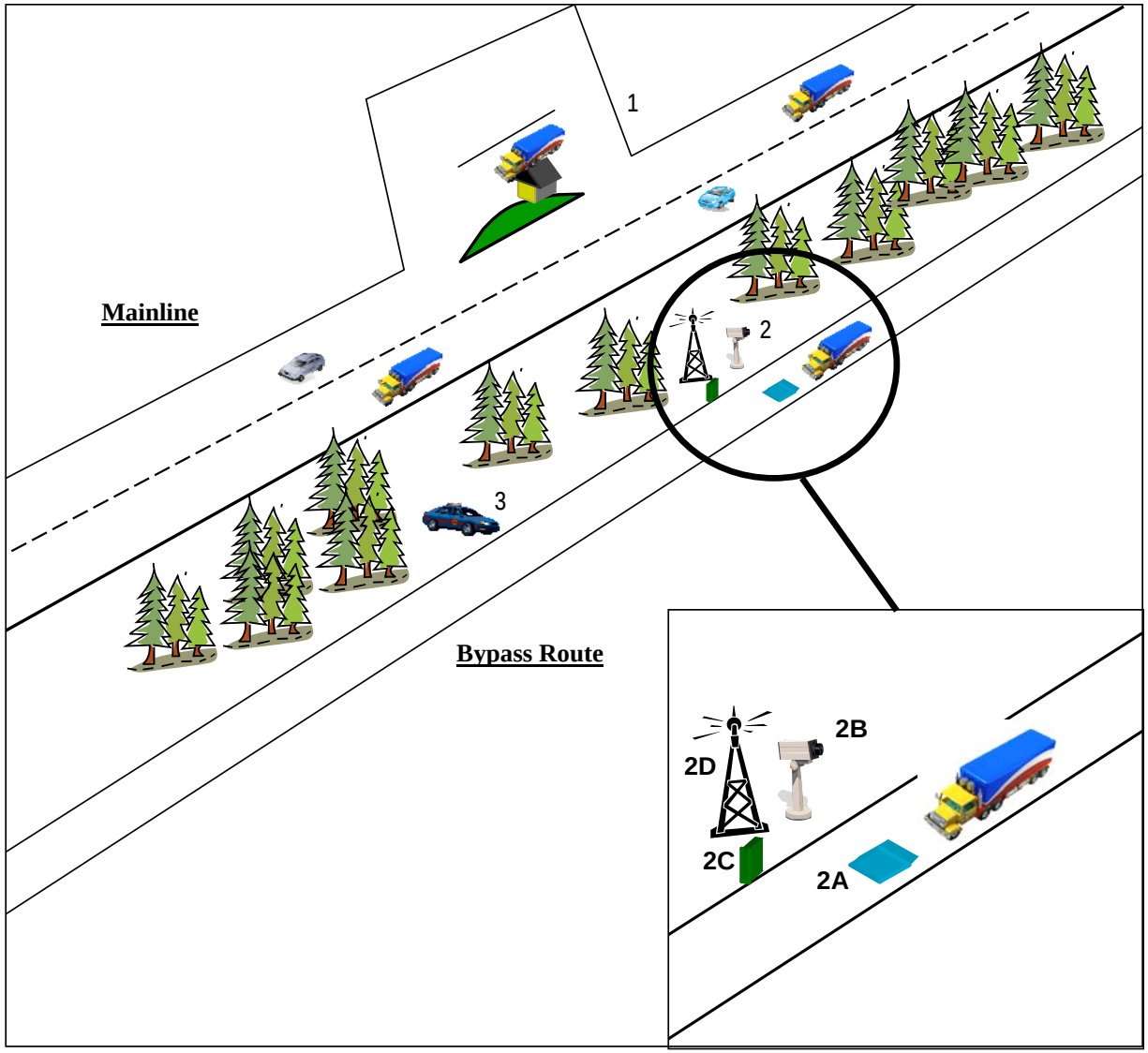
- **License plate reader (LPR) and/or USDOT number reader system,** which takes an image of the vehicle's license plate or side of the commercial vehicle and uses OCR software to generate an electronic value of the vehicle's license plate or USDOT number, respectively;
- **Commercial Vehicle Information Exchange Window (CVIEW) or an equivalent,** which provides real-time access to motor carrier safety (e.g., out-of-service [OOS] orders, safety algorithm scores) and credentials (e.g.,

operating authority, Unified Carrier Registration [UCR], International Fuel Tax Agreement [IFTA]) data, as well as commercial vehicle safety (e.g., past inspection reports) and credentials (e.g., International Registration Plan [IRP], oversize/overweight [OS/OW] permits, intrastate vehicle registration) data. This repository also could contain commercial driver's license data for use in the screening process;

- **State-issued permit compliance,** which accesses on-board information in order to verify a permit has been obtained and is in valid operation when oversize or overweight elements are detected. Verification that the vehicle is operating on an "approved route" and at a legal time and within the limits provided for on the State-issued permit can be conducted at highway speed with proper information added to a transponder or radio frequency identification-based device, or through the real-time accessing of permit data stored in back-office safety and credentialing systems (i.e., CVIEW, OS/OW permitting system);
- **Repository of past weight performance,** which provides real-time access to a motor carrier's and/or commercial vehicle's previous compliance record with Federal and/or State truck size and weight limits;
- **Driver identification system**, which provides an electronic means to accurately identify the operator of a commercial vehicle while the vehicle is in motion;
- **Augmented WIM scales**, which enhances the accuracy in the weighing of the commercial vehicle, in order to support more reliable screening and ramp sorting enforcement operations; and
- **Two-way communication**, which provides the ability to share data from the commercial vehicle (e.g., speed, windshield wiper on/off, temperature) to the roadside, as well as from the roadside to the commercial vehicle (e.g., traveler information, truck parking information).

Figure 4.1 illustrates a typical layout of a basic VWS. Figure 4.2 illustrates the potential layout of a more robust VWS. To illustrate how operations of the basic VWS and a more robust VWS may differ, an operational scenario for each is detailed following the layout illustrations.

Figure 4.1 Basic Virtual Weigh Station Physical Layout



Legend

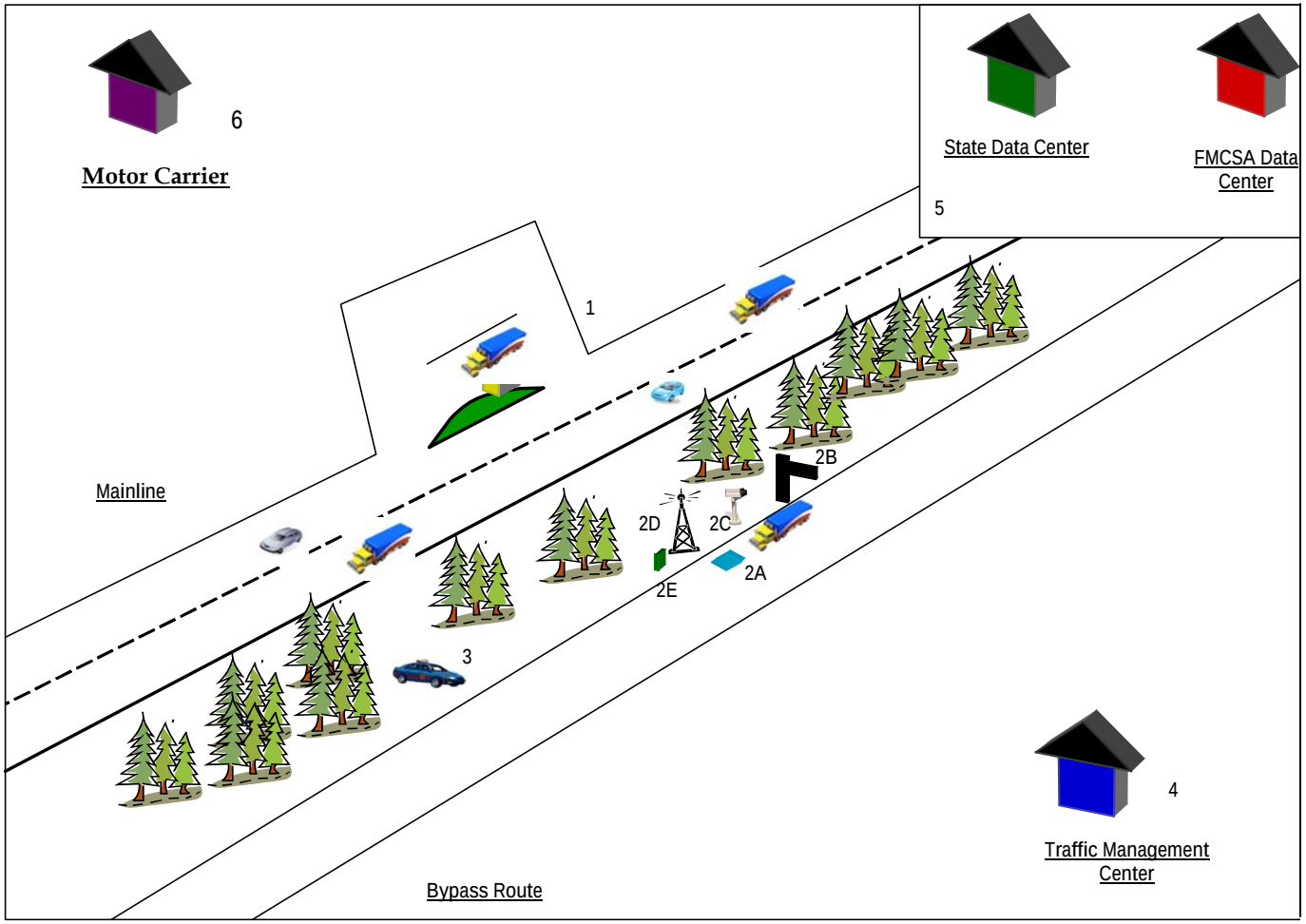
1 . Fixed weigh station on mainline highway

2. Virtual weigh station deployed on bypass route

- 2A. WIM scales
- 2B. Camera system
- 2C. Screening software
- 2D. Communication system

3. Mobile enforcement unit deployed downstream from VWS

Figure 4.2 Expanded Virtual Weigh Station Physical Layout



Legend

1. Fixed weigh station on mainline highway

2. Virtual weigh station deployed on bypass route
   - 2A. WIM scales
   - 2B. Dimensional sensors
   - 2C. AVI system
   - 2D. Communication system
   - 2E. Screening system

3. Mobile enforcement unit deployed downstream from VWS

4. State/Urban/Regional Traffic Management Center (TMC)

5. Back-office systems hosted at State Data Center or FMCSA Data Center

6. Motor carrier terminal/operations center

Basic VWS Operational Scenario

As illustrated in Figure 4.3, the following five steps summarize the typical operations of VWS:

1. As a commercial vehicle approaches the virtual weigh station, it is weighed while in motion on the WIM scales.

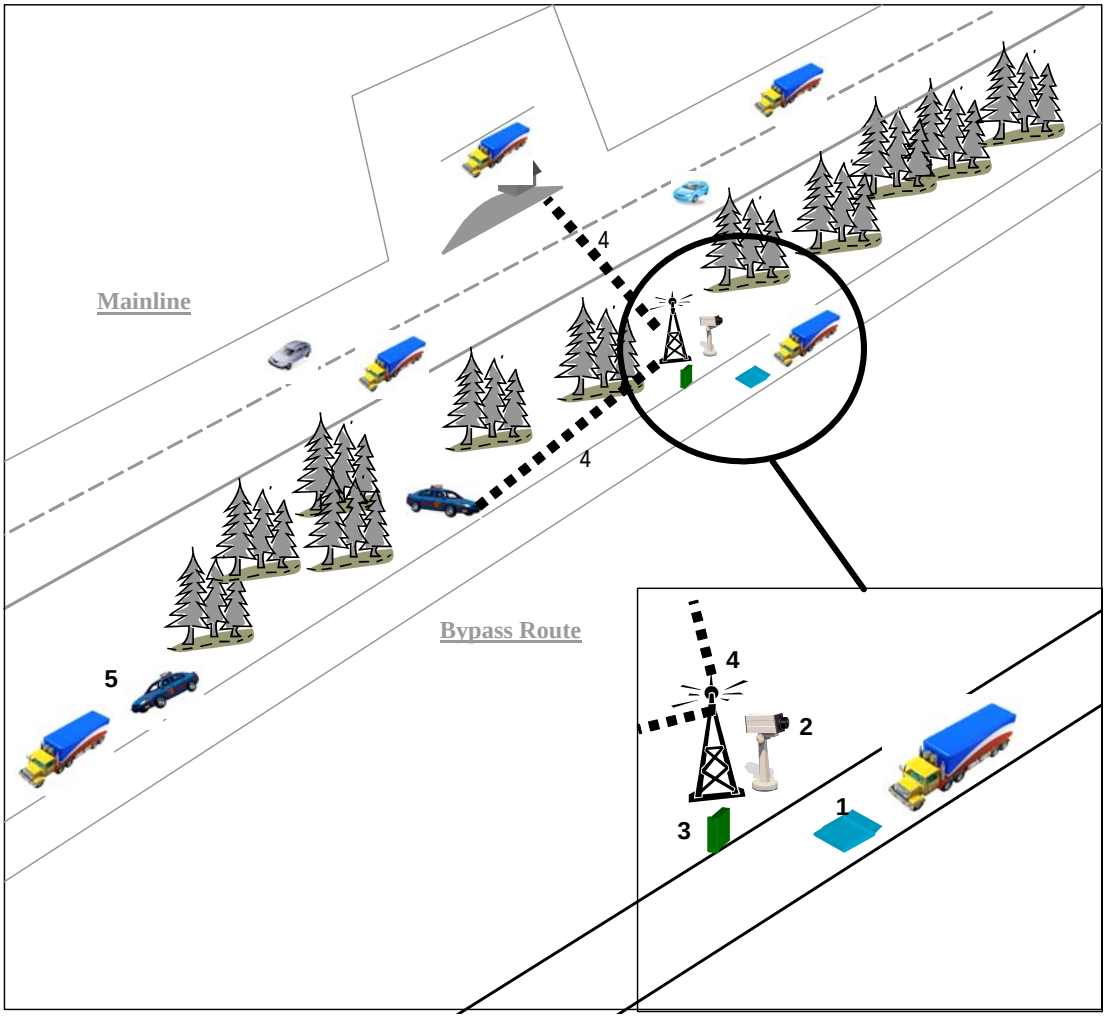
2. A picture of the commercial vehicle is taken for identification purposes.

3. Screening software integrates data from the WIM and camera system.

4. Mobile enforcement officer positioned downstream from the VWS accesses the VWS data (e.g., photo of commercial vehicle, WIM data) and makes a screening decision. Enforcement personnel at the fixed site access the VWS data (e.g., photo of commercial vehicle, WIM data) and make a screening decision.

5. Overweight commercial vehicle is intercepted for weighing/inspection.

Figure 4.3 Basic Virtual Weigh Station Concept of Operations



Expanded VWS Operational Scenario

As illustrated in Figure 4.4, the following 13 steps summarize the potential operations of a VWS in the future:

1. As a commercial vehicle approaches the virtual weigh station, it is weighed on the WIM scales and measured by dimensional sensors.

2. AVI system automatically identifies the specific vehicle.

3. License plate/USDOT number reader and associated optical character recognition (OCR) software identify the motor carrier that is responsible for operating the commercial vehicle.

4. Screening system uses vehicle identifier and motor carrier identifier to query back-office safety, credentials, and weight performance data. (NOTE: These data may be stored in a single repository, such as a State's Commercial Vehicle Information Exchange Window [CVIEW], or in separate repositories.)

5. Screening system integrates weight data with safety, credentials, and weight data in order to determine whether a commercial vehicle should be targeted for additional enforcement actions.

6. Mobile enforcement officer positioned downstream from the VWS and/or enforcement personnel stationed at a fixed site access the VWS system (e.g., photo of commercial vehicle, vehicle identifier(s), WIM data, screening decision).

7. A commercial vehicle/motor carrier that is overweight or noncompliant with safety (e.g., out-of-service order) or credential (e.g., IRP, IFTA, UCR, OS/OW) is intercepted for weighing/inspection. If monitoring is conducted at the fixed site, an officer is dispatched to locate and pull the vehicle over for weighing/inspection, or direct the vehicle to the weigh station for weighing/inspection.

8. If human resources are unable to intercept the vehicle, a warning letter or a citation could be generated by a back-office process and forwarded to the motor carrier identified by the USDOT reader. The concept of issuing warning letters to motor carriers that are routinely noncompliant is consistent with FMCSA's new operational model (Comprehensive Safety Analysis for 2010 {CSA 2010]) that places a greater emphasis on more frequent interactions with motor carriers.

9. Vehicle, motor carrier, and commercial driver identifiers, as well as compliance (i.e., weight, safety, credential) data are sent to a back-office repository so the State can develop a history of compliance/noncompliance with weight standards for each motor carrier and/or commercial vehicle (similar to the safety performance metrics calculated by FMCSA).

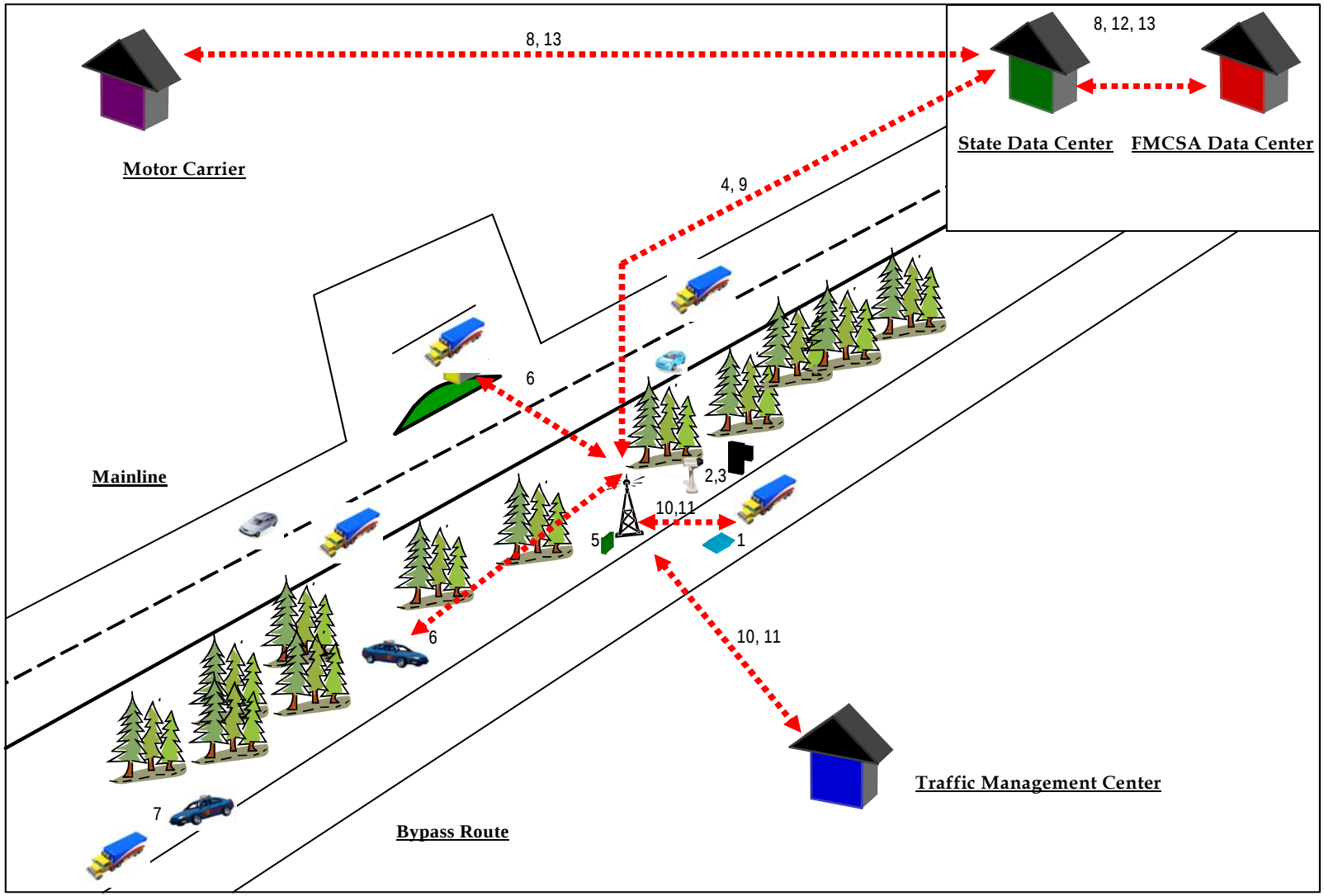
10. Weather data from the vehicle is sent to system operators for real-time traffic management.

11. Localized and real-time traveler information is sent to the commercial vehicle for integration with on-board systems designed to display this information safely and with a minimum amount of driver distraction.

12. Data from the VWS is available to authorized users for planning and reporting purposes.

13. Data from the VWS is available to motor carrier users for tracking of the company's assets and their performance.

Figure 4.4 Expanded Virtual Weigh Station Concept of Operations



4.5 ARCHITECTURE

Figures 4.5 and 4.6 provide high-level overviews of the proposed system architecture for basic and expanded VWS systems. The basic VWS architecture in Figure 4.5 includes two groupings – one for ***Roadside*** technology components and another consisting of back-office components grouped into a ***State Data Center***. The expanded VWS architecture in Figure 4.6 adds a third grouping called ***External User Services***, which provide for additional VWS operations/support capabilities for external users. These three architecture groupings are further defined as follows:

- **Roadside**—This grouping includes the set of technologies and operations that involve the identification, observation, and enforcement interaction with the commercial vehicle and the driver. Baseline core VWS technologies include AVI transponder vehicle identification, camera systems, and WIM scales. Expanded VWS roadside technologies include driver identification technologies (e.g., biometrics, smart cards), OCR systems (e.g., LPRs and USDOT number readers), and dimensional sensors.
- **State Data Center**—This grouping provides the set of information technology systems and databases that enable the functionality of the VWS system. The State Data Center referenced in the context of this ConOps is a multi-agency data system fusing information stores maintained by Departments of Transportation or Highway Agencies, Departments of Motor Vehicles, State Enforcement Agencies, and State Revenue Agencies supporting high-speed information exchanges at roadside enforcement sites. In the basic VWS scenario, only a repository of transponder identifiers would be hosted in the State Data Center. Expanded VWS functionality is largely based on the increased amount of data/factors that can be queried at the roadside and/or stored from the roadside. As such, the expanded VWS scenario has several additional components that would be hosted at a State Data Center, including:
  - CVIEW—repository of motor carrier, commercial vehicle, and commercial driver safety and credential information that can be queried to support the real-time screening at the roadside. CVIEW also could store wireless roadside inspection data that is collected from a VWS. CVIEW also serves as the conduit to exchange data to/from other jurisdictions and FMCSA. For instance, CVIEW is the means by which a State gains access to FMCSA's screening algorithm data, as well as other states' IRP and IFTA status information. Many State CVIEWs also store other commercial vehicle credentials (e.g., OS/OW permit, intrastate vehicle registration) that can be accessed in real-time at the roadside;
  - Warning/citation generation—back-office process that could generate warning letters and/or citations to a motor carrier if a commercial vehicle is found to be noncompliant by a VWS; and

  - Historical size and weight compliance database—back-office application that records a motor carrier's long-term compliance with Federal and State size and weight regulations, in order to support planning activities, as well as development of warning letters.

- **External User Services**—This grouping encompasses future potential uses of VWS information to support public and private sector operations. Motor carriers would be provided with time-stamped vehicle location information that could support enhanced productivity, as well as tailored traveler information. Transportation management centers would receive tailored information concerning roadway congestion and conditions. Through CVIEW, State and Federal safety systems would receive key enforcement data outputs. State enforcement agencies would also receive key statistical information that could assist them in better planning for VWS deployment across a State.

The arrows connecting each of the components in Figures 4.5 and 4.6 illustrate the specific information interfaces for the VWS architecture. In general, the Roadside elements identify and weigh the commercial vehicle, as well as conduct enforcement activities. The screening computer integrates data from the Roadside systems and vehicle and uses this data to query (in the expanded scenario) data from the State Data Center in order to screen and target vehicles at the roadside. The screening computer also relays the data from the commercial vehicle and Roadside elements to enforcement personnel stationed at a fixed site or in a mobile unit. These enforcement personnel conduct roadside enforcement activities on targeted vehicles.

In addition to providing data to be queried by the screening computer, the State Data Center systems also provide the outputs necessary to support the External Users of the VWS data (e.g., traffic management centers, motor carriers, Federal safety systems, planning offices). State Data systems also could generate automatic citations and record a motor carrier's historical compliance with size and weight regulations. In this construct, at a point in the future, two-way communication also could facilitate actual communication between the truck and back-office and External User systems.

Boxes shown in white are components of the basic VWS concept. Boxes shown in gray are components of the expanded VWS concept. The box shown in green is indicative of a future system (e.g., 5.9 GHz) that could support two-way communication between a commercial vehicle and back-office systems.

Figure 4.5 Basic Virtual Weigh Station Interfaces

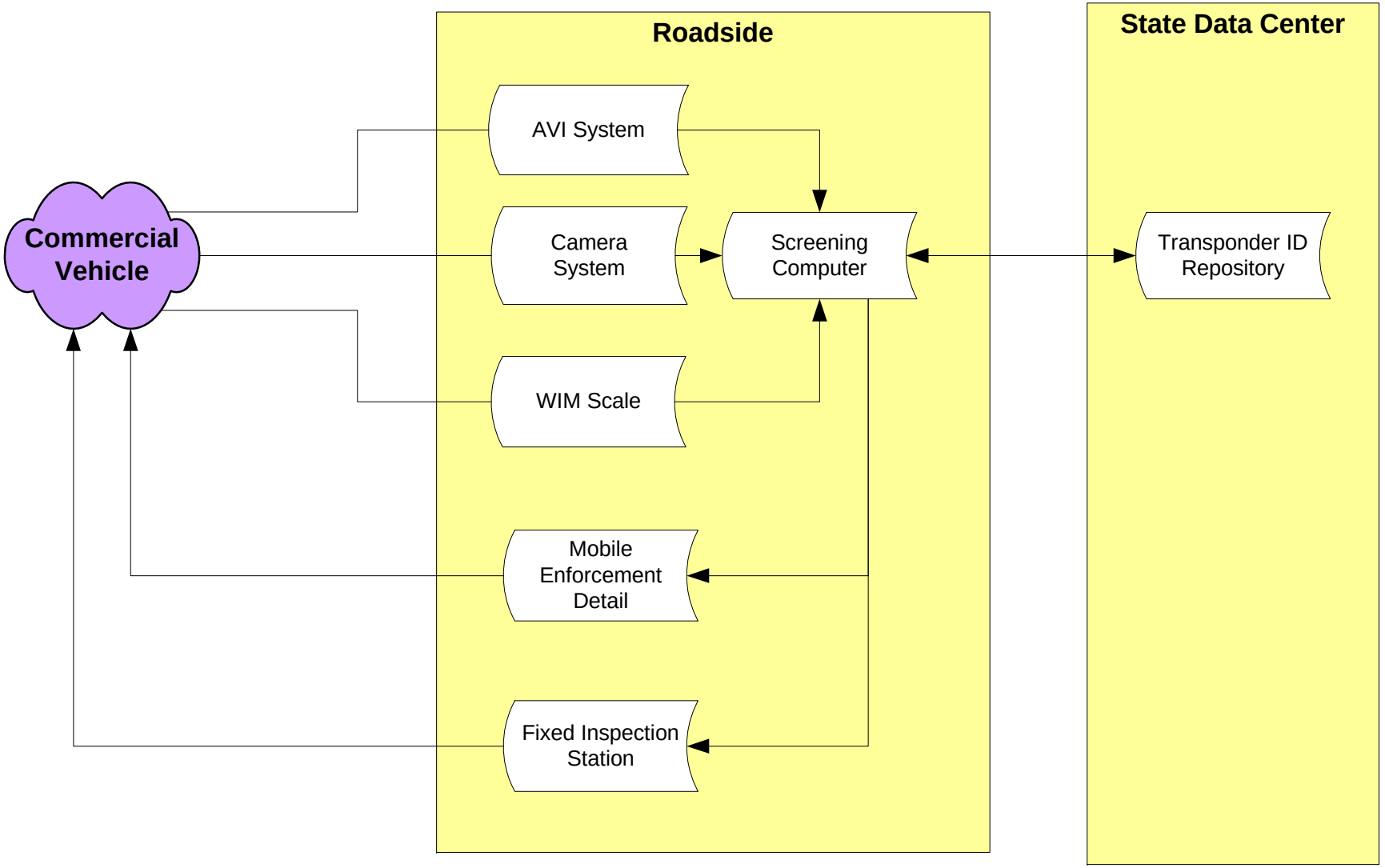
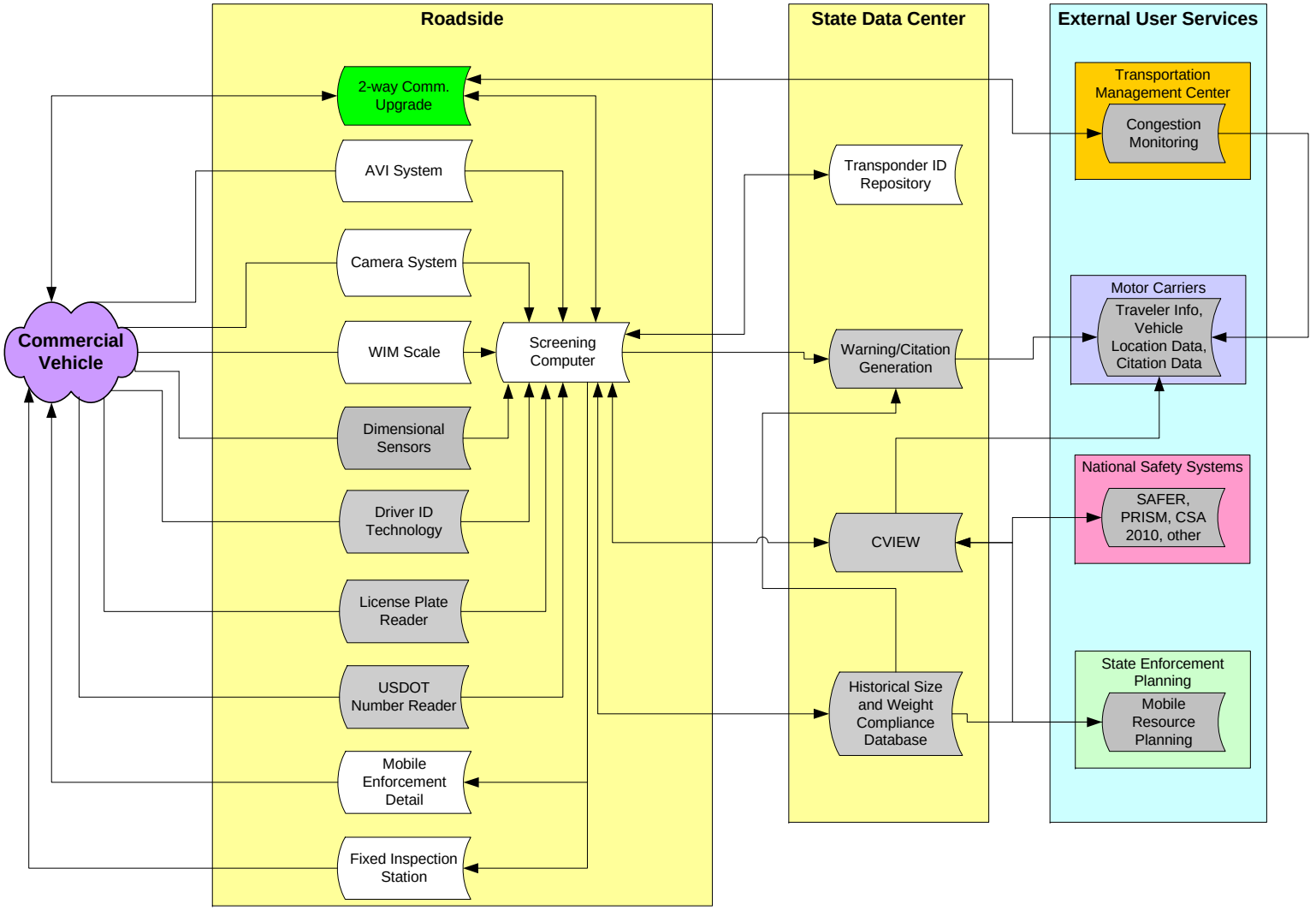


Figure 4.6 Expanded Virtual Weigh Station Interfaces



4.6 COMMON STEPS

There are five basic steps that are shared between the two operational scenarios:

- **Identify commercial vehicle**—An accurate and timely identification of the commercial vehicle is at the core of all VWS functionality. The vehicle identification ensures that the proper vehicle is screened and/or targeted for additional enforcement activities. Most states that have augmented the basic camera system with AVI functionality currently are using LPRs to identify commercial vehicles. Performance of LPRs has been uneven and remains under investigation. Some states have reported LPR accuracy rates of 85 percent while others have reported rates as low as 30 – 50 percent. A variety of operational (e.g., speed, placement of license plate, ink used on license plate) and environmental (e.g., shadows, glare, weather) issues directly impact the effectiveness of these systems. Concerned about the long-term viability of LPRs as the identification technology, some states have begun to investigate alternate detection systems for use in their roadside enforcement systems. For instance, New York is investigating the use of 5.9 GHz (IntelliDrive/Vehicle Infrastructure Integration [VII]) technology, and Tennessee is studying the use of a cellular/satellite communication system. Other applications (e.g., tolls) also have begun to migrate towards inexpensive passive ("sticker") tags that are affixed to vehicle windshields. FHWA is initiating a new project to identify which technology is best suited to attain its long-term objective of identifying all commercial vehicles in real-time at highway speeds.
- **Weigh commercial vehicle**—Like vehicle identification, accurately weighing a commercial vehicle is a core component of any VWS. The accuracy of the gross vehicle weight or axle weight estimate can be affected by the WIM scale technology in use. When installed on the mainline, more expensive WIM systems have less variance in their readings and may better compensate for filtering external factors that affect vehicle weight calculations. Conversely, less expensive WIM scales or sensors may not be as accurate at highway speed. An example of a low-cost WIM device that has been deployed in the United States is the piezoelectric sensor. More recently, several states have begun including quartz piezo WIM systems in their programs because of the acceptable level of accuracy these sensors produce. Quartz piezo WIM devices, like electric piezos, are relatively inexpensive and not difficult to install but feature a short service life, especially on routes with high truck volumes. More expensive systems like load cell and bending plate offer higher accuracy in weight estimates but are more expensive to procure and are significantly more intrusive to the pavement structure. Bending plate systems offer high accuracy but are quite difficult to maintain; their expected service life far outperforms piezo sensors. Load cell scales are very durable, feature a significantly longer service life than the other devices, if maintained

properly, and are quite easy to maintain. The trade-off among "up-front cost," expected service life, and ease of maintenance should be carefully worked through before procurements take place. Typically, accuracy rates for all of these devices range from 85 to 97 percent.

- **Establish vehicle dimensions—**Another aspect of truck enforcement is measuring the vehicle dimensions to determine compliance with length, width, or State-specific height requirements. Verification of vehicle dimensions for State-issued oversize permit compliance can be automated by deploying overhead gantry or roadside elevated laser scanning systems. Many commercial vendors have vehicle dimension technology bundled into their "off-the-shelf" virtual weigh station packages. The military has had vehicle dimension detection systems in operation for quite some time now to support rapid deployments. Recently, more advanced laser-based systems have been emerging, offering enhanced image quality and greater accuracy in determining vehicle envelopes.
- **Determine screening decision—**If a VWS is designed to support a manual screening model, the system simply delivers a photo of the vehicle and accurate weight information to a roadside enforcement resource in real-time. The system also may use color (i.e., a red border around the photo, red text for overweight data) to highlight an overweight vehicle. If a VWS is designed to automatically screen commercial vehicles based on a series of criteria (e.g., weight, safety algorithms, past compliance with size and weight standards), the screening software must be programmed to weigh the various criteria and determine what factor or combination of factors will yield a decision to target a commercial vehicle for further scrutiny. A similar approach (e.g., pre-determined weights are assigned to specific evaluation criteria with the sum total of the criteria yielding a pull-in/bypass decision) is used to support electronic screening in some states.
- **Share data—**Conceptually, a VWS is designed to take data from a commercial vehicle and share it with authorized users. In the basic VWS concept, only vehicle identification (either via a transponder or a photo) and weight data is shared and enforcement personnel are the only authorized personnel authorized to access this data. In the expanded VWS concept, a larger amount of data is shared between the commercial vehicle and the roadside and a broader range of authorized users can access specific types of data. The expanded data being shared from the commercial vehicle includes vehicle identification via OCR, driver identification, weather data, and operational data. Further with the expanded VWS concept, data also may be shared from the roadside (e.g., truck parking information, traffic/traveler advisories) to the commercial vehicle and from back-office systems to the motor carrier (e.g., tracking data, citation data). Regardless of the type or amount of data being shared, the VWS concept provides a platform that serves as a conduit for information sharing.

4.7 OPERATIONAL POLICIES

While VWS deployments vary widely by states, the following policies summarize the minimum policies that should be enacted by all states deploying VWS technology:

- All commercial vehicles must be identified and weighed by a VWS;
- Commercial vehicles should be allowed to proceed at the normal speed for the road on which they are operating when passing a VWS;
- Deployment of VWS technology should be designed to limit driver distraction;
- VWS deployments should leverage existing information technology (IT) and data infrastructure and standards (e.g., a State's CVISN systems, existing WIM deployments) whenever possible;
- Motor carriers should be made aware of how data collected by a VWS will be used;
- Access to VWS data should be limited to authorized users that have a clear and pertinent business need for the information (e.g., roadside enforcement personnel to support screening decisions, motor carriers to track their own vehicles);
- Motor carriers should be provided with a means to challenge any data that they believe to be inaccurate;
- Direct enforcement and/or a change to a motor carrier's safety rating will occur only if the VWS data (e.g., motor carrier/vehicle identification, weight information) can be certified as being accurate;
- Standards should be developed to govern the storage and retention (e.g., how long will data be kept) of all data associated with VWS deployments; and
- Data used by government agencies for non-enforcement purposes (e.g., planning) should be anonymous.

4.8 IMPACTS

Deployment of VWS technology has the potential to fundamentally change the way truck size and weight standards and regulations are enforced in the United States. Anticipated impacts include:

- **All commercial vehicles subject to electronic screening—**Current deployments of electronic screening are voluntary in nature (i.e., motor carriers determine if they wish to participate and thereby install a transponder). VWS deployments are designed to enable the screening of all commercial vehicles. This "100 percent" screening would be attained by the reading of identifiers that all commercial vehicles are required to have (i.e.,

license plate, USDOT number) or through the adoption of a new technology that all commercial vehicles would be required to install. With respect to current identifiers, additional research and refinement of technology are required to achieve 100 percent accuracy in reading commercial vehicles.

- **Improved operational efficiency for enforcement personnel—**VWS technology has the potential to dramatically improve the efficiency and effectiveness of the nation's size and weight enforcement regime. Currently, less than one percent of commercial vehicles that are weighed at the roadside are found to be overweight. While this is in part a testimony to the number of legal carriers operating in the United States, it also is an indication that noncompliant carriers are successful in bypassing enforcement activities. VWS deployments will allow roadside enforcement personnel to target their efforts at commercial vehicles that are known to be operating over legal limits and allow compliant carriers to avoid roadside enforcement stops. VWS deployments also have the potential to exponentially expand the geographic scope of a State's enforcement program and limit the number of routes on which a noncompliant vehicle can operate without being detected and/or monitored by enforcement personnel. This improved efficiency is a key factor in states' decisions to deploy VWS technology, especially given the budget constraints under which many states currently are operating.
- **More frequent verification of commercial vehicle compliance—**The use of automated systems will allow for the frequent verification of commercial vehicle compliance with Federal and State size and weight regulations, as well as safety and credentialing regulations (if expanded VWS functionality is deployed). These more frequent inspections will be enabled by the deployment of enforcement assets (i.e., VWS) on bypass roads and in remote/urban areas that currently cannot accommodate roadside enforcement actions. More frequent inspections also will be supported by the 24X7 operational nature of VWS, as opposed to the shift deployments associated with human assets. Expanded VWS functionality (i.e., maintenance of a historical size and weight compliance database, issuance of warning letters/citations, targeting of motor carriers that regularly operate beyond legal limits) also will improve motor carrier compliance even in cases where enforcement personnel cannot be dispatched to execute a roadside inspection based on VWS data. Enforcement interventions (e.g., warning letters, company visits, inspections) also could be utilized on noncompliant carriers that cannot be addressed in real-time when fixed inspection sites become occasionally overwhelmed by commercial vehicle traffic, which likely will happen even if 100 percent of commercial vehicles could be identified electronically.
- **Improved mobility for compliant motor carriers—**VWS technology will continually verify the compliance of all commercial vehicles with Federal and State regulations but only target enforcement resources at high-risk motor carriers and commercial vehicles. This robust targeting will ensure that

compliant commercial vehicles will avoid being stopped for a roadside inspection even though their compliance with Federal and State regulations will frequently be checked. The targeting will save time and money for compliant carriers while disproportionately delaying unsafe and noncompliant carriers, which should encourage compliance and ensure that noncompliant carriers do not enjoy an operational advantage over compliant carriers.

- **Greater geographic enforcement coverage from limited financial resources**—Many states continue to struggle with deep budget crises that are requiring them to seek alternate and more cost-effective means of doing business. Deployment of VWS has the potential to improve the efficiency of states' roadside enforcement programs while reducing the costs associated with the deployment and operation of roadside assets.
- **Development and maintenance of new data interfaces**—The greatest benefits from VWS technology will be achieved through the deployment of expanded VWS functionality that will leverage deployments to monitor compliance with both size/weight and safety/credentialing regulations. In order to support this expanded functionality, interfaces must be developed and maintained from the roadside to the State's CVISN architecture. CVISN is a national initiative designed to share safety and credentialing information across jurisdictional boundaries; it provides a rich repository of safety and credentialing data for the screening of commercial vehicles and targeting of high-risk commercial vehicles and motor carriers. Other Federal programs (e.g., Performance and Registration Information Systems Management [PRISM], Comprehensive Safety Analysis for 2010 [CSA 2010]) also can provide data to support the real-time screening of commercial vehicles. A forum to discuss these interfaces is provided through FMCSA's Expanded CVISN Roadside Identification Ad Hoc Team, in which FHWA, states, industry, and other parties also participate.
- **Development of new targeting data**—Numerous targeting resources (e.g., ISS, PRISM, Safety Status Measurement System [SafeStat], CVIEW) exist to focus enforcement resources on carriers with poor histories of safety performance and/or noncompliance with credentialing regulations. At this point, there is no similar electronic repository of past performance data for a carrier's compliance with Federal and State size and weight issues and as such, resources cannot be targeted at commercial vehicles operated by motor carriers that routinely operate overweight. FHWA and FMCSA could discuss the possibility to leverage the existing CVISN architecture to provide this information. Similarly, one of the new Behavioral Analysis Safety Improvement Categories (BASICs)—Improper Loading/Cargo—that will be at the core of FMCSA's CSA 2010 program may provide a means to target enforcement resources at carriers that are routinely noncompliant with size and weight standards.

5.0 Summary of Benefits and Costs

5.1 BENEFITS

While no formal evaluation of VWS has been completed, anecdotal information and evaluation results from deployments of similar roadside applications provide examples of the wide range of benefits that likely will accrue to public and private sector stakeholders by VWS. These benefits include:

- **Increased protection and preservation of pavement and the nation's infrastructure—**Overweight trucks are estimated to cause hundreds of millions of dollars in damage to the nation's roadways each year. Virtual weigh stations have the potential to dramatically reduce the damage done to the roadways by overweight vehicles operating illegally (i.e., without a valid OS/OW permit) by expanding the geographic scope of the nation's truck size and weight enforcement programs and deploying enforcement assets into areas currently not monitored by fixed or mobile enforcement resources. Recent research indicates that an 80,000 pound commercial vehicle has the equivalent single axle load (ESAL) value of 26,000 passenger vehicles, while a 100,000 pound commercial vehicle has the same ESAL value as 70,500 passenger vehicles.[9] As such, every illegally operating, severely overweight (at least 20,000 pounds greater than the legal limit) truck that can be removed from the roadways has the same impact on the infrastructure as removing 44,500 passenger vehicles from the traffic flow. State estimates suggest that reducing the number of overweight trucks will save tens of millions of dollars. Arizona estimates that overweight trucks cause $12 million to $53 million in damage to the State's infrastructure annually.[10] A similar study conducted in 1999 found that overweight vehicles in Texas caused an estimated $6 million to $48 million in damage to the State's roads and bridges annually.[11] In addition to reducing this excessive damage to the nation's

[9] American Association of State Highway Transportation Officials (AASHTO), *Virtual Weigh-in-Motion: A "WIM-win" for transportation agencies,* http://www.transportation.org/sites/aashtotig/docs/021907%20Short%20Version.pdf , February 2007.

[10] Eric Volante, "Overweight Trucks Damage Roads, Bridges," *The Arizona Daily Star*, September 11, 2007.

[11] "Keeping overweight trucks from getting a-weigh," *Texas Transportation Researcher,* Volume 35, No. 3.

infrastructure, virtual weigh stations also may increase overall compliance with size and weight regulations because commercial vehicles may be unable to avoid enforcement resources as easily in the future and their operators will therefore be more willing to "voluntarily" comply.

- **Increased efficiency of enforcement assets—**Enforcement personnel continue to be overwhelmed by the number of commercial vehicles operating in the United States and the volume of trips made by these vehicles. Between 1990 and 2006 (the most recent year for which data is available), vehicle miles traveled by large trucks increased by 53 percent and the number of large trucks registered in the United States increased by 42 percent.[12] The sizeable increase in the number and volume of commercial vehicles to be regulated occurred without a corresponding increase in enforcement personnel. As a result, the time between inspections and roadside weighings of commercial vehicles has increased. Further, the potential for a commercial vehicle to avoid enforcement has increased in recent years as commercial vehicles elect to use bypass routes to avoid fixed inspection stations and are less likely to encounter mobile enforcement personnel. Virtual weigh stations have the potential to address these issues by extending a State's enforcement program to bypass and secondary routes and focusing its limited human enforcement assets on commercial vehicles that are known to be overweight or have other increased risk factors (e.g., operated by a carrier with a poor history of safety performance). In addition, VWS data can be used to more effectively schedule enforcement resources and ensure that human assets are deployed at locations/days/times when data indicates there is an increased occurrence of overweight trucks. This improved efficiency of enforcement personnel also will benefit legally operating commercial vehicle operators because it will serve to "level the playing field" and ensure that some operators are not deriving an unfair competitive advantage by operating illegally.
- **Improved highway safety—**The recently completed national evaluation of the Commercial Vehicle Information Systems and Networks (CVISN) program included an in-depth analysis of the safety benefits that could be derived from the increased use of roadside enforcement technologies and the increased targeting of commercial vehicle operators with histories of poor safety performance. This analysis revealed that the nationwide deployment of roadside technologies (e.g., infrared brake testers, safety algorithms associated with high driver OOS rates) could result in as many as 17,907 fewer crashes and 215 fewer fatalities per year than if the inspection selection process was based solely on manual (human) screening.[13] Expanding the

[12] *Large Truck Crash Facts 2006,* Federal Motor Carrier Safety Administration, January 2008, page 4.

[13] *CVISN National Evaluation Report*, Volume 1, Federal Motor Carrier Safety Administration, 2008, page 7-13.

number of technology-equipped sites through the deployment of virtual weigh stations with expanded functionality should directly support these safety results.

- **Improved operations/turnaround time**—As part of the national CVISN evaluation, 848 motor carriers were interviewed to document their experiences using CVISN services, including the program's electronic screening functionality. Similar to VWS, electronic screening targets enforcement resources at high-risk commercial vehicles based on a series of screening factors (e.g., weight, safety performance) and roadside technologies (e.g., WIM, AVI). Nearly 98 percent of motor carrier respondents indicated that they had experienced "reduced delays" based on their participation in the program. Nearly 80 percent of motor carrier respondents also reported reduced labor costs associated with their use of electronic screening.[14] Based on the similarity of the VWS and electronic screening concepts, a similar percentage of motor carriers interacting with VWS likely will derive operational benefits from this technology.
- **Improved freight data for planning**—Having access to accurate data regarding the movement of commercial vehicles across the transportation system is a key component of effective and accurate transportation planning, especially freight planning. These data are used to identify corridors that support commercial vehicle traffic, as well as to provide inputs to travel demand models that forecast the impact of a change to a region's infrastructure. The freight planning community currently is beginning to use data from wireless technology providers (e.g., satellite, cellular) to capture vehicle-specific movements, as well as general corridor-level freight flows and/or system performance. Virtual weigh stations, especially those with expanded functionality, have the potential to generate and provide this type of data to planners and those responsible for overall system performance.
- **Improved air quality**— Idling long-haul trucks are estimated to "consume 20 million barrels of diesel fuel and generate 10 million tons of CO^2, 50,000 tons of nitrogen oxides, and 2,000 tons of particulates annually."[15] While most of this environmental impact is caused by commercial vehicles idling overnight, the targeting of enforcement resources at high-risk motor carriers and commercial vehicles should reduce air quality costs associated with trucks idling while waiting for roadside inspections. The PrePass electronic clearance program estimates that over 309,000 metric tons of carbon emissions have been prevented through its bypass program, which currently

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[14] *CVISN National Evaluation Report*, Volume 1, Federal Motor Carrier Safety Administration, 2008, page 5-13.

[15] Argonne National Laboratories, "Reducing Heavy Truck Idling," http://www.transportation.anl.gov/engines/idling.html.

is deployed at over 280 sites and has 413,224 commercial vehicles enrolled.[16] A nationwide deployment of similar technologies (i.e., VWS) has the potential to substantially increase these benefits.

- **Improved asset tracking—**VWS technologies and other roadside enforcement technologies can generate the requisite data (e.g., vehicle identification, date, time, location) to allow a motor carrier to track its commercial vehicles' movements. To date, motor carriers have expressed minimal interest in accessing VWS data for the purpose of asset tracking because 1) they already use private sector service providers for this function and 2) there are concerns about timeliness and robustness of the data. As VWS is deployed more widely, motor carriers may express an increased interest in this functionality.

5.2 COSTS

VWS is a low-cost alternative to expanding a State's truck size and weight enforcement program. Costs associated with VWS deployments vary by the scope of the VWS being deployed, the amount of existing infrastructure that can be leveraged by a State, as well as the type of technology being deployed. Based on requests to FMCSA for Federal CVISN Deployment funds, estimated costs of recent VWS deployments are between $300,000 and $1,400,000.[17] Even the high-end costs are much lower than the costs associated with building a new fixed weigh station, which typically costs $12 million but can cost as much as $300 million if land acquisition is required.

5.3 AVAILABLE FUNDING SOURCES

Various funding sources are available to support the deployment of VWS. These funding sources include:

- **Federal-Aid Highway Program (FAHP)—**Deployment of WIM systems in conjunction with a VWS deployment may be an eligible FAHP expense. FAHP funding eligibility is determined by the primary intended purpose and use of the WIM. Construction of WIM systems "that directly facilitate an effective vehicle weight enforcement program" are eligible for FAHP funding as defined under "construction" in Section 101(a)(3)(H) of Title 23, United States Code (USC).

[16] PrePass website, www.cvo.com, June 18, 2009.

[17] Data is from State applications for Federal CVISN Deployment Grant applications, Fiscal Years 2006-2008.

- **State Planning and Research (SP&R) program**—WIM systems that are built to primarily support the statewide traffic monitoring program for uses including analysis of travel and weight trends, pavement and bridge monitoring and management, and pavement design, qualify for funding through the State Planning and Research (SP&R) program. These WIM sites can be used secondarily by enforcement personnel for resource planning and commercial vehicle weight screening.
- **Commercial Vehicle Information Systems and Networks (CVISN)**—In the past few years, over a dozen states have used Federal CVISN Deployment Grant funds to implement virtual weigh stations. Among components of the virtual weigh station that are eligible expenses for CVISN funding are WIM scales, cameras, OCR technology, system electronics, screening software, and system integration. A State's CVIEW system, which is an eligible CVISN expense, also can serve as a key data repository in support of VWS deployments (e.g., serve as a database of motor carrier and commercial vehicle safety and credentials data that can be queried by the VWS screening system, serve as a repository for data collected from the VWS). CVISN funds also can be used to support expanded communication networks to support the timely and secure transmission of virtual weigh station data to users, as well as integration of safety data/screening algorithms into roadside operations.

Many states' WIM systems originated as part of FHWA's Strategic Highway Research Program (SHRP) or Long-Term Pavement Performance (LTPP) Program. These programs, focused on pavement research, placed an emphasis on collecting locally- or segment-specific vehicle loadings. Some states have upgraded the WIM systems originally used only for data collection to contain screening capabilities, as found in virtual weigh stations, at relatively low cost. Traffic monitoring functions have remained intact, while the addition of screening capabilities is attractive to the State's enforcement agency and optimizes the utility of the WIM equipment. If consideration is given to using existing WIM sites to support roadside enforcement, a State must be diligent in ensuring that an off-road location is available for enforcement officials to conduct more extensive weighing activities safely removed from the traffic stream should a roadside inspection be warranted.

6.0 Conclusions

6.1 SUMMARY OF IMPROVEMENTS

As previously noted, virtual weigh stations have the potential to:

- Improve operational efficiency and effectiveness of states' roadside enforcement programs by targeting resources at commercial vehicles that are known to be overweight, are known to be operated by carriers with histories of poor safety performance and/or compliance with Federal and State size and weight regulations, or are currently noncompliant with Federal and/or State credentialing regulations;
- Expand the geographic scope of a State's roadside enforcement program to limit the number of roads on which a noncompliant commercial vehicle can operate without being detected by an enforcement resource;
- Improve motor carrier compliance with Federal and State truck size and weight regulations;
- Improve motor carrier safety through improved enforcement and a reduction in the number of operating overweight commercial vehicles;
- Improve productivity of compliant motor carriers through a reduction in the number of roadside inspections to which they are subjected;
- Provide an additional source of tracking information for motor carriers;
- Reduce fuel consumption by legally loaded and operating carriers caused by unnecessary delays at weigh stations;
- Reduce costs associated with new roadside enforcement assets due to the cost differential between deployment of a VWS and a fixed weigh station;
- Improve real-time data sharing with commercial vehicles;
- Provide a rich source of weather and traffic information for system managers; and
- Provide augmented data sources for use by freight and highway planners.

6.2 DISADVANTAGES AND LIMITATIONS

While there currently are no known disadvantages to the deployment of VWS technology, the current state of technology does limit the applications that can be supported by these systems. These limitations include:

- **Universal identification of commercial vehicles currently is not possible—** The only identifiers that currently are common to all commercial vehicles are

license plates, vehicle identification numbers, and USDOT numbers (for interstate motor carriers, as well as intrastate motor carriers in states participating in the PRISM program). Unfortunately, these devices were designed to be read by a human and not by a machine/automated system. License plate readers and USDOT number readers use a combination of cameras and OCR to interpret these visually-based identifiers into data that can be used as part an automated system. The accuracy of the current LPR and USDOT reader technology varies widely due to operational and environmental factors and prohibits all commercial vehicles from being identified by VWS systems at this time. Research is continuing to refine the camera hardware, as well as the OCR software, to improve the reliability of these systems but some states are concerned that optically-based VWS will never be able to achieve the goal of 100 percent identification.

- **Human interaction is still required**—A variety of technical (e.g., accuracy of current WIM technology) and institutional/legal factors dictate that VWS technology serve only as a screening and planning tool for roadside enforcement personnel. VWS deployments currently require that a human issue a citation for any overweight or compliance issue that may be detected. As such, despite the presence of VWS technology a State's enforcement capacity remains limited to the number of enforcement personnel that are on duty at one time in a given region. These enforcement resources can be easily overwhelmed by the number of noncompliant vehicles operating in a region thereby reducing the overall utility and effectiveness of the technology.

6.3 NEXT STEPS

In order to overcome the current technical/operational limitations affecting the effectiveness of VWS deployments, the following should be pursued:

- **Develop architecture for "e-Permitting/Virtual Weigh Stations"**—With the complexity of the data model, business case, and overall use case associated with "e-Permitting/VWS," schematics and diagrams are needed to identify and document data production and storage aspects supporting enforcement and truck support services at the roadside platform. Data interrelationships can be identified, eliminating unnecessary duplication of information employed by the wide array of automated systems operating at the roadside. Data flows enabling all Title 23 and Title 49 of the United States Code truck checks and measurements coupled with State permit verifications, revenue agency oversight interests, and truck company and driver services, need to be mapped in a comprehensive roadside architecture model providing insights that could enhance system performance and deliver Smart Roadside Initiative program objectives.
- **Determine which vehicle identification technology is best suited to identify all commercial vehicles**—A variety of research is underway to

determine the suitability of LPR, USDOT number readers, 900 MHz transponders, passive transponders, 5.9 GHz radios, cellular, and satellite technologies to achieve the goal of identifying 100 percent of commercial vehicles in real-time at highway speeds. Each of these technologies has unique strengths and weaknesses. For instance, while license plate readers currently do not offer 100 percent accuracy, they are based on an identifier (license plate) that is required on all commercial vehicles and for which there is an existing process of distribution and renewal (i.e., the registration process). Conversely, passive transponders, while offering 100 percent accuracy in identification, currently do not have a process by which they can be distributed. The FHWA universal truck identification project is designed to consider these operational and implementation issues and provide greater clarity regarding which technology offers the greatest potential to accurately identify all commercial vehicles at the roadside within three to five years. The benefits/costs associated with mandating a technology also will be evaluated.

- **Conclusively document the benefits of VWS**—The benefit data associated with VWS deployments currently is derived from evaluations of related systems/programs (e.g., electronic screening, CVISN). In order to encourage future deployments of VWS and ensure that deployments are delivering their intended benefits, FHWA should commission a formal evaluation of the VWS concepts. To the extent possible, the evaluation should isolate the relative benefits and costs associated with basic and expanded VWS components so that states can determine which VWS elements they want to deploy.
- **Investigate the deployment of direct enforcement concepts in the United States**—The real compliance, safety, and operational benefits of VWS will be seen if the United States is able to move towards a direct enforcement regime using advanced technology. Several countries in Europe currently employ direct enforcement based on the data from their WIM scales. Similarly, some jurisdictions in the United States use direct/photo enforcement for red-light running and driving through an automated toll lane without a transponder. An alternative to the current VWS model would include a gross vehicle and axle or axle set weight detection system capable of determining vehicle and axle weights with enough accuracy to enable the issuance of citations for violations. Further, research into the institutional and legal implications associated with issuing citations and/or warnings based on an automated system also should be studied. Precedents and lessons learned from other direct enforcement applications (e.g., red-light running cameras) should be a key part of this research.

Appendix – Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AVI	Automatic Vehicle Identification
BASIC	Behavioral Analysis Safety Improvement Categories
ConOps	Concept of Operations
COST	Cooperation in Science and Technology
CSA	Comprehensive Safety Analysis
CVIEW	Commercial Vehicle Information Exchange Window
CVISN	Commercial Vehicle Information Systems and Networks
DOT	Department of Transportation
ESAL	Equivalent Single Axle Load
ETA	Estimated Time of Arrival
FAHP	Federal-Aid Highway Program
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GHG	Greenhouse Gas
GHz	Gigahertz
HSWIM	High-Speed Weigh-in-Motion
IFTA	International Fuel Tax Agreement
IRP	International Registration Plan
ISS	Inspection Selection System
IT	Information Technology
LPR	License Plate Reader

LTPP	Long-Term Pavement Performance
MHz	Megahertz
NCHRP	National Cooperative Highway Research Program
OCR	Optical Character Recognition
OOS	Out-of-Service Order
OS/OW	Oversize and Overweight
PRISM	Performance and Registration Information Systems Management
SAFER	Safety and Fitness Electronic Records
SafeStat	Safety Status Measurement System
SHRP	Strategic Highway Research Program
SP&R	State Planning and Research
TIG	Technology Implementation Group
TMC	Traffic Management Center
UCR	Unified Carrier Registration
USC	United States Code
USDOT	United States Department of Transportation
VII	Vehicle Infrastructure Integration
VIN	Vehicle Identification Number
VMT	Vehicle Miles Traveled
VWS	Virtual Weigh Station
WIM	Weigh-in-Motion
WIM-VID	Weigh-in-Motion and Visual Identification

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16. Abstract

This document describes the concept of operations (ConOps) for the virtual weigh station (VWS). The ConOps describes the goals, functions, key concepts, architecture, operational scenarios, operational policies, and impacts of virtual weigh stations. This ConOps will provide technical guidance to jurisdictions regarding their implementations of the virtual weigh station concept and will be a tool that can be used to plan roadside programs, support states' funding requests, obtain buy-in from public and private stakeholders, and communicate information among State, Federal, and private sector parties. The document consists of six sections:

1. **Section 1.0, Introduction –** Provides the context for developing a concept of operations for the virtual weigh station.
2. **Section 2.0, Current Situation –** Reviews current roadside enforcement operations and existing virtual weigh station deployments.
3. **Section 3.0, Motivation for Virtual Weigh Station –** Describes the challenges and needs underlying states' virtual weigh station deployments and the operations that will address the challenges.
4. **Section 4.0, Concept of Operations –** Presents the operational scenarios, information needs, and functionality associated with virtual weigh stations.
5. **Section 5.0, Summary of Benefits and Costs –** Relates the expected benefits and costs of deploying virtual weigh stations.
6. **Section 6.0, Conclusions –** Summarizes the enforcement improvements gained from virtual weigh stations, as well as limitations and next steps.

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