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North/West Passage Freight Task Force - Year 3

Working Paper 2: Virtual Weigh Station Research

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North/West Passage Freight Task Force

The North/West Passage Freight Task Force (Task Force) was established in 2014 to enhance activities and help realize the North/West Passage Corridor's vision of developing effective methods for sharing, coordinating, and integrating traveler information and operational activities across state and provincial borders.

Year 3 activities of the Task Force are being pursued to continue the momentum of work conducted during Years 1 and 2. Specifically the activities are designed to 1) support the active engagement of Task Force members on emerging freight operations issues in the corridor and nationally, 2) conduct research on and recommend criteria for regulations in the corridor to support truck platooning, and 3) recommend guidance for selecting virtual weigh station deployments in the North/West Passage states.

Working Paper

This Working Paper represents the Task 4 deliverable. The aim of Task 4 is to research the current state of practices and available infrastructure for commercial vehicle weight enforcement in the NWP, and provide suggestions and guidelines for moving towards virtual technology deployment.

Acknowledgments

The CPCS Team acknowledges, and is thankful for, the input of those consulted in the development of this Working Paper, as well as the guidance and input of representatives from state trucking associations, state DOTs, and the state highway patrol officers.

Opinions

Unless otherwise indicated, the opinions herein are those of the authors and do not necessarily reflect the views of North/West Passage.

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Table of Contents

Table of Figures

Acronyms / Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
CVES	Commercial Vehicle Enforcement Systems
CVISN	Commercial Vehicle Information System and Network
DOT	Department of Transportation
ELD	Electronic Logging Device
ESAL	Equivalent Single Axle Loads
ESD	Electronic Screening Devices
FAF	Freight Analysis Framework
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
ILD	Inductive Loop Detectors
ISP	Idaho State Police
ITD	Idaho Transportation Department
LiDAR	Light Detection and Ranging
LPR	License Plate Reader
MDT	Montana Department of Transportation
MnDOT	Minnesota State Department of Transportation
MSHA	Maryland State Highway Administration
MSP	Minnesota State Patrol
NDDOT	North Dakota Department of Transportation
NORPASS	North American Preclearance and Safety System
NWP	North/West Passage
POE	Ports of Entry
RADAR	Radio Detection and Ranging
RITIS	Regional Integrated Transportation Information System
SDDOT	South Dakota Department of Transportation
TIG	Technology Implementation Group
TWIS	Truck Weigh and Inspection Station
U.S.	United States
VMT	Vehicle Miles Traveled
VWS	Virtual Weigh Station
WIM	Weigh In Motion
WSDOT	Washington State Department of Transportation
WYDOT	Wyoming Department of Transportation

Executive Summary

Virtual weigh station (VWS) technology consists of Weigh-In-Motion (WIM) sensors and scales, digital imaging devices, communication methods, and other equipment that provide commercial vehicle records and real-time size and weight data to enable commercial vehicle size and weight enforcement staff to remotely monitor compliance with size, weight, and safety regulations.

In a virtual weigh station, the weight, size, digital image, and driver's credentials data of an overweight commercial vehicle are collected while the vehicle is in motion. The data is then communicated with the enforcement staff to perform follow-up procedures.

In current VWS practices in the U.S., weight, size, and drivers' credentials data of an overweight commercial vehicle are collected while the vehicle is in motion. Also, digital imaging devices capture a vehicle's image, license plate number, and the U.S. Department of Transportation (USDOT) registration number. The screening software then processes the data and notifies the enforcement staff who either intercept the violators and reweigh and inspect the vehicles using portable devices or direct the drivers to a nearby weigh station for follow-up procedures. In expanded VWS operations, the screening software can generate notices or issue tickets based on the collected information, without the need for human resources to intercept the vehicles.

Virtual weight enforcement practices can increase the efficiency of weight enforcement and improve highway safety for all road users. The cost associated with implementing VWS technology is significantly lower than more traditional weigh station operations. A virtual facility has negligible land acquisition costs compared to fixed or mobile operations and has lower labor costs as it can operate unstaffed or with minimal staffing. Additionally, the costs savings resulting from efficiency and safety improvements are expected to be even greater, making emerging VWS technology an attractive option for state Department of Transportations (DOT) and state highway patrol departments.

"Weigh station" and "weight enforcement facility" are terms used interchangeably in this document.

Virtual weigh stations increase enforcement efficiency, improve safety, and reduce costs.

Most North/West Passage (NWP) states have already developed weight enforcement Concept of Operations (ConOps) reports and laid the groundwork for virtual technology applications through statewide data collection facilitated by WIM technology deployment. For instance, Idaho, Montana, Washington, and Minnesota have actively conducted virtual technology demonstrations, data collection projects, as well as pilot programs. Overall, state DOT and

highway patrol staff believe that virtual technology deployment has the potential to significantly increase efficiency and decrease the resource-intensiveness of commercial vehicle weight enforcement practices.

Building from this basis of existing WIM data collection sites and previous ConOps reports, the NWP states that are interested in a more advanced VWS technology application will need to work with technology vendors who can provide hardware and technical expertise to equip the WIM locations with advanced weigh scales, effective digital imaging systems, and a reliable remote access platform.

Benefits of VWS Technology Deployment

After an initial review of the current weight enforcement practices in the U.S., especially in the NWP states, a series of consultations were conducted with stakeholders to get a better understanding of the differences in truck weight enforcement operations between states and to gather lessons learned from deploying weight and size compliance technologies. The three categories of stakeholders consulted for this purpose were State DOT staff, highway patrol officers and trucking associations. All of these groups consistently considered VWS technology as a valuable screening tool on major highway corridors to identify potential violators for further inspection at nearby fixed or mobile facilities. Specifically, the stakeholders pointed out that the most important benefit of VWS would be fewer staff involved with weighing of a commercial vehicle, which leads to improved enforcement efficiency. According to the consultations, if well implemented, virtual weigh stations may also reduce the safety issues that overweight trucks impose on other road users, due to their higher kinetic energy which increases the likelihood and the severity of a crash.

Virtual technology is considered as a valuable screening tool for identifying the potential size and weight law violators.

Another important benefit of VWS technology is better management of staff time and availabilities. VWS can operate without the need for dedicated staffing, allowing for 24/7 monitoring and enforcement operations. Also, in VWS operations, enforcement staff are either positioned at an administration office or in a patrolling vehicle, monitoring commercial vehicle traffic remotely. Such remote roadside monitoring would expand enforcement operations by reducing the truckers' chance to take alternate routes to avoid stopping at weigh stations.

In general, the stakeholders' expectations for virtual technologies include:

- Safety improvement due to a reduction of truck-related crashes;
- Congestion and delay reduction on highways due to efficient weigh station operations;
- Reduction in fuel consumption and environmental pollution due to vehicle idling reductions;
- Decrease in total logistics costs of freight companies due to fuel consumption reduction;

- Highway and bridge infrastructure protection;
- Reduction in costs of highway infrastructure maintenance and weight/size enforcement activities; and
- Improved commercial vehicle traffic data availability and reliability.

Challenges of VWS Technology Deployment

As is the case with any computer-based system, an inherent challenge associated with virtual weight enforcement applications is privacy. The sensitivity of the information collected by the digital imaging systems of a VWS and the possibility of hacking the system is a matter that worries the carriers and truckers, and also affects the extent to which the state transportation and law enforcement agencies can implement the virtual technology. In current practice, VWS operations are only for the purpose of monitoring and prescreening, providing the enforcement staff with probable cause to intercept potential violators. However, the trucks should be weighed again and inspected in the presence of enforcement staff before being cited for violations.

The data sensitivity concerns around the virtual weigh station operations limit the extent to which the enforcement staff can implement the virtual technology.

Moreover, the automatic notification/citation step of expanded virtual technology applications raises concerns related to due diligence and lack of consideration of context. Regulators and carriers alike want to ensure that a level of tolerance is introduced in the system to deal with the first-time violation cases or special circumstances. Other challenges associated with VWS technology identified by the stakeholders are:

- Lack of funding programs and the need for legislative reforms;
- Technical issues such as wireless network connection problems exacerbated by inclement weather;
- Pavement surface conditions which limit the accuracy of scale results; and
- Lack of staff and financial resources for periodic scale calibration.

1 Introduction

1.1 Project Background

The North/West Passage (NWP), is a multi-state operations-focused partnership initiated in 2002 between the Departments of Transportation (DOTs) in the states of Idaho, Minnesota, Montana, North Dakota, South Dakota, Washington, and Wyoming. These states work together to address operational challenges on Interstates 90 and 94, often associated with extreme weather, to improve passenger and commercial vehicle highway safety and reliability. Operational issues relevant to commercial vehicles include truck parking management, traveler information, truck permitting and enforcement, and other operational issues.

The North/West Passage Freight Task Force (Task Force) was established in 2014 to enhance North/West Passage activities and help realize the North/West Passage Corridor's vision of…

…developing effective methods for sharing, coordinating and integrating traveler information and operational activities across state and provincial borders.

The year 3 activities of the Task Force continue the momentum of work conducted during Years 1 and 2. Specifically these activities aim to 1) support the active engagement of Task Force members on emerging freight operations issues in the corridor and nationally, 2) conduct research on and recommend criteria for regulations in the corridor to support truck platooning, and 3) recommend guidance for selecting virtual weigh station deployments in the North/West Passage states. Each of these activities is aimed at getting the coalition closer to the implementation of projects that will improve freight operations in the NWP corridor.

1.2 Purpose of this Working Paper

The purpose of this working paper is to provide an overview of current weigh station applications in the U.S. and suggest the key steps for developing a virtual weigh station Concept of Operations (ConOps) in the NWP states based on the best practices and lessons learned in other states.

1.3 Methodology

A combination of desk research and stakeholder consultations were used to understand commercial vehicle weight enforcement applications across the country and provide a guide for developing the concept of operation for future virtual weigh station applications in the NWP states.

The working paper is organized into three chapters:

1. **Commercial vehicle size and weight enforcement practices**: focusing on commercial vehicle weight and size regulations and enforcement methods including an overview of infrastructure and technology used in different weight enforcement facilities. This section also includes an overview of the weight enforcement facilities in the NWP states.
2. **Needs, challenges, and best practices**: reviewing the needs and challenges associated with VWS applications across the country through a combination of desk research and consultations.
3. **Developing a virtual weigh station concept of operations**: reviewing the ConOps for the virtual weigh stations as laid out by the FHWA guide in 2009, and describing the necessary steps for creating a ConOps that could facilitate implementation/expansion of virtual weigh/size monitoring practices.

1.4 Limitations

Some of the findings in this report are based on the analysis of third-party data. While CPCS makes efforts to validate data, CPCS cannot warrant the accuracy of third-party data.

2 Commercial Vehicle Size and Weight Enforcement Practices

Key Chapter Takeaway

This chapter provides an overview of commercial vehicle size and weight regulations and enforcement methods. Commercial vehicle weight regulations aim to protect roadway infrastructure from excessive wear and tear and reduce the safety issues associated with overweight trucks. Truck size and weight regulations may vary depending on the road type and jurisdictional boundaries.

The federal minimum allowable vehicle length on and off the interstate system is 65 ft. to 75 ft., depending on the type of connection between truck and the trailer with exceptions for the states with grandfathered minimum length. While on the interstate and highway bridge system, the federal legislation uses a formula to define weight limits, state DOTs are responsible for setting the weight limits off-interstate. The state DOTs cooperate with the state highway patrol offices to control the commercial vehicle compliance with federal and state size and weight limits. There are three primary types of weigh station operations: fixed, mobile, and virtual, each with a different purpose, infrastructure, and technology.

2.1 Commercial Vehicle Size and Weigh Compliance

Roadways are engineered and constructed based on the number of Equivalent Single Axle Loads (ESAL) they can carry over a specified period. One ESAL is equal to 18,000 pounds per single axle for rigid pavement and 20,000 pounds per single axle for flexible pavement. Regardless of the pavement type, the amount of pavement life decreases drastically as the gross vehicle weight per axle increases exponentially.

The load-equivalence factors provided by the American Association of State Highway and Transportation Officials (AASHTO) follow a fourth-power relationship. Thus a 5,000-pound increase in the vehicle weight per axle on rigid pavement surfaces results in a 1.5 ESAL which means a 50% increase in the wear and tear impacts on the pavement.[1]

[1] FHWA and USDOT (1995) Comprehensive Truck Size and Weight (TS&W) Study Phase 1—Synthesis: Working Paper 3—Pavements and TS&W Regulations. Available at: https://www.fhwa.dot.gov/reports/tswstudy/TSWwp3.pdf

Also, studies show that a 1% increase in the number of overweight trucks traveling on roadways leads to 1.8% reduction in pavement lifespan. This relationship is linear regardless of the pavement structure and traffic configuration.[2]

Commercial vehicle weight regulations aim to protect roadway infrastructure from excessive wear and tear. Moreover, weight regulations reduce the safety issues that overweight trucks impose on other road users. Overweight trucks have higher kinetic energy which increases the likelihood of the truck being involved in a crash and the severity of the crash. Also, overloaded trucks may be unstable, leading to loss of maneuverability and suspension performance reduction which in turn, results into braking defaults.[3]

These regulations may vary depending on the road type and jurisdictional boundaries. For instance, while the federal weight regulations apply only to the Interstate Highway System the length and width regulations apply to the National Network (NN).[4] On the other hand, the states can define the size and weight limits off the interstate and NN system or use the grandfathered limits that exceed the federal limits. The following subsections provide a summary of the federal and state commercial vehicle size and weight regulations.

The National Network established by the Surface Transportation Assistance Act (STAA) of 1982, includes the interstates and other designated highways on which trucks are allowed to travel. The NN and the National Highway System (NHS) both cover about 200,000 miles of highways across the country. However, NN includes 65,000 miles of highway outside of the NHS system while the NHS includes about 50,000 miles of highway that are not part of the NN system (*U.S. DOT, FHWA, Office of Freight Management and Operations-Last modified 2017*).

2.1.1 Commercial Vehicle Size Limitations

The federal commercial vehicle size regulations define the minimum truck length allowed in different states. Overall, the maximum allowable length on and off the NN system is 65 ft. to 75 ft., depending on the type of connection between truck and the trailer, with exceptions for the states with grandfathered minimum length. There are no federal commercial vehicle height requirements, yet the states usually set their limitations ranging from about 13.6 ft. to 14.6 ft. The maximum allowable commercial vehicle width on and off the NN system is 102 inches, and the States must issue special permits to allow the trucks wider than 102 inches to operate.[5]

[2] Wang H., Zhao J., Wang Z., 2015, "Impact of Overweight Traffic on Pavement Life Using Weigh-In-Motion Data and Mechanistic-Empirical Pavement Analysis", Virginia Tech Library. http://hdl.handle.net/10919/56450
[3] Jacob et al. "Improving truck safety: Potential of weigh-in-motion technology" (2010). https://doi.org/10.1016/j.iatssr.2010.06.003
[4] American Trucking Association "Federal Truck Size and Weight Regulation" (November 2018). https://www.trucking.org/article/ATA-Position-on-Federal-Truck-Size-and-Weight-Regulation
[5] FHWA, Federal Size Regulations for Commercial Motor Vehicles (May 2018).

2.1.2 Commercial Vehicle Weight Regulations

On the Interstate Highway System

On all highway bridges, commercial vehicles should conform to the following formula, which defines a maximum weight for different axle group of trucks as:

$$Maximum\ Truck\ Weight\ Allowed = 500\left(L \times \frac{N}{N-1} + 12N + 36\right)$$

Where "L" is the distance between the axles and "N" is the number of axles.[6]

Figure 2-1: Federal Commercial Vehicle Maximum Standards on the Interstate System

Commercial Vehicle Axles	Maximum Allowable Weight*
Single	20,000 pounds
Tandem	34,000 pounds

*Maximum gross vehicle weight = 80,000 lb.

Source: FHWA Report to Congress (2015) Compilation of Existing State Truck Size and Weight Limit Laws.

As Figure 2-1 shows, the federal law sets an overall 80,000 lbs. as the gross vehicle weight limit for commercial vehicles. Federal law also limits the maximum weight of single axle trucks to 34,000 lbs. and double-axle trucks to 68,000 lbs.

Off the Interstate Highway System

Off the interstate system, different states may have different sets of standards for allowable commercial vehicle weight. Figure 2-2 shows the commercial vehicle weight regulations in the NWP states.

Figure 2-2: Summary of NWP States Truck Weigh Limits for Vehicle in Regular Operations

State	Montana	Minnesota	Idaho	North Dakota	South Dakota	Washington	Wyoming
Single Axle	20,000	10,000-20,000	20,000	20,000	20,000	20,000	20,000
Tandem Axle	34,000	34,000	34,000	17,000-34,000	34,000	State Table	36,000
Tridem Axle	State Table	42,000	State Table	48,000	Federal Table	State Table	42,000
Gross Weight	131,060 - 137,800	80,000	80,000	105,500	State Table	105,500	80,000-117,000

Source: FHWA Report to Congress (2015) Compilation of Existing State Truck Size and Weight Limit Laws.

There are also different state requirements governing which trucks that must stop at weigh stations. The following table is an overview of the stopping conditions in the NWP states.

[6] FHWA Report to Congress (2015) Compilation of Existing State Truck Size and Weight Limit Laws.

Figure 2-3: Stopping Conditions at NWP States' Weigh Stations

State	The Condition for Stopping at Weigh Stations	Source
Montana	All trucks or truck combinations with a gross vehicle weight of 26,000 lbs. or more.	MDT
Minnesota	All truck with a gross weight of 10,000 lbs. and more.	MnDOT
Idaho	All trucks or truck combinations with a gross weight of 26,001 lbs. or more; all trucks hauling hazardous materials and livestock with a gross weight of 10,001 lbs. or more.	ITD
North Dakota	All trucks.	NDDOT
South Dakota	All trucks and drive-away operations with a gross weight of 8000 lbs. and more.	SDDOT
Washington	All trucks with gross weight of 16,000 lbs. and more.	WSDOT
Wyoming	All trucks are required to stop when flagged by an officer or a regulatory sign.	WYDOT

Source: CPCS compilation of stopping condition provided at the states trucker's handbooks or commercial vehicle guides.

2.2 Weigh Station Operations

Weigh stations are checkpoints located along major highways and ports of entry to inspect commercial vehicle compliance with federal and state size and weight regulations. While measuring the size and weight of trucks, the state enforcement agency staff may inspect the following safety-related features as well:

- Drivers' license, logbook, Electronic Logging Devices (ELDs), and permits;
- Drivers' medical examination records;
- Compliance with hazmat transportation requirements;
- Vehicles' physical appearance (checking safety based on visual clues); and
- USDOT number and vehicles' violation records.

In the traditional method of operation, either all the trucks or only the trucks with specific configurations must stop at the weigh stations. The limited processing capacity of this method, especially during peak times, may cause truck queue spillbacks which can lead to blocking of highway lanes and creating bottlenecks. In such situations, the enforcement staff may decide to randomly select some of the trucks for inspection to address the limited processing capacity of the station. However, the level of success in the random selection method is highly dependent on the number of trucks already waiting at the weigh station and the officers' ability to distinguish visual clues associated with overweight vehicles. To address such issues, the majority of weigh stations in the U.S. deploy electronic screening technologies to allow the registered vehicles to legally bypass the stations. Studies show that electronic prescreening can improve inspection effectiveness by 28% compared to random selection method.[7]

[7] State Highway Administration, Maryland Department of Transportation "Maryland Virtual Weigh Station" (2009).

The following sections discuss the weigh station infrastructure and technologies in more detail and provide an overview of the different types of commercial vehicle weight enforcement methods.

2.3 Commercial Vehicle Weigh Station Technologies and Infrastructure

The following are the typical infrastructure components and technology used in weigh station operations:

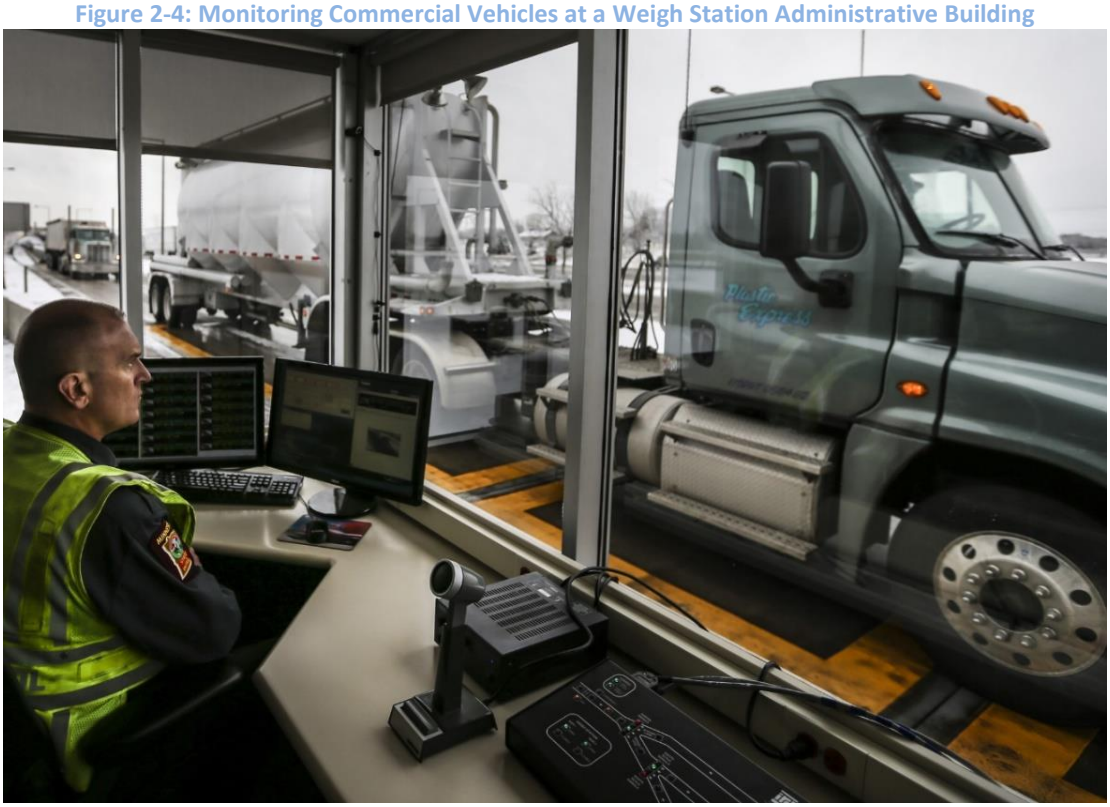
- Administrative Building
- Truck Scales
- Bypass Technologies
- Bypass Lanes
- Enforcement Camera and License Plate Reader (LPR)
- Inductive Loop Detectors (ILD)
- RADAR/LiDAR Technology
- Communication Method
- Pre-selection Board
- Weigh-In-Motion Technology

Each of these components is further described in the following sections.

2.3.1 Administrative Building

Most fixed weigh stations include an administrative building which functions as the hub of the facility, serving as the base of operations. Activities performed at the administrative building typically include vehicle safety inspections and weighing, checking permits, credentials, and Electronic Logging Devices (ELD). Figure 2-4 shows a highway patrol officer monitoring commercial vehicle weight and credentials at a weigh station administrative building located on I-94 in Minnesota.

Figure 2-4: Monitoring Commercial Vehicles at a Weigh Station Administrative Building



Source: Star Tribune (May 2018). http://www.startribune.com/when-big-rigs-push-past-the-safety-rules/321965591/

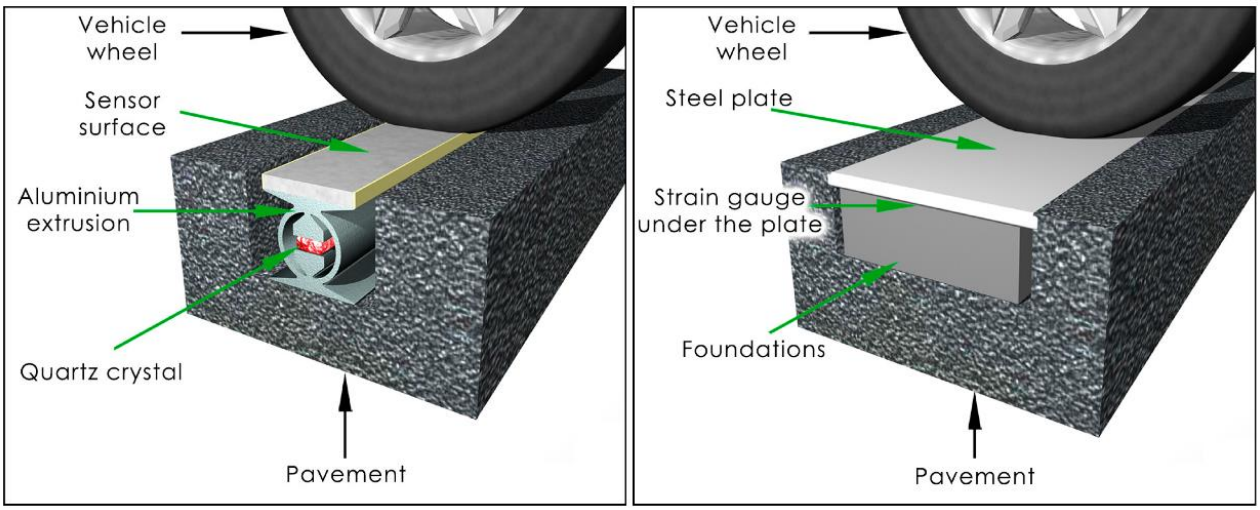
2.3.2 Truck Scales

The scales used to measure truck weights are comprised of a series of sensors that can measure the vertical force imposed by an object standing on or passing over them. Load cell, bending plate, strip sensors, and piezoelectric are the most common types of truck weighing scales.

In the load cell system, wires embedded in steel cells transmit the vertical energy applied to them as a mild electric current. Similar to the load cell system, the bending plate system uses strain gauges to transfer the stress caused by a truck's weight to a change in the wires' impedance. A computer then collects this electric signal and calculates the truck weight.

In the piezoelectric system, the quartz crystals or other polymers embedded in the pavement produce electricity proportional to the force applied to them and then send a high impedance charge signal to a voltage output connected to the weight analysis system. Figure 2-5 shows the differences between a bending plate system and a quartz scale.

Figure 2-5: Quartz Sensors (Left) and Bending Plate System (Right)



Source: Piotr Burnos and Janusz Gajda (2016), Thermal Property Analysis of Axle Load Sensors for Weighing Vehicles in Weigh-in-Motion System, MDPI Open Source Journal.

Studies compare the different types of truck weighing systems based on their cost, reliability, accuracy, sensitivity, and applicability. The following table summarizes these features for selecting truck weighing scales.

Figure 2-6: Comparison of the Commercial Vehicle Weight Sensors

Scale Sensor Type	Number of Sensors Required per Lane	Life Years	Sensor Installation Cost ($)	
			Low	High
Polymer Piezo	4	2-3	4,000	6,400
Quartz Piezo	2	3-5	16,000	24,000
Strain Gauge/Strip Sensor	2	3-5	16,000	24,000
Bending Plate	2	6-8	18,000	28,000
Load Cell	2	10-12	44,000	53,000

Source: FHWA "WIM Pocket Guide" (2018).

As Figure 2-6 shows, load cell scales have a relatively higher cost but longer expected lifetime compared to other scale sensors. These factors are important considerations when planning a weigh station facility. Other factors such as the level of required accuracy, calibration methods, pavement type, and projected truck traffic also affect the type of scale system selected for a weigh station facility.

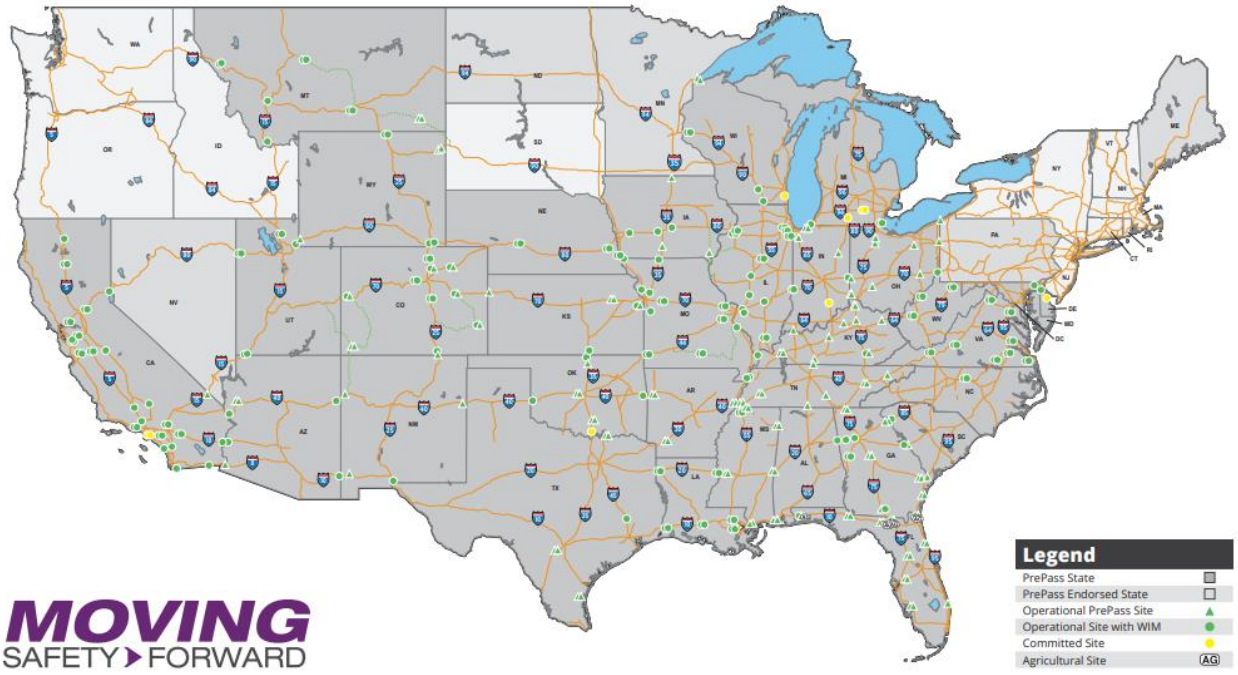
2.3.3 Bypass Technologies

The Electronic Screening Devices (ESD) that allow registered commercial vehicles to bypass the weight stations legally are collectively called "bypass technology" in this working paper. The technology includes an in-vehicle sensor and an external reader. The sensor can be a specialized transponder mounted on the inside of the truck windshield (similar to toll collection transponders), a smartphone, an electronic logging device, or other electronic devices used by the driver. When a truck passes by a participating station, the reader device at the roadside checks the trucks' credentials, permits, and additional information and allows them to pass by the weigh

station without stopping. Multiple vendors in the U.S. offer weigh station bypasses via their technology applications. These differ by state, and the most widespread of these are noted below.

PrePass: this system operates with a driver-specific transponder and is currently operating in 35 states with more than 360 participating weigh stations (Figure 2-7). From the NWP states, weigh stations in Idaho, Montana, North Dakota, South Dakota, Washington, and Wyoming participate in PrePass operations.

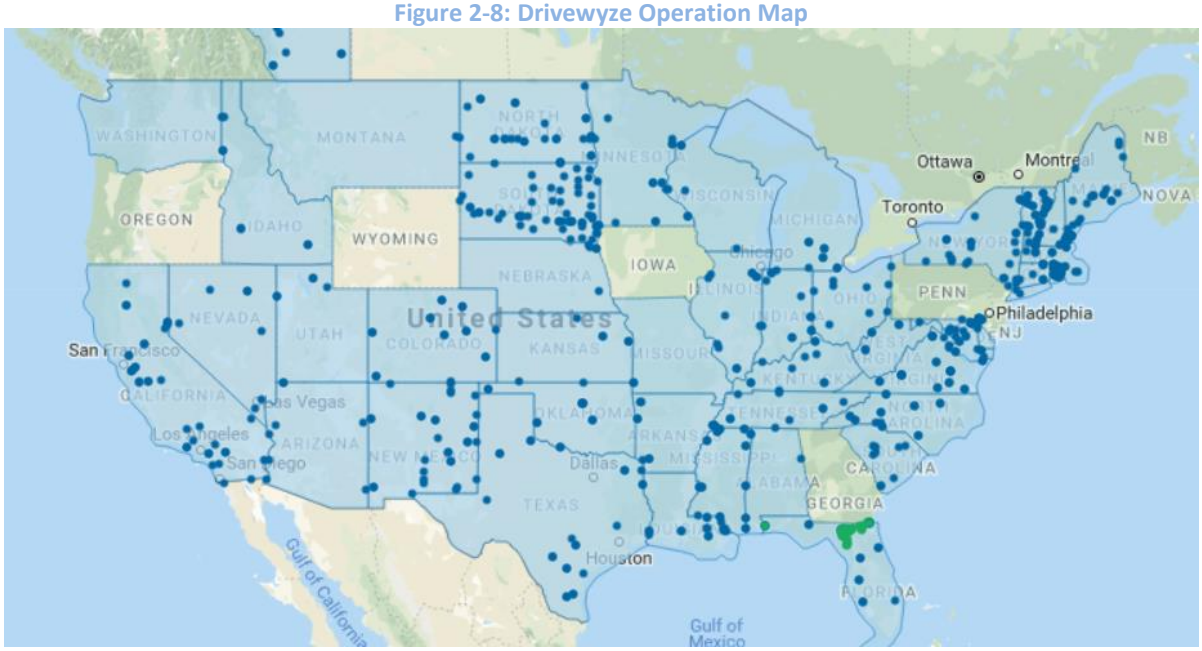
Figure 2-7: PrePass Operation Map



Source: PrePass Online Interactive Map (May 2018). https://prepass.com/wp-content/uploads/2017/09/PP_CombinedMaps_20170426.pdf

Drivewyze: this system operates with an application installed on smartphones and tablets to provide legal bypassing option at participating weigh stations. This system operates in 43 states with more than 700 locations (Figure 2-8). The NWP states, of Idaho, Washington, Montana, North Dakota, South Dakota, and Minnesota participate in Drivewyze bypassing operations.

Figure 2-8: Drivewyze Operation Map



Source: Drivewyze Online Interactive Map (May 2018). https://drivewyze.com/coverage-map/

NORPASS: the North American Preclearance and Safety System operates with in-vehicle transponders issued by the state DOTs in cooperation with the North American Trucking Industry. This system exists in 10 U.S. states and Canadian provinces to increase the efficiency of weigh station services. Idaho, Washington, and South Dakota participate in the NORPASS program.

In 2012, NORPASS partnered with Drivewyze to offer bypass opportunity in additional sites. Recently in 2018, NORPASS signed a partnership with PrePass for using a single transponder to expand its service even further.[8]

National Safety and Credential Information

The Commercial Vehicle Information System and Network (CVISN) is a grant program administered by the Federal Motor Carrier Safety Administration (FMCSA) to support commercial vehicle data sharing, increase weight and size efficiency, and improve the safety of commercial vehicle operations. The CVISN provides some states[9] with access to nationwide safety and credential information to enable identification of violators and unsafe trucking operators. The safety information exchange process is through CVIEW and CVIEW-Safer operational system. CVIEW is the inter-agency data sharing platform at the state level that can be used to access

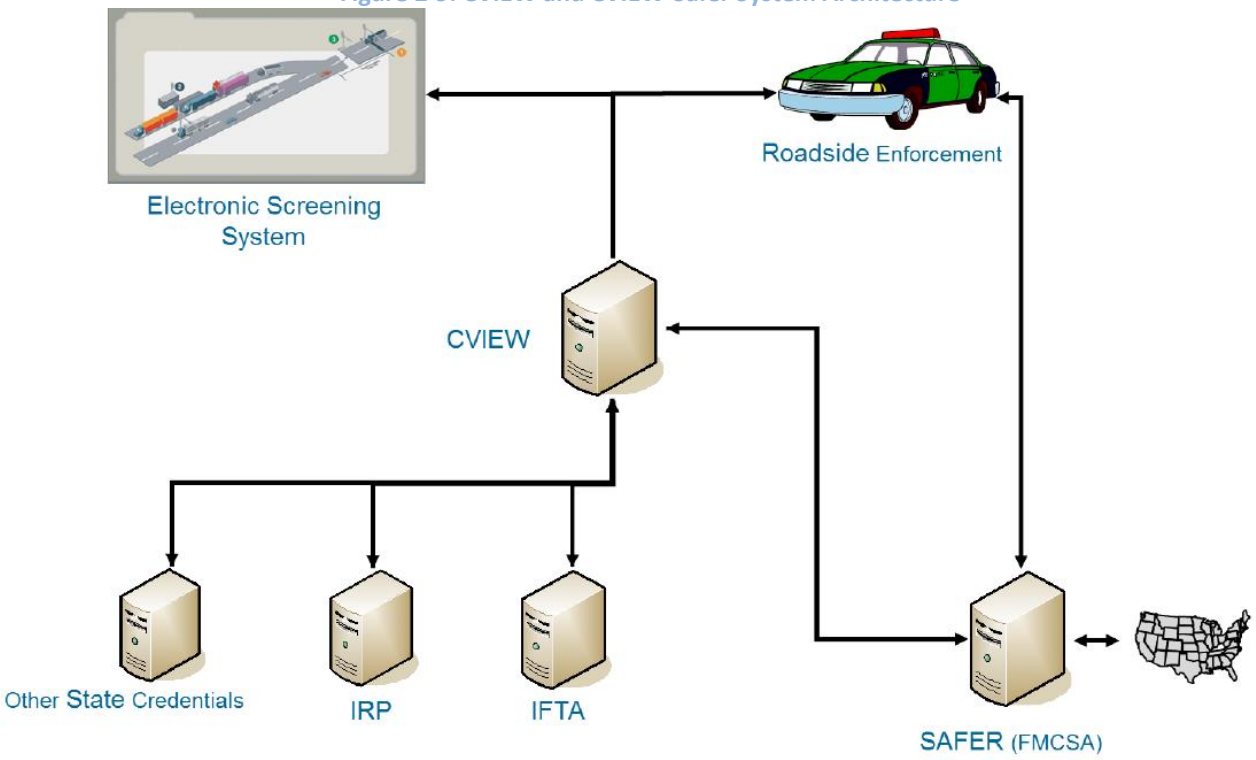
[8] CJJ Staff "PrePass creates single-transponder agreement with NORPASS" (May 2018). https://www.ccjdigital.com/prepass-creates-single-transponder-agreement-with-norpass/

[9] According to USDOT's Intelligent Transportation Systems program, 50 states and District of Columbia have access to CVIEW safety data while only 33 states have access to both CVIEW and CVIEW-Safer safety information. 48 states are participating in credential data clearinghouse activities and 40 states are currently using ESD for credential and safety inspection. For more information see: https://www.its.dot.gov/research_archives/cvisn/cvisn_progress.htm

vehicle credential data sources such as the truck credential database of other states, International Registration Plan (IRP)[10] data, and the International Fuel Tax Agreement (IFTA)[11] information. The CVIEW-Safer is an inter-state data sharing platform, accessible by certified users only.

The following figure shows the safety and credential information exchange process. The roadside enforcement computer and the electronic screening devices installed at a fixed facility's entrance or a virtual facility receive statewide data from CVIEW and have certification to access CVIEW-Safer for nationwide safety and credential data. Fourteen jurisdictions received Federal Commercial Vehicle Information Systems and Networks (CVISN) Deployment Grants in Fiscal Years 2006 – 2008 to deploy VWS technology.

Figure 2-9: CVIEW and CVIEW-Safer System Architecture



Source: FHWA "Introduction to Commercial Vehicle Information Systems and Networks" (2012).

2.3.4 Bypass Lanes

Weigh stations often have multiple lanes parallel to highways which allow the using registered ESDs to legally pass the stations without stopping. Bypass lanes may have WIM scales embedded underneath their pavement surface for recording truck weight and often operate together with

[10] IRP is an international registration agreement between the U.S. states, District of Columbia, and the Canadian provinces to facilitate inter-state and international commerce through registration fee payments allocated based on vehicle miles traveled. More information available at: https://www.irponline.org/

[11] IFTA is a registration agreement between 48 states of the U.S. and Canadian provinces to facilitate fuel tax payments for carriers and truckers involved in inter-state and international commerce. More information available at: https://md.iftaipc.com/login.aspx?ReturnUrl=%2fDefault.aspx

other weigh station technologies such as State DOT number readers and other intelligent transportation system devices that check a truck's credentials.

2.3.5 Enforcement Camera and License Plate Readers

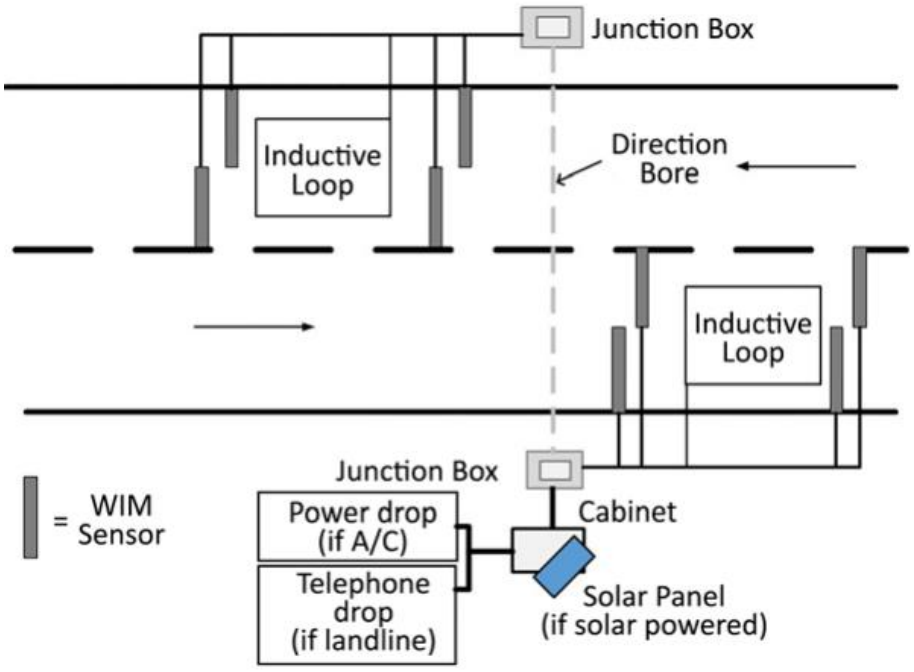
Cameras and other optical character recognition devices such as license plate readers (LPR) and USDOT number readers facilitate the identification of potential violators. The weight sensors in the pavement trigger the enforcement camera when they detect an overweight truck passing. The photo captured from the potential violators is then transferred to an analysis system that records the photos or converts the image data into usable information like a license plate number.

2.3.6 Inductive Loop Detectors

Inductive Loop Detectors (ILD) are vehicle detection devices that use electrically conductive loops embedded in the road surface that are connected to a controller box at the roadside. When a vehicle is stopping or passing over the loops, the vehicle's metal frame alters the system's magnetic field, and a controller receives a signal for changes in the inductance and records the event. Other than vehicle counts, ILD sites may provide detailed vehicle signature information which facilitates vehicle classification. Also, two sets of ILDs installed in a short distance enable the analysis system to capture vehicle speed.

The ILD technology is often used combined with a truck weighing system to calculate weight per axle. As the following figure shows, the first ILD defines the vehicle's configuration, and the scale system measures the vehicle's gross weight. The analysis system then interprets this combined information into weight per axle. The second ILD facilitates vehicle speed calculation.

Figure 2-10: Example of a Weight Scale and ILD Combination Layout



Source: FHWA "WIM Pocket Guide" (2018).

2.3.7 RADAR/LiDAR Technology

Radio Detection and Ranging (RADAR) and Light Detection and Ranging (LiDAR) are systems that use radar waves or light waves to detect objects. When mounted on a pole at the roadside, RADAR and LiDAR equipment can capture vehicles' size, speed, and configuration, and thus replace ILD technology. The combination of RADAR or LiDAR technology with weighing sensors facilitates trucks' weight per axle calculation.

2.3.8 Communication Infrastructure

A weigh station's central computer may use various types of applications to communicate the information (such as weight data, photos, etc.) captured from multiple devices, with the authorized personnel in patrolling vehicles or at the weigh stations. These communication methods can be wireless, meaning that the information is updated on an online platform and should be accessed using internet connection, or closed circuit, which does not rely on an internet connection for operation. The following figure presents an online weigh station communication interface which displays vehicle weight and configuration information real-time.

Figure 2-11: Example of Real-Time Communication Interface

Source: Cardinal Scale Manufacturing Co. (May 2018) http://wimscales.com/product/virtual-weigh-stations/

2.3.9 Pre-selection Board

The information collected by the WIM system may be combined with other technology such as LPR and USDOT readers to provide legal bypass permission prior to a weigh station entrance. The following figure provides an example of a pre-selection board that communicates bypass signals with the truck drivers at Inkom weigh station in Idaho.

Figure 2-12: Example of a Weigh Station Pre-Selection Board

Source: Overdrive (February 2017) Idaho adds weigh-in-motion system at I-15 weigh station. Available at: https://www.overdriveonline.com/idaho-adds-weigh-in-motion-system-at-i-15-weigh-station/

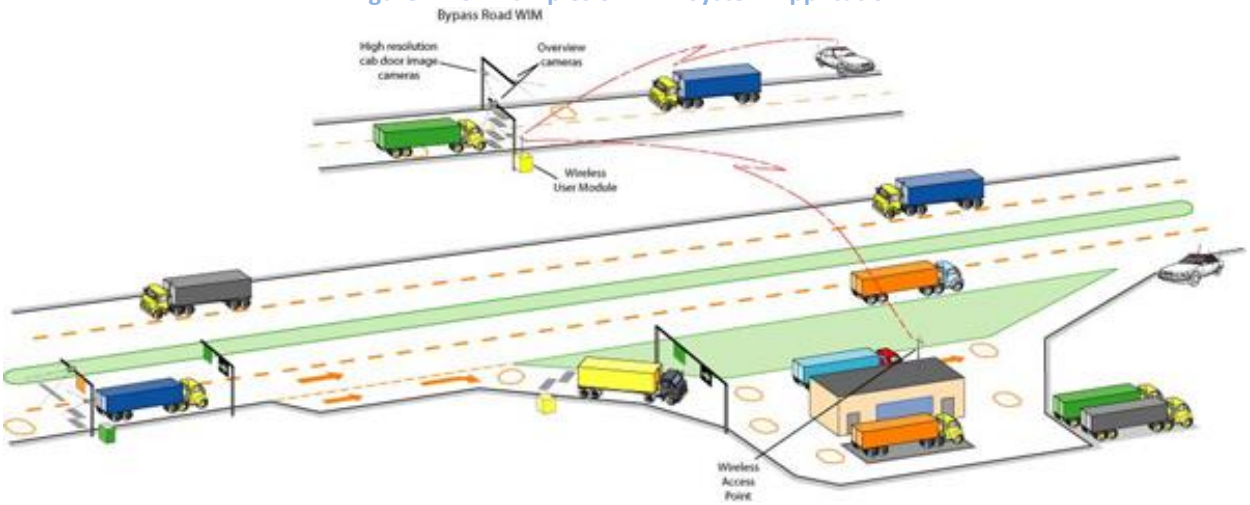
2.3.10 Weigh-In-Motion Technology

Weigh-In-Motion (WIM) technology is a collection of techniques and measurement devices embedded in or installed on the pavement surface to capture and record commercial vehicle gross weight and weight per axle without the need to stop the vehicles. A basic WIM system includes a scale, a classification device, and a communication method.

The data captured at a WIM location facilitate the pre-screening of trucks before entering a weigh station and enable the enforcement staff to monitor a station remotely. WIM locations also support planning and future enforcement decision-making because they are capable of automatic traffic data recording.[12] The following figure presents WIM technology application in monitoring commercial vehicle weight compliance in an unstaffed location (above) and pre-screening of vehicles entering a fixed inspection facility (below).

[12] Devices and technologies that facilitate traffic data collection without interfering traffic flow. Automatic traffic data recording (ATR) sites provide large amounts of traffic counting and classification data over a desired period of time. ILDs, RADAR, and LiDAR are some examples of devices and technologies used in ATR sites.

Figure 2-13: Examples of WIM System Application



Source: Mettler Toledo (May 2018) WIM (Weigh In Motion) Systems. Available at: https://www.mt.com/gb/en/home/products/Industrial_Weighing_Solutions/Terminals-and-Controllers/vehicle-scale-terminals/IND780/WIM-systems.html

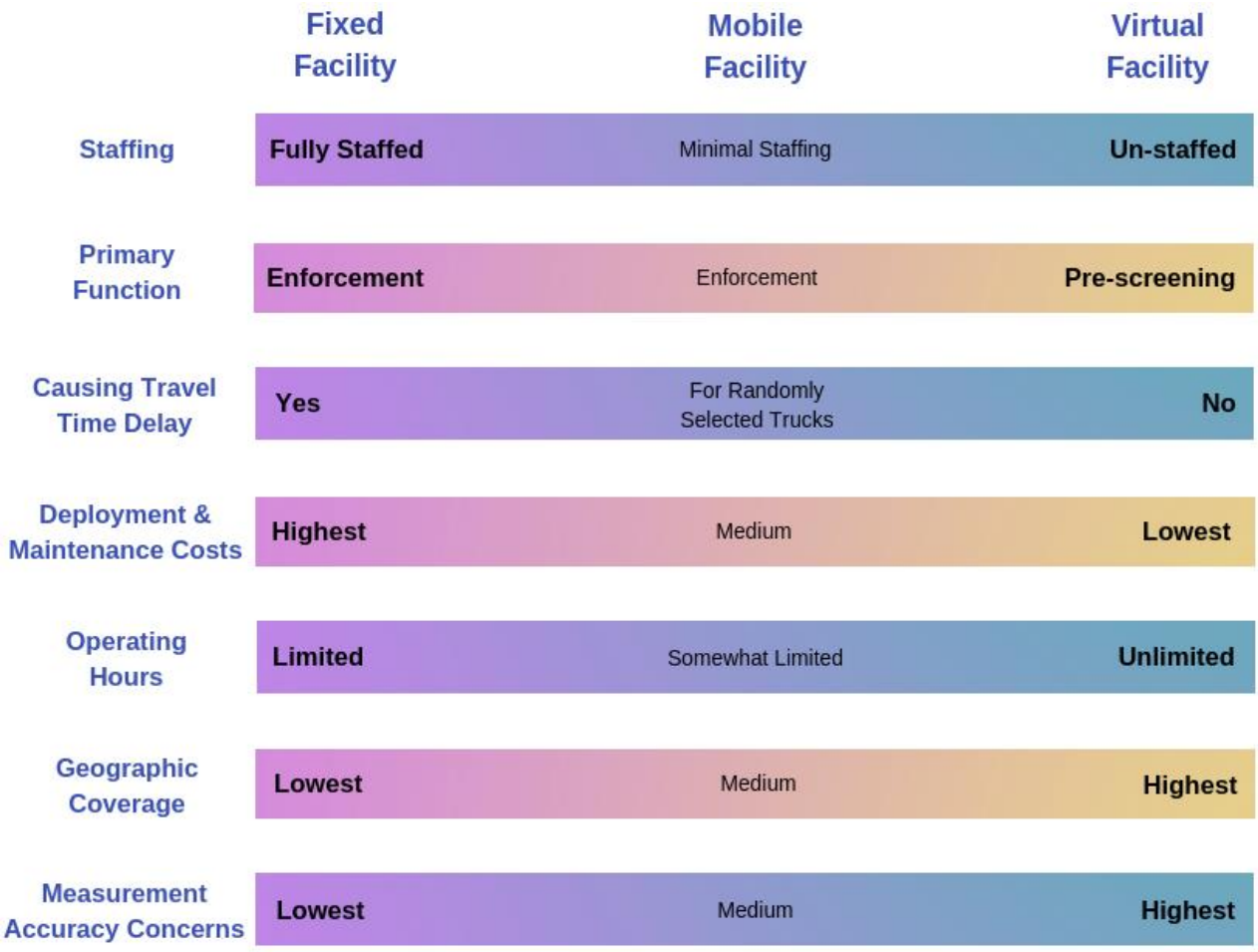
2.4 Commercial Vehicle Weigh Station Spectrum

Commercial vehicle weighing and inspection facilities may be configured differently, depending on enforcement needs, resources, and other factors. This report divides the weigh station facilities into the following categories:

- Fixed facilities
- Mobile facilities
- Virtual facilities

The spectrum presented in Figure 2-14 displays the differences among these three weigh monitoring facilities.

Figure 2-14: Commercial Vehicle Weigh Station Spectrum



Source: CPCS Analysis of Weigh Station Facilities in the U.S.

As Figure 2-14 shows, commercial vehicle weighing facilities are different in terms of their primary function, deployment and maintenance costs, operating limitations such as staff availability and hour of work, and the probability of being bypassed by potential violators. Much thought and planning go into the strategic deployment of stations to ensure the majority of vehicles are weighed, and system safety is preserved.

Since fixed weigh station operations only cover limited sections of a highway, some trucks may detour to avoid the fixed weigh stations. The potential size and weight violators may take rural highways as detours, imposing safety and environmental risks to the local communities. On the other hand, operating a permanent weigh station off of a rural highway may not be feasible solutions as connected road networks can always offer other detours. While the operations at a fixed facility are limited by physical capacity and staff availability, a mobile facility may operate staffed or unstaffed at a different hour of the day.

Both fixed and mobile facilities may deploy ESDs and WIM technology for pre-screening the commercial vehicle traffic to increase their service efficiency. However, this method prescreening of commercial vehicles cannot address the limitations associated with fixed stations, as the violators still may avoid the weight stations by taking detours or driving on hours that the fixed

stations are not operating (night time or weekends). The final advancement stage of the fixed and mobile facilities, is the virtual weigh station concept which highly relies on ESD and WIM technologies and is capable of operating fully unstaffed.

The following section provides a brief introduction to each facility.

2.4.1 Fixed Facilities

The most common type of weigh stations in the U.S. are fixed facilities, which are sometimes known as Ports of Entry (POE) if located at the state borders. A fixed facility is a permanent weigh station located directly off of highways, at which the enforcement staff inspect commercial vehicles and are capable of enforcing commercial vehicle size and weight regulations. Fixed facilities typically include the following features:

- Administrative building;
- Static scales embedded in or installed on the pavement surface;
- Bypass lanes;
- Bypass Technology (ESDs);
- Enforcement staff; and
- Communication infrastructure.

Within half to a quarter-mile from a fixed facility, the drivers can find signs directing them to the weighing and inspection area. The same signs should indicate the type of technology that the weigh station uses to provide legal bypass (if available).

In a typical fixed facility, the weigh scales are positioned on lanes adjacent to the administrative building from which the station authorities are able to see the trucks and evaluate the information communicated on their computer screen. The trucks entering a fixed facility should move over the scales at the designated speed. After weighing the trucks, the staff at the station check the State DOT number, ELDs, and special permits as well as drivers' credential and health information.

The staff at a fixed facility also inspect the following vehicle features to ensure highway safety:

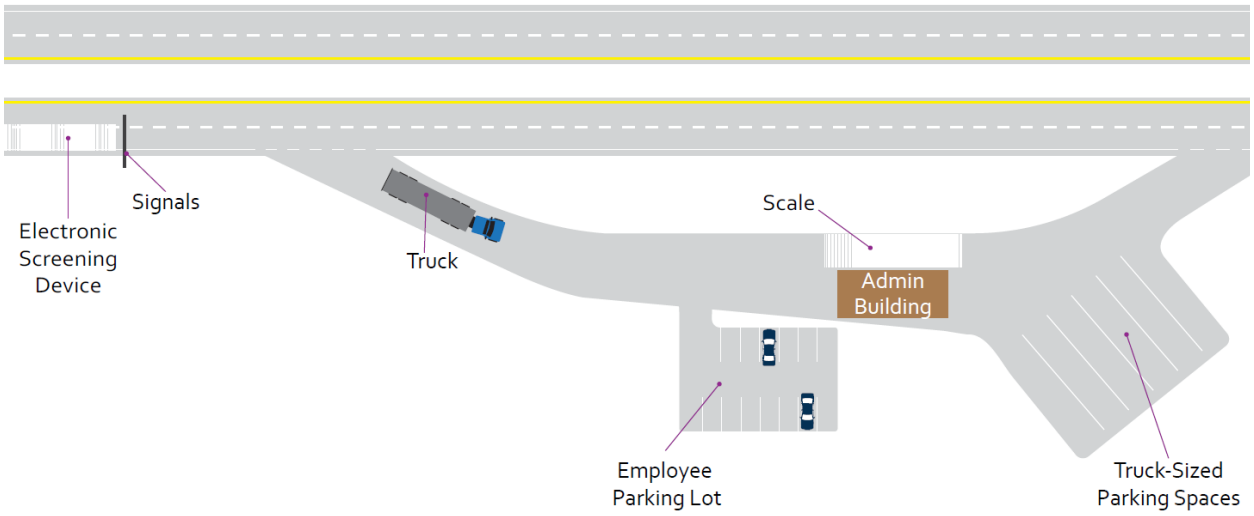
- Tire quality and state of wheel rims;
- Oil, fuel, or anti-freeze leaks;
- Functioning of the brakes;
- Cargo securing devices; and
- Other visible safety issues.

In case of violations or safety issues, the staff may issue a citation or stop the truck in the facility's parking for further inspection. If a truck weighs more than allowed by a certain amount of excess

load (around 6,000 pounds), the officers may request the carrier to send another truck to carry the excess load.[13]

Figure 2-15 shows the layout of a typical fixed weighing facility. Using ESDs such as PrePass, Drivewyze or NORPASS transponders for checking the credentials is especially useful to address the capacity related issues at the fixed facilities during rush hours.

Figure 2-15: Example of a Fixed Facility with Electronic Screening Device



Source: Washington State Joint Transportation Committee "Efficiency and Effectiveness of Weigh Station Management In Washington State" (June 2016).

The efficiency of fixed weigh stations may decrease significantly due to staff availability, hours of operation, geographic coverage, and capacity limitations.

While fixed stations are advantageous for providing comprehensive size and weight, credential, and safety inspections as well as staff training opportunities, the efficiency of fixed weigh stations may decrease significantly due to staff availability, hours of operation (especially on weekend and holidays), geographic coverage, and capacity limitations which lead to lengthened truck queues and potentially blocking of the highway right lane.

WIM Application at Fixed Facilities

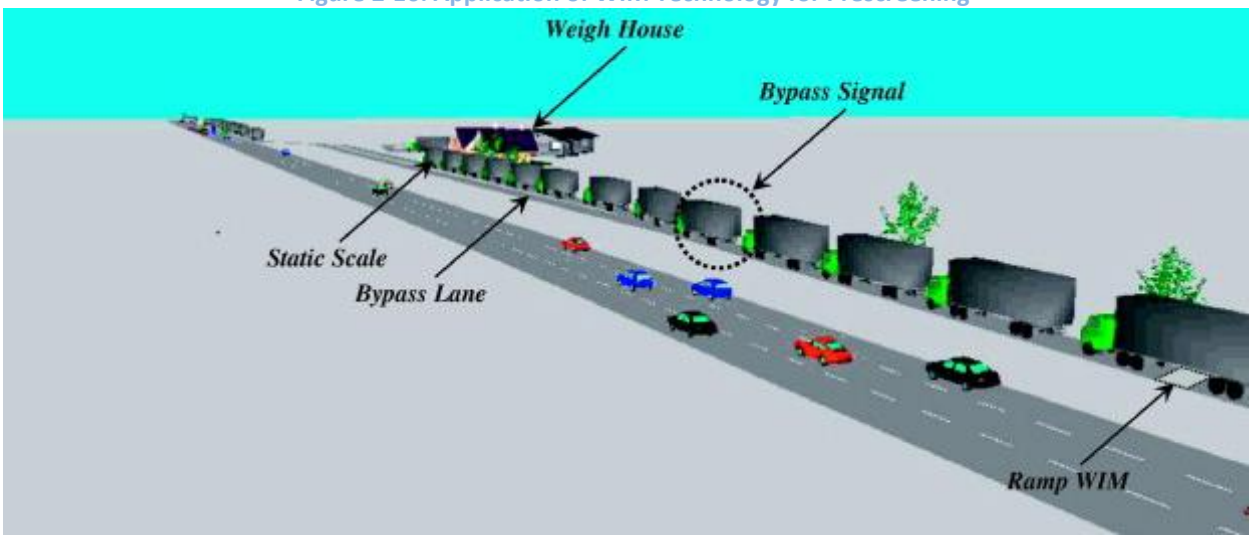
Applying WIM technology combined with ESDs can improve the prescreening process. Installed at one half to one quarter-mile in advance of a fixed facility entrance, WIM technology facilitates truck weight prescreening. This way, only potential violators are required to stop at the weigh

[13] Lantech Blog "4 Things You Need To Know About Overweight Trucks" (May 2018). https://www.lantech.com/blog/4-things-you-need-to-know-about-overweight-trucks?region=1

station. Electronic screening combined with WIM technology can lead to a 15-20% decrease in the truck volume entering the fixed facilities for inspection,[14] as non-violators may bypass the facility.

The following figure displays a WIM ramp prescreening system installed at the entrance of a weigh station. After being weighed on the WIM ramp, the potential violators get a signal denying their bypass. The potential violators will then be weighed again on the static scales in front of the weigh station authorities.

Figure 2-16: Application of WIM Technology for Prescreening



Source: Han L et al. "Adaptive weigh-in-motion algorithms for truck weight enforcement" (2012). Transportation Research Part C: Emerging Technologies, Volume 24, Pages 256-269.

[14] FHWA, Concept of Operations for Virtual Weigh Station, June 2009, Office of Freight Management and Operations, FHWA-HOP-09-051. Available at: https://ops.fhwa.dot.gov/publications/fhwahop09051/index.htm

2.4.2 Mobile Facilities

Mobile weigh enforcement activities facilitate relatively more flexible size and weight and safety enforcement, especially in remote areas, routes known for truck violations, and highways bypassing fixed facilities. In mobile weighing operations, highway patrol officers equipped with portable scales take a position in designated areas such as widened shoulders and rest areas.

Lower operating costs and a higher probability of catching the violators by surprise are some of the benefits of the mobile facilities. However, the errors associated with the portable scale results, limited hours of operation, and risks to the officer's safety (especially in remote areas) are challenges to mobile site operations.

Figure 13: Example of a Mobile Facility in Maryland

Source: GEScales "Portable Axle Scales" (May2018). http://www.gecscales.com/truck-scales/axle-scales/md70011001200-portable-axle-scales/

Weigh-In-Motion Application at Mobile Facilities

Incorporating electronic screening and WIM technology with mobile weighing facilities increases the enforcement efficiency and impact by enabling the officers only to stop the potential violators. In this method, the mobile weighing facility is positioned near permanent WIM locations. By logging into the WIM analysis system on a laptop, officers are able to monitor the weights of the trucks as they travel past the mobile facility. A patrolling officer then intercepts the potential violators for additional inspection.

Although mobile enforcement method improves upon the fixed facility concept in terms of placement flexibility, the need for dedicated personnel decreases its efficiency.

2.4.3 Virtual Facilities

The issues associated with fixed and mobile size and weight enforcement practices such as higher costs and limited capacity, and challenges associated with truck weight enforcement in dense urban or remote rural areas have led to the deployment of virtual weigh stations (VWS). Virtual facilities typically include the following elements:

- Static scales embedded in the pavement or mobile scales installed on the road surface;
- Electronic screening devices;
- Camera, LPR, and USDOT number reader;

- ILD, RADAR, or LiDAR technology; and
- Real-time communication method.

In summary, a VWS consists of WIM technology in combination with real-time communication and digital imaging technology. The most important features of a virtual facility are 1) its ability to operate unstaffed and 2) provision for the element of surprise. These factors in combination with other VWS features such as remote roadway monitoring provide the potential to weigh a higher number of trucks, leading to cost reduction and enforcement capability improvement.[15]

In current VWS practices in the U.S., weight, size, and credentials data of an overweight commercial vehicle are collected while in motion. Also, digital imaging devices capture vehicles' image, license plate number, and the USDOT registration number. The screening software then processes the data and notifies the enforcement staff who either intercept the violators and reweigh and inspect the vehicles using portable devices or direct the drivers to a nearby weigh station for follow-up procedures. In the expanded VWS operations, the screening software can generate notices or issue tickets based on the collected information, without the need for human resources to intercept the vehicles.

Despite the benefits of VWS compared to fixed and mobile weight enforcement practices, some uncertainties around the VWS technology have limited their expanded deployment.

The following are of the most common uncertainties around VWS practices:

- **Safety inspection concerns:** one of the essential features of fixed facilities, and to some extent mobile facilities, is the safety inspection procedure conducted by the weigh station staff. Checking the overall condition of the truck and the cargo it carries has significant impacts on increasing highway safety for all the users. State DOT staff, Trucking Associations, and Highway Patrol Officers unanimously noted lack of safety inspection as one of the main drawbacks of the virtual weighing facilities.[16]

  Thermal Inspection System (TIS) technology addresses the safety inspection concern by allowing for automatic screening of commercial vehicles' mechanical gear and rolling chassis deficiencies. Using Infra-Red cameras, this system can detect vehicle defects in brakes, tires, bearings, vehicle exhaust, and fluid tubes. Suspected vehicle deficiencies accompanied by vehicle credentials will be sent to nearby stations or laptops of mobile officers for safety enforcement.[17] Also, the information can be stored in a computer for electronic warning letter issuance.

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[15] FHWA, Concept of Operations for Virtual Weigh Station, June 2009, Office of Freight Management and Operations, FHWA-HOP-09-051. Available at: https://ops.fhwa.dot.gov/publications/fhwahop09051/index.htm
[16] CPCS Stakeholder Consultation, March-April 2018.
[17] IIS "Automated Thermal Inspection System" (June 2018). https://intelligentimagingsystems.com/wp-content/uploads/2015/09/IIS-Automated-Thermal-Inspection-System-v1.5.pdf

- **Privacy issues and legislative limitations.** These two factors are closely interrelated as the privacy concerns associated with LPR information and data system hacks have led legislators to restrict the application of VWS technology. In many states, electronic issuance based on digital data captured by traffic cameras and LPRs is prohibited.

  There are also concerns about the inflexibility of electronic citations. Typically, there are some levels of tolerance introduced to the weigh enforcement operations, especially when a state's truck travel pattern has dramatic seasonal changes or in case of trucks serving intermodal terminal operations.

  To introduce tolerance in virtual weigh station operations, one approach is to send warnings to trucking companies or the truck operators instead of tickets. A record of warnings issued to a certain trucker can inform fixed and mobile station operations.

- **Errors.** Another challenge with VWS technology is the error associated with the WIM scale results compared to the fixed facility scales which are constantly checked and calibrated.[18] The level of errors in the scale weighing results is highly dependent on external factors such as sensor type, pavement material, weather condition, and the installation and calibration methods. Agencies can significantly reduce WIM scale errors by calibrating the scales regularly and by using high-quality sensors in combination with temperature sensors, that adjust the weight measurements based on pavement temperature, and wandering sensors, that detect the relative position of the truck with respect to the lanes.

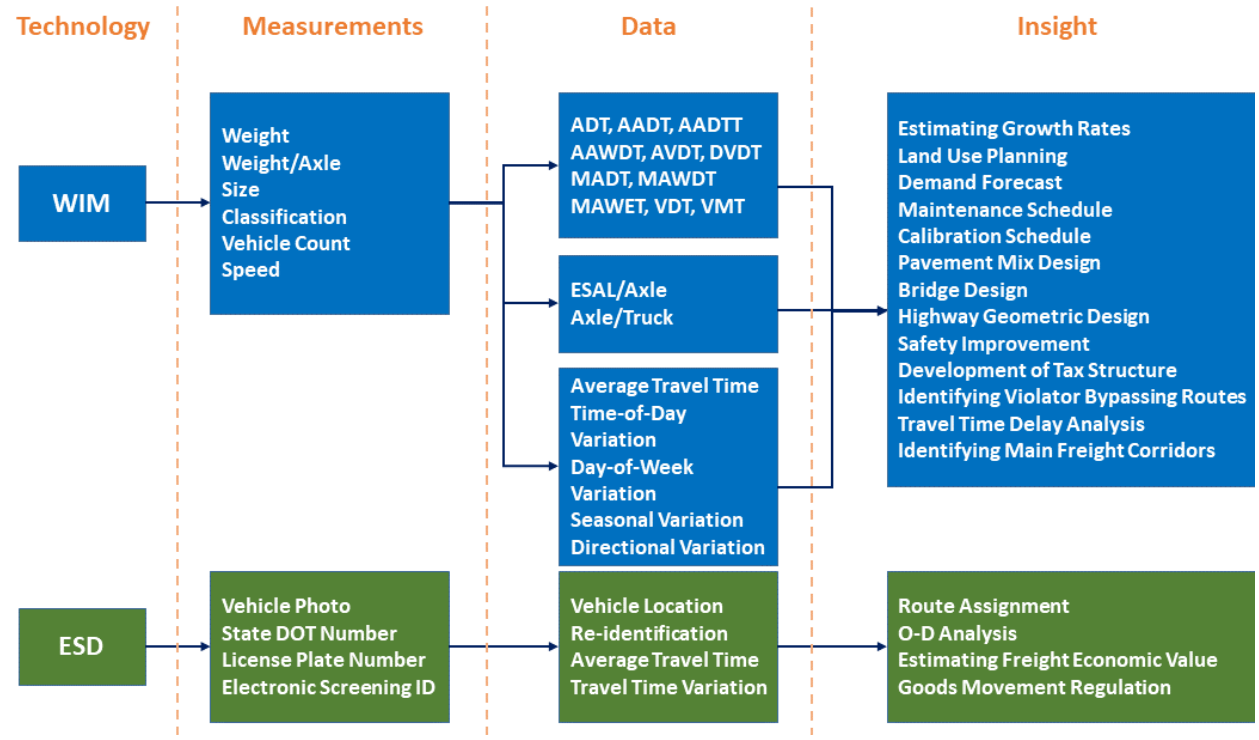
2.5 Weigh Station Data Application

In addition to commercial vehicle weight and safety enforcement, weigh stations produce road user data that can be used to inform federal and public agency decision-making processes. However, the type, quality, and granularity of the data needed are highly dependent on the desired results.

Figure 2-17 provides a summary of the type of information collected at a facility or data collection location equipped with WIM and/or ESD technology. While national agencies such as FHWA use the data for national-level transportation policy-making and preparing trend reports, state DOTs may apply the data to their state-level planning, design, enforcement, and investment operations. Local transportation agencies may also request access to the data to support regional freight planning, highway maintenance planning, and trucking demand forecasting.

[18] CPCS Stakeholder Consultation, March-April 2018.

Figure 2-17: Weigh Station Data Type and Application



Source: CPCS Analysis of Weigh Station Data Applications

2.6 Current Weight Enforcement Facilities in NWP

The seven states in the NWP are connected with a series of interstates and primary highways, the most important of which are I-90 and I-94. The states have a total of 135 fixed facilities, 37 virtual monitoring facilities, and more than 270 locations designated for mobile enforcement. Within the NWP state borders, 18 fixed facilities monitor the trucking activities along I-90, and 6 fixed facilities are located along I-94.

The following subsection provides an overview of the weigh station infrastructure and technologies that are currently available in the NWP states. Each subsection includes pictures and maps of weigh stations (if available).

2.6.1 Idaho Weight Enforcement Facilities

Idaho's commercial vehicle weigh enforcement system includes 17 fixed facilities known as the State's ports of entry (POE) and about 200 portable scale sites.[19] Idaho Transportation Department (ITD) operates the fixed and mobile facilities with nearly 100 personnel who work as administrative staff and inspectors, supporting Idaho State Police (ISP) enforcement activities.

Four of the fixed facilities in Idaho are equipped with WIM technology and ESDs to offer a legal bypassing option to compliant trucks. The WIM scales are embedded on both sides of I-90 (two miles west of Coeur d' Alene), I-84 (11 miles east of Boise), U.S. Route 95 (one mile east of

[19] ITD "State of Idaho Port of Entry Study" (May 2016). http://itd.idaho.gov/wp-content/uploads/2017/07/RP_248_ID-POE_Study.pdf

Lewiston), and U.S. Route 20 (five miles south of Ashton), upstream of nearby fixed facilities for pre-screening of the trucks. All of these WIM sites use Automatic Vehicle Identification technology (PrePass and NORPASS) for identifying the vehicles with the exception of the facility located upstream of the Huetter POE at I-90, which uses LPR technology for vehicle identification.

In addition to the fixed and mobile sites, three virtual facilities exist in Idaho. ITD and Idaho State Police (ISP) started operating two of the virtual sites located at the Idaho-Canada border on U.S. Route 95 and State Highway 1 in 2008. The stations were funded through a Border Enforcement Grant provided by FMCSA.[20] The third virtual facility is located on U.S. Route 20 in Ashton but is not operating at the moment due to undesirable[21] pavement conditions.

All three of the virtual facilities in Idaho are equipped with WIM technology as well as cameras that take a picture of the potential violators and notify the ISP officers in patrol vehicles. The officers then intercept the potential violators further downstream and escort them to a temporary location designated for undertaking necessary enforcement activities.

Figure 2-18: Summary of Weigh Station Operations in Idaho

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	17	200	3
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Pre-screening
Legal Bypass Option	✓	-	✓
Camera and LPR	✓	-	✓

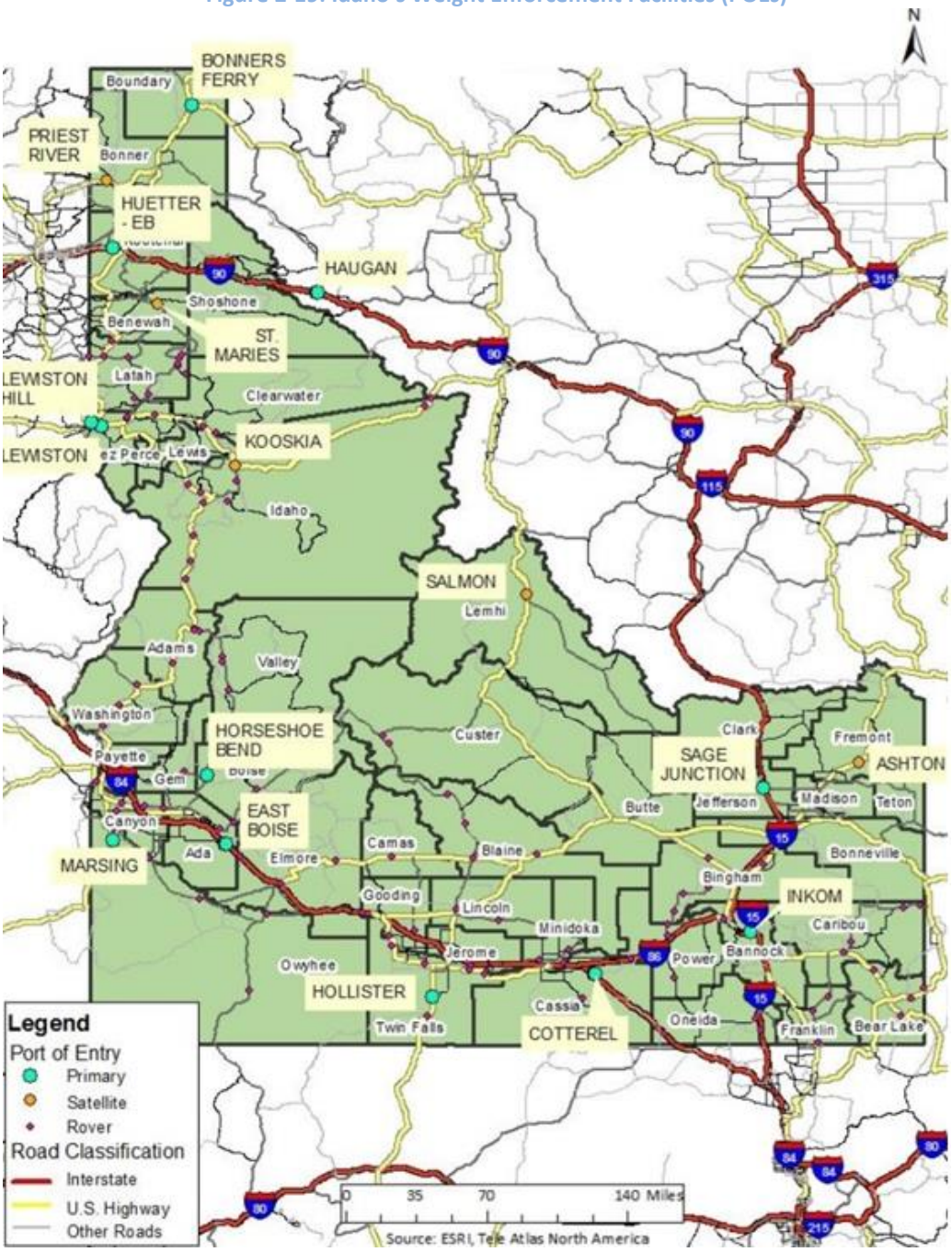
Source: CPCS analysis of ITD weigh station data and information provided on Drivewyze, NORPASS, and PrePass websites

The State of Idaho Port of Entry Study published in 2017 recommends the use of virtual weigh stations as monitoring and pre-screening facilities to inform the nearby fixed facilities or the patrol officers. The current state legislation does not allow for electronic ticket issuance based on digital photos or license plate information and the vehicles identified as violators should be weighted again in front of an officer and then the tickets will be issued. Figure 2-19 shows the current layout of the commercial vehicle weight enforcement facilities in Idaho.

[20] BEG is a Federal discretionary grant program providing financial assistance to States and entities that carry out border safety and enforcement projects. For more information see: https://www.fmcsa.dot.gov/mission/grants/border-enforcement-grant

[21] Pavement surface condition can be described based on Ride Index (RI); a performance measure between 0 (unsatisfactory) to 100 (superior). The states usually set their own goals for the lowest level of RI allowable. For most of the states, the RI of undesirable pavement condition is 40-59. For more information see: https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/02057/02057.pdf

Figure 2-19: Idaho's Weight Enforcement Facilities (POEs)



Source: ITD "State of Idaho Port of Entry Study" (May 2016). http://itd.idaho.gov/wp-content/uploads/2017/07/RP_248_ID-POE_Study.pdf

ITD's long-term plan for improving weight enforcement efficiency includes two virtual facilities at the State Route 9 (Sedro Woolley) and State Route 290 at Idaho-Washington border,[22] which are currently facing funding challenges. With the state running short of staff to run the fixed and mobile facilities, more virtual site projects are expected to start in the future.

[22] ITD "State of Idaho Port of Entry Study" (May 2016). http://itd.idaho.gov/wp-content/uploads/2017/07/RP_248_ID-POE_Study.pdf

2.6.2 Minnesota Weight Enforcement Facilities

Minnesota has 6 fixed facilities located at primary highways with high truck volume and at the State's POEs. In addition, there are 18 mobile facilities on secondary and by-pass routes throughout the state. While the Minnesota DOT (MnDOT) owns and maintains these facilities, the Minnesota State Patrol (MSP) is responsible for enforcement operations. The MSP officers flag the vehicles suspected of being oversized/overweight (using visual clues) and escort them to the mobile facilities.

In addition to the 6 existing fixed WIM stations in Minnesota, and three more sites have been proposed for future deployment. The WIM stations function as data collection sites, but the goal is to use the information provided by the WIM technology to improve the efficiency of services at the fixed and mobile stations. The WIM sites measure weight per axle, gross weight, classification and truck counts by axle configuration as well as speeds and travel time information. All the WIM sites provide legal bypassing option for participating trucks.

Figure 2-20: Summary of Weigh Station Operations in Minnesota

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	6	18	1
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Prescreening
Legal Bypass Option	✓	✓	-
Camera and LPR	-	-	✓

Source: CPCS analysis of MnDOT data and information provided by Drivewyze, NORPASS, and PrePass websites.

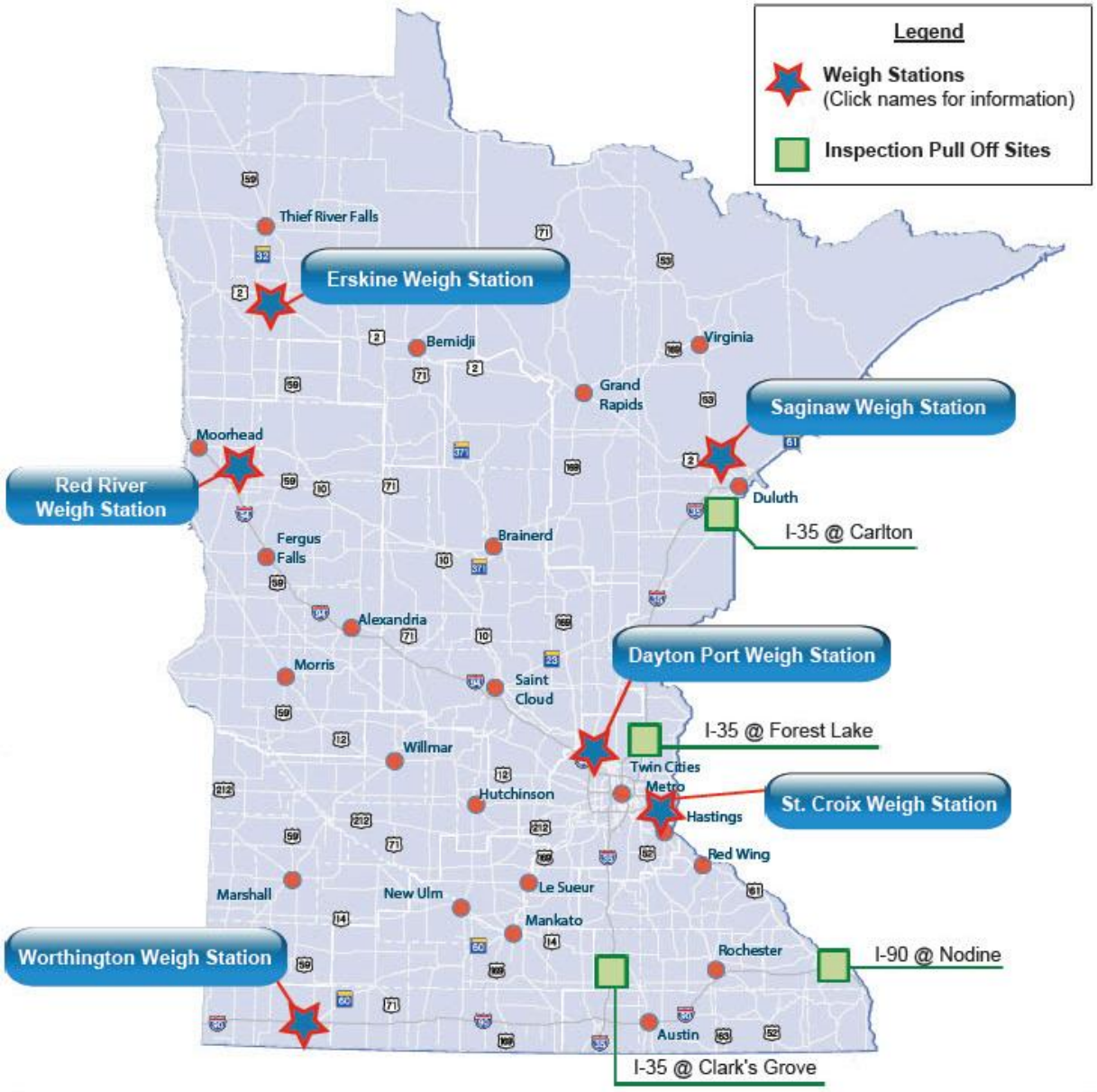
In 2005, the "Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan" was published to help the state in improving commercial vehicle weigh compliance. Later in 2007, MnDOT conducted a study to lay out plans for the State's long-range weigh station deployment in the advancement of the concepts developed in the 2005 study. The plan included guidelines for enhancing the WIM technology application and introducing the VWS technology. The primary objectives of introducing virtual technology in Minnesota are maintaining the current function of WIM sites while enabling the MSP to use real-time data as probable cause for flagging the potential violators. The real-time data obtained from VWS can also help MSP to identify areas that are in need of targeted enforcement. [23] MnDOT currently has ongoing plans for improving and rehabilitating the existing weigh stations.[24]

The following figure shows the current layout of the weigh stations operating in Minnesota.

[23] MnDOT "Virtual Weigh Station Demonstration" (2007). https://www.dot.state.mn.us/guidestar/2006_2010/virtual_weigh_station/MnDOT_VWS_Demo_Final_Report_080718.pdf

[24] MnDOT "State Transportation Improvement Program – STIP" (2017). https://www.dot.state.mn.us/planning/program/pdf/stip/2017-2020%20Approved%20CIP.pdf

Figure 2-21: MnDOT Weigh Stations Map



Source: MnDOT, "Weigh stations" (July 2018). http://www.dot.state.mn.us/cvo/weighstations.html

2.6.3 Montana Weight Enforcement Facilities

Montana has 12 fixed facilities and 8 mobile facilities that operate with 2 mobile weighing trailers. Montana began studying WIM technology applications during the early 90s. In 2008, the State deployed WIM technology at two locations near the U.S.-Canada border to monitor cross-border trucking activities. Currently, all of the fixed facilities in the State are equipped with WIM and Automatic Screening Devices (ASD) for pre-screening and to offer truckers legal bypass.

The State also has 32 permanently installed data collection WIM sites that are equipped with license plate reader technology. Although Montana's legislation does not allow electronic issuance for commercial vehicle weight enforcement, the State DOT is supporting future adjustments to accommodate electronic issuance. The Montana DOT (MDT) uses the information

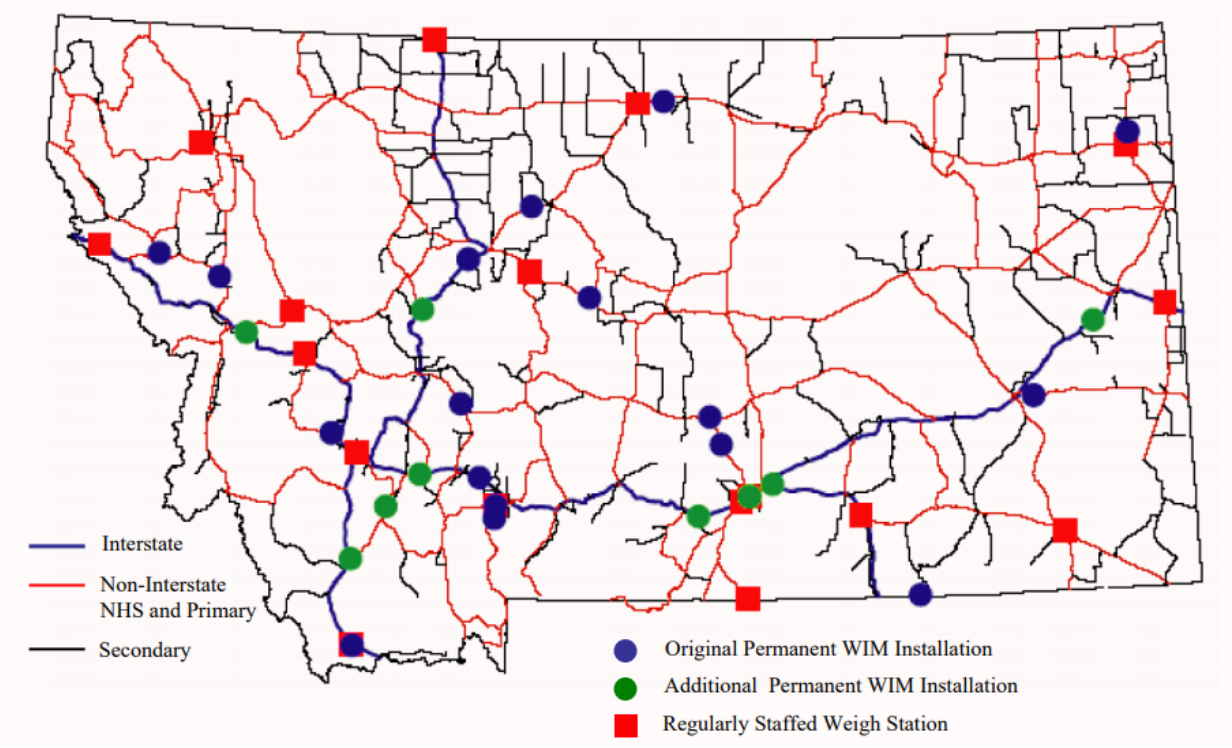
obtained from the WIM sites for targeted enforcement planning and data sharing on an online platform called the State Truck Activities Reporting System (STARS). STARS contains information on the weight and configuration of the vehicles traveling on State's road network.[25] Figure 2-22 provides a summary of the weight enforcement operations in Montana and Figure 2-23 presents a map of the weigh stations.

Figure 2-22: Summary of Weigh Station Operations in Montana

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	12	8	32
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Prescreening
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	✓

Source: CPCS analysis of STARS data and information provided on Drivewyze, NORPASS, and PrePass websites.

Figure 2-23: Map of Weigh Station in the State of Montana



Source: MDT "State Truck Activities Reporting" (2005).

[25] MDT "State Truck Activities Reporting" (2005). http://www.mdt.mt.gov/publications/docs/brochures/mcs_stars_final_report.pdf

2.6.4 North Dakota Weight Enforcement Facilities

The Motor Carrier Division of NDDOT operates nine fixed facilities operating as well as 23 sworn officers with portable weighing instruments. The fixed facilities in North Dakota are staffed on a random basis when a trooper or civilian inspector is assigned to work at a facility.[26]

NDDOT started deploying WIM technology around 2004, aiming to increase the efficiency of commercial vehicle weight enforcement. Since then, the technology has been applied in 13 locations, and three more sites are currently under development. The WIM locations are also equipped with Automatic Screening Devices to provide legal bypass option for law-abiding truckers.

The information obtained from the WIM sites is only used for screening and monitoring the weight and size violations at fixed and mobile facilities. Currently, the State legislation does not support electronic issuance based on information provided through digital cameras or license plate readers.

Some of the State's WIM sites are equipped with cameras that capture snapshots of passing trucks to help the patrol officers in flagging the violators, but none of the sites have been equipped with license plate reader technology. As of 2017, none of the WIM sites operate as virtual weigh stations but the State DOT is considering whether to add more WIM sites.

Figure 2-24: Summary of Weigh Station Operations in North Dakota

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	9	23	0
Staffing Status	Randomly Staffed	Staffed	-
Primary Purpose	Enforcement	Enforcement	-
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	-

Source: CPCS analysis of NDDOT data and information provided by Drivewyze, NORPASS, and PrePass websites

2.6.5 South Dakota Weight Enforcement Facilities

As of 2018, South Dakota operates five fixed facilities all known as POEs. Two of these are located on I-29 at Jefferson and Sisseton; one is located on I-90 at Tilford, one located on U.S. Route 16 near Rapid City, and one on U.S. Route 14 near Blunt.

All of these facilities in South Dakota are equipped with WIM technology for prescreening trucks. The WIM facilities in the state capture vehicles' weight and check safety rating and credentials using bypass technology and give a red light to the potential violators to stop at the weigh station facility[27]. The WIM sites also have a random selection feature which may give a red light to vehicles

[26] NDHP inputs provided on November 26th, 2018.
[27] SDDOT "Motor Carriers Handbook, Chapter 4: Electronic Screening" (May 2018). http://www.sdtruckinfo.com/docs/MCHandbook_chap8.pdf

that are not potential violators. In addition to the fixed facilities, South Dakota has 13 mobile facilities, 11 of which are equipped with ESD technology to provide legal bypassing option.

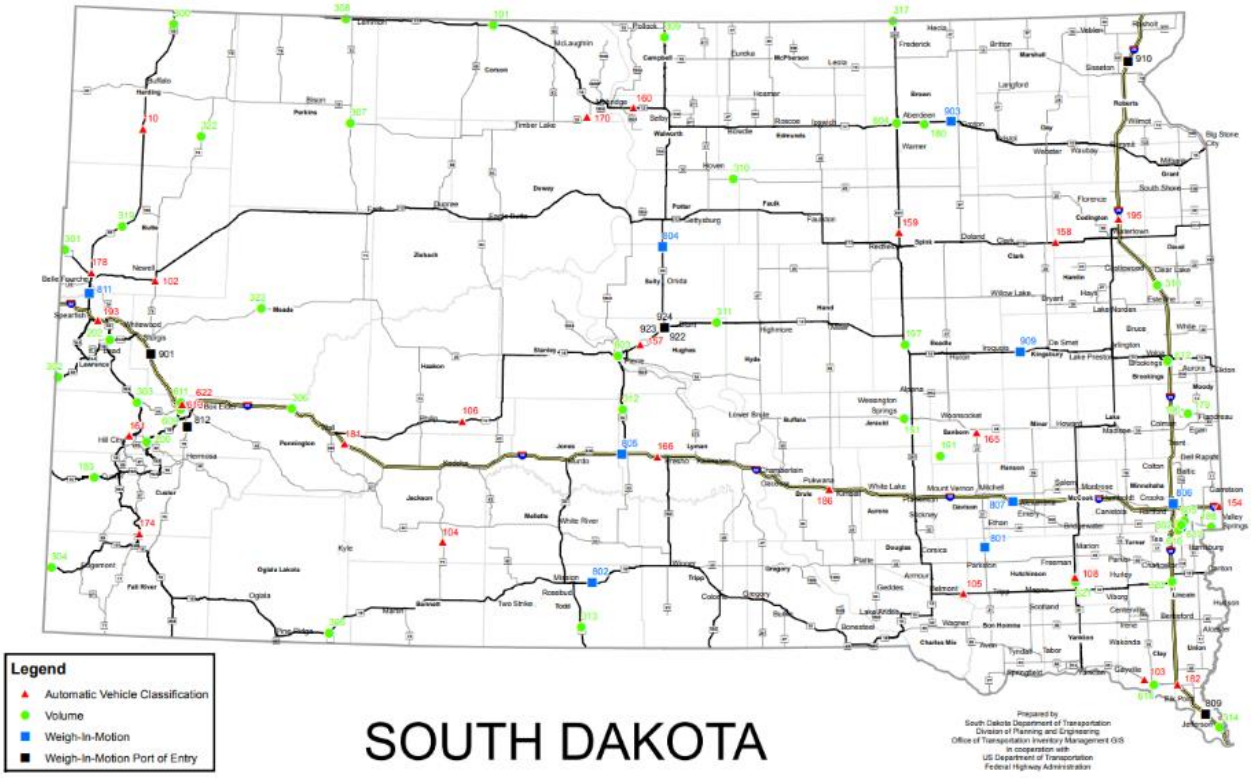
Nine additional WIM sites operate in the state as data collection sites, to inform future weigh station operations. The following table provides a summary of the weigh station operations in South Dakota, and the map in Figure 2-26 displays the weigh station and other data collection applications across the state.

Figure 2-25: Summary of Weigh Station Operations in South Dakota

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	5	13	0
Staffing Status	Staffed	Staffed	-
Primary Purpose	Enforcement	Enforcement	-
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	-

Source: CPCS analysis of SDDOT data and information provided by Drivewyze, NORPASS, and PrePass websites

Figure 2-26: Map of South Dakota Automatic Traffic Data Collection Sites



Source: SDDOT "Automatic Traffic Recorder Data" (April 2018). http://www.sddot.com/transportation/highways/traffic/docs/ATRReport.pdf

All trucks (whether carrying agricultural products or not) and drive-away operations with a gross weight of 8,000 lbs. and more are required to stop at fixed weigh enforcement facilities in South Dakota. The issuance of an electronic citation is not supported in South Dakota's legislation. Also, since July 2014, South Dakota law protects the residents from electronic citations outside of the

state boundaries.[28] The state law specifically bans the electronic ticket issuance explicitly based on LPR information captured from the red light camera and speed cameras.

2.6.6 Washington Weight Enforcement Facilities

There are 33 fixed facilities operating in Washington, all equipped with fully operating administrative centers and safety inspection services. The State has 11 additional fixed facilities that are equipped with WIM technology and Electronic Screening Devices for Pre-screening and providing legal bypassing option. Five of these WIM-equipped facilities are located at the State's border facilities (POEs). There are five additional fixed facilities that operate on an as-needed basis, whenever a patrol officer connects a laptop to the static scales. The State has 11 locations designated as mobile facilities.[29]

Two VWS locations currently operate in Washington, located on WA-290 and I-90 which are unstaffed facilities used for monitoring and targeted enforcement.[30] WSDOT selected these two locations for VWS technology deployment in order to monitor the truck weight and size violations on weigh station bypass routes. WSDOT is responsible for installing, monitoring, and maintaining the weigh stations across the state. The data from two VWS locations is only used for pre-screening as electronic issuing is not allowed in Washington and an officer must physically issue the ticket. The use of license plate readers is under consideration for the two VWS sites.

The table in Figure 2-27 and the map in Figure 2-28 summarize the weigh station and other data collection applications across the state.

Figure 2-27: Summary of Weigh Station Operations in Washington

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	49	11	2
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Pre-screening
Legal Bypass Option	✓	-	-
Camera and LPR	✓	-	-

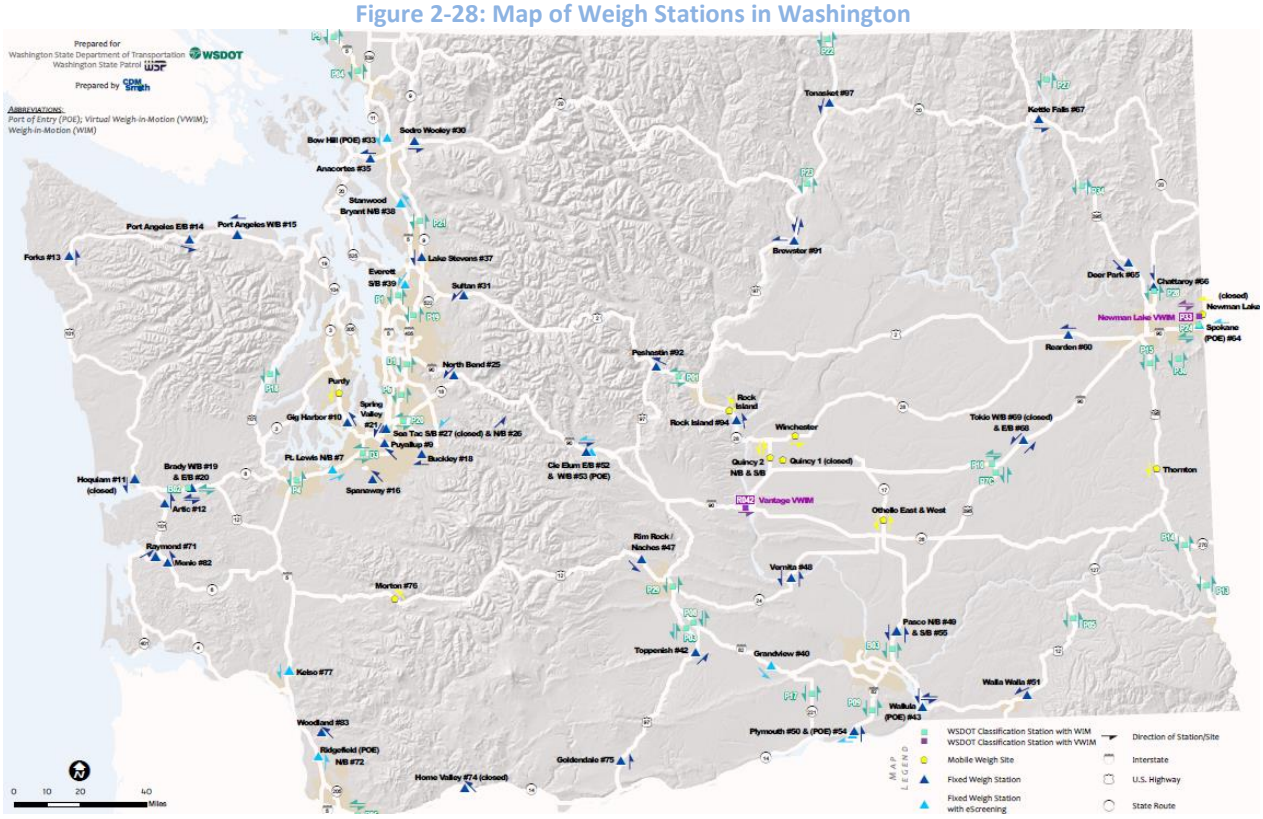
Source: CPCS analysis of information provided by WSDOT, Drivewyze, NORPASS, and PrePass websites.

[28] TheNewspaper "South Dakota Enacts Most Sweeping Photo Ticket Ban in US" (May 2018). https://www.thenewspaper.com/news/43/4372.asp

[29] Washington State Joint Transportation Committee "Efficiency and Effectiveness of Weigh Station Management in Washington State" (2016). http://leg.wa.gov/JTC/Documents/Studies/Weigh%20Station_2015/FinalReportWeighStationStudy_January2016.pdf

[30] WSDOT, "Commercial Vehicle Enforcement System Strategic Plan" (2017). https://www.wsdot.wa.gov/NR/rdonlyres/40C12FD6-5318-439A-8DB6-A54E66DCF187/0/CVSWeighstationStrategicPlan.pdf

Figure 2-28: Map of Weigh Stations in Washington



Source: WSDOT, "Commercial Vehicle Enforcement System Strategic Plan" (2017). https://www.wsdot.wa.gov/NR/rdonlyres/40C12FD6-5318-439A-8DB6-A54E66DCF187/0/CVSWeighstationStrategicPlan.pdf

2.6.7 Wyoming Weight Enforcement Facilities

Wyoming has 37 fixed facilities, 14 of which are located at the State borders (POEs). All of the fixed facilities in the State are equipped with Electronic screening Devices and provide legal by-passing option. Trucks that receive a green light in weigh stations of Wyoming must still enter an open weigh station if they are pulling an oversize/overweight (even permitted) load or a livestock load for further inspections.

Currently, Wyoming Department of Transportation (WYDOT) is advancing an ongoing project to add WIM technology to both northbound and southbound Cheyenne weigh stations, and the eastbound Evanston weigh station on I-80 to support the pre-screening, and commercial vehicle weight enforcement.[31]

Wyoming Highway Patrol operates five mobile weight enforcement teams that monitor remote roads for commercial vehicle size, weight, and safety compliance.[32] The table in Figure 2-29 provides a summary of the weight enforcement operations in Wyoming.

[31] Help Inc "Help Inc. Funds a Dozen New Weigh-In-Motion Scales at Prepass Sites" (July 2018). http://www.helpinc.us/help-inc-funds-a-dozen-new-weigh-in-motion-scales-at-prepass-sites/

[32] WY Commercial Vehicle Safety Plan for the Federal Motor Carrier Safety Administration's Motor Carrier Safety Assistance Program FY 2017. https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/fastact/83221/wyomingaccepted-20161216.pdf

Figure 2-29: Summary of Weigh Station Operations in Wyoming

Weigh Station Type	Fixed Facilities	Mobile Facilities	Virtual Facilities
Quantity	37	5	0
Staffing Status	Staffed	Staffed	-
Primary Purpose	Enforcement	Enforcement	-
Legal Bypass Option	✓	-	-
Camera and LPR	✓	-	-

Source: CPCS analysis of WYDOT data and information provided on Drivewyze, NORPASS, and PrePass websites

3 Needs, Challenges, and Best Practices

Key Chapter Takeaway

This chapter provides an understanding of the best practices and lessons learned from virtual technology applications, and was informed by consultations with commercial vehicle weight enforcement stakeholders from 10 states. Four of the consulted states belong to the NWP group, while the rest are the states that have experience in virtual weigh station practices or are considering virtual technology as a method to meet the projected growth in truck volume and changes in configuration.

A review of the current virtual technology practices showed that if well implemented, virtual weigh stations increase safety and provide better management of staff time and availabilities. Although virtual citations based on electronic imaging technologies is legal in some states, WIM technology is only applied for screening and monitoring commercial vehicle activities and not for enforcement due to concerns about the accuracy of scale results, and privacy controversies associated with traffic digital imaging systems such as LPR and camera.

3.1 The Need for Virtual Technology Implementation

According to the 30-year freight projections by the USDOT based on Version 4.3 of the Freight Analysis Framework (FAF), trucks are the most-utilized mode of freight transportation. In the U.S. In 2016, trucks carried 11,513 million tons of cargo nationwide, accounting for nearly 65% percent of the total tonnage and 69% of the total value of freight. The 2045 projections estimate a 44% increase in tonnage and 84% in value of the cargo carried by trucks.[33]

In 2016, the total truck vehicle miles traveled (VMT) in the NWP states was more than 38,176 million. The truck VMT is forecasted to increase substantially to accommodate the forecasted increase in demand. The FHWA 2018 forecasts estimate an average annual growth rate of 0.8% in the truck VMT over the 30 year projection period.[34]

[33] U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Highway Administration, 30-Year Freight Projections, 2016 (updated December 2017).
[34] FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2018. https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.pdf

The following table shows truck VMT in the NWP states.

Figure 3-1: Truck VMT in the NWP States

State	2016 Truck VMT (in millions)	2046 VMT Projections (in millions)
Idaho	4,460	5,664
Minnesota	9,628	12,228
Montana	3,456	4,389
North Dakota	2,707	3,437
South Dakota	2,114	2,685
Washington	12,510	15,888
Wyoming	3,302	4,193

*Calculated based on 0.8% growth rate over 30 years.
Source: CPCS Analysis of FHWA Highway Statistics 2016.

Virtual technologies can help NWP states expand/increase their enforcement abilities to accommodate increasing truck volumes.

Given projected increases in truck VMT—growing at a faster pace than automobiles[35]—states will need to expand their weight, size, and safety enforcement activities keep pace. Virtual technologies not only reduce delay through enabling automatic safety and weight monitoring and enforcement but also help the states to augment current enforcement infrastructure to help mitigate the growth of unsafe commercial vehicle traffic.

3.2 Stakeholder Consultation

After an initial review of the current weight enforcement practices in the U.S., especially in the NWP states, a series of consultations with stakeholders were conducted to get an understanding of the differences in truck weight enforcement operations at different states and to record the lessons learned from deploying size and weight compliance technologies.

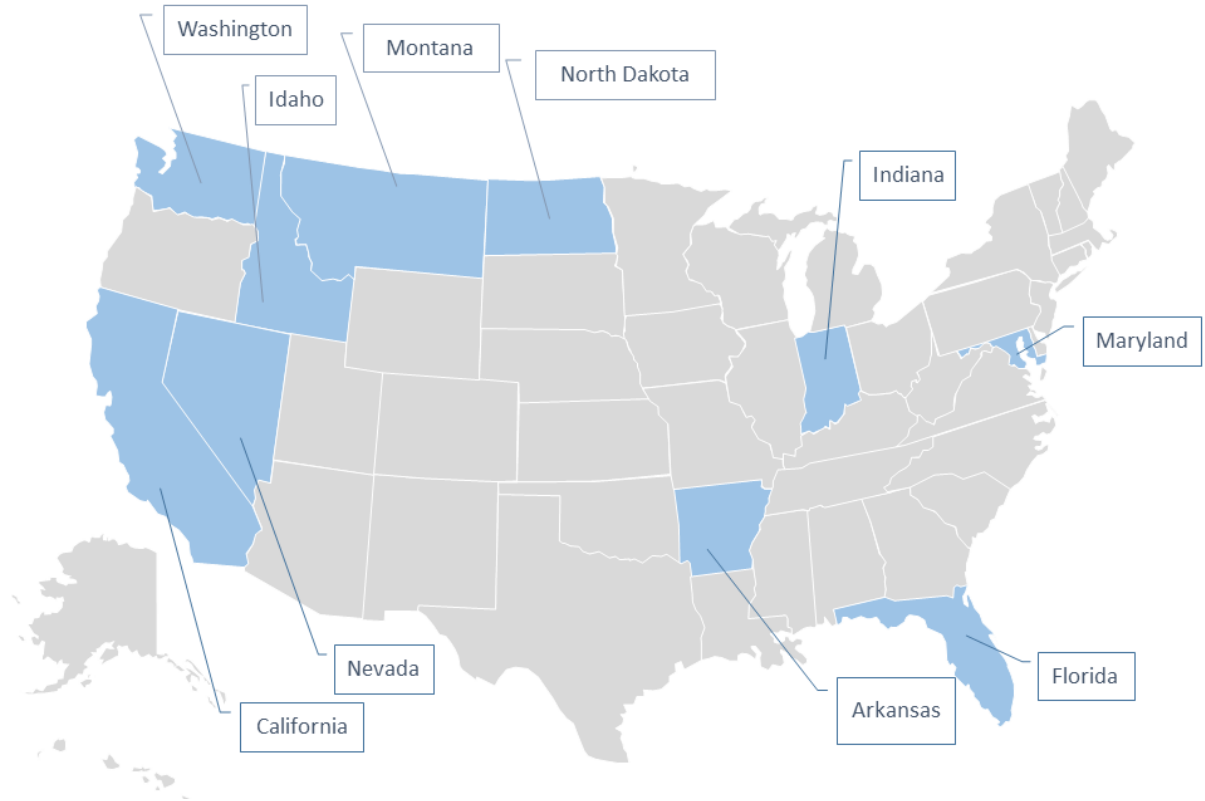
Stakeholder consultations were informed by the Virtual WIM (VWIM) technology focus project by the Technology Implementation Group (TIG) of the American Association of State Highway and Transportation Officials (AASHTO). The goal of the project was to investigate the benefits of virtual weight enforcement practices through pilot implementation projects in North Dakota, California, Florida, Indiana, and Nevada.[36] In addition to these pioneering states in WIM technology applications, Maryland and Arkansas were selected for consultation due to the recent deployment of virtual technology in weigh station operations.

[35] The FHWA 2018 forecasts estimate an average annual growth rate of 0.7% in the automobile VMT over the 30 year projection period. For more information, see: https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.pdf

[36] AASHTO TIG "Virtual Weigh-In-Motion a WIM-win for Transportation Agencies, Industry, and the Public" (2006-2007).

The list of stakeholders consulted consisted of individuals in the state DOTs, state enforcement agencies, and state trucking associations that were knowledgeable about truck weight and size regulations, available infrastructure, and the current state of practice. The consultations were focused on the challenges associated, and the lessons learned related virtual weigh deployment and enforcement practices. Figure 3-2 shows the states that provided input to this study. Detailed weight enforcement facility profiles of the non-NWP states are in Appendix A.

Figure 3-2: States Selected for Stakeholder Consultations



Source: CPCS

According to the consultations, if VWS technology is deployed using high-quality sensors and the latest deployment methods, it can improve safety and provide better management of staff time and availabilities. The most important benefit of WIM and VWS technology is that 24/7 weigh monitoring becomes possible, which allows for better-targeted law enforcement. Also, the fact that the officers are not located in an enforcement site helps to decrease the number of trucks bypassing the weigh stations.

State DOT staff, highway patrol officers and trucking associations consistently identified VWS technology as a valuable screening tool for selecting potential violators for inspection at fixed or mobile facilities.

The following sections summarize the challenges and lessons learned from virtual weight monitoring and enforcement practices in the select NWP and non-NWP states, informed by the previous research and stakeholder consultations.

3.2.1 Challenges associated with Virtual Weight Enforcement

As is the case with any computer-based system, privacy is an inherent challenge associated with virtual weight enforcement applications. In current practice, VWS operations are only for the purpose of monitoring and prescreening, providing the enforcement staff with probable cause to intercept the potential violators. However, the trucks should be weighed again and inspected in the presence of enforcement staff before being cited for violations.

The sensitivity of the information collected by the digital imaging systems of a VWS and the possibility of hacking the system is a matter that worries carriers and truckers and also affects the extent to which the state transportation and law enforcement agencies can implement the virtual technology.

Moreover, the electronic citation step of virtual technology applications raises concerns related to due diligence and lack of consideration of context. Regulators and carriers alike want to ensure that a level of tolerance is introduced in the system to deal with the first-time violation cases or special circumstances.

> "In Washington State, many carriers handle intermodal containers to/from Ports of Seattle and Tacoma, without knowing the exact weight and commodities inside the trailer. Therefore, a happy medium might be giving the system some "tolerance" [for considering the context behind the violations] before issuing electronic tickets."
>
> *– CPCS Stakeholder Consultation, February 2018*

Although virtual citations based on electronic imaging technologies are legal in some states, WIM technology is still only applied for screening and monitoring commercial vehicle activities and not for enforcement given the variability of accuracy in scale results. Other challenges associated with VWS technology identified by the stakeholders are:

- Lack of incentives for the states in the form of funding programs and legislative reforms;
- Technical issues worsened by inclement weather;
- Infrastructure conditions which limit the accuracy of scale results; and
- Lack of resources for periodic scale calibration.

3.2.2 Lessons Learned from Virtual Technology Implementation

A review of the lessons learned from the previous research and consultation with stakeholders revealed that investing in the following measures would significantly improve the operations at a VWS.

Vehicle Identification Technologies

The results of the past pilot projects and the stakeholders' experience with VWS technology highlight the need for using LPR and USDOT number readers at the virtual sites in addition to digital cameras. While cameras record digital images of potential violators to help the officers in identifying suspected vehicles, digital images of trucks traveling at highway speed lack the precision that LPR or USDOT number reader technologies provide. This is especially important in locations where inclement weather can affect the clarity of images.

Consultations with highway patrol officers confirmed that LPRs and cameras are essential features of the virtual facilities that help the officers in getting detailed information about violating vehicles. Using cameras in combination with USDOT number readers and LPRs ensures carrier identification even in the face of challenges such as in inclement weather or when other vehicles block the camera view on multi-lane highways.

Data-Informed Scale Calibration

Data-informed scheduling of periodic calibrations can improve the reliability of the measurements reported at virtual facilities. The timing of the periodic scale calibration as a function of the mainline volume and truck re-identification data obtained from the VWSs and nearby fixed facilities would improve the reliability and enforce stakeholders' confidence in virtual operations. Equipping the WIM cabinets with monitors and keyboards will also make the cabinet self-contained and improve calibration and maintenance process.[37]

Infrastructure Improvements

Previous research and consultation with state DOT stakeholders revealed that the quality of pavement surface, access to power, proximity to cell towers, and availability of safe pull-off sites should be considered in VWS location selection. When embedded in the elastic pavement (asphalt surface), the scale sensors show higher fluctuation in presented weights compared to the scales embedded in the rigid pavement (concrete surface). Therefore, rigid pavement sites are better candidates for VWS scale installation, given their higher expected reliability in reporting weights.

Stakeholder Involvement

By involving stakeholders from the very first stages of virtual weigh enforcement operations, the DOTs can determine from the beginning, who should expect what from the new technology deployment. For instance, at the decision-making stage, the state DOTs may create mockup enforcement plans subject to changes and recommendations made by the stakeholders form

[37] CPCS Stakeholder Consultation (March-April 2018); State Highway Administration, Maryland Department of Transportation "Maryland Virtual Weigh Station" (2009).

public agencies at the freight advisory committees and industry associations. At the next stage, the DOTs need to collaborate with the trucking associations to establish communication with truckers in order to inform them about the scope of the new weight enforcement practices and potential impacts on trucking operations. After the VWS technology deployment, the state DOTs may communicate with the trucking companies or inform the truckers through roadside signage, smartphone applications or online portals.

Other VWS Operation Improvement Measures

- **Ongoing collaboration between the State DOT and Enforcement Agency** is the key to successful virtual operations, especially in the presence of laws that dismiss the electronic citation.
- **Expanding WIM technology to all stations** will ensure overall consistent weight enforcement. While being an essential part of every VWS operation, WIM technology can improve fixed mobile weight enforcement practices by helping the officers only to stop the potential violators.

4 Developing a Virtual Weigh Station Concept of Operations

Key Chapter Takeaway

This chapter reviews the concept of operations (ConOps) for virtual weigh stations as described by the FHWA, and discusses the necessary steps for creating a ConOps that could facilitate implementation/expansion of virtual weigh/size monitoring practices. A review of the existing weigh station ConOps of the NWP group of states and consultation with stakeholders revealed that, with limited inspection resources and escalating costs of highway and bridge maintenance due to increasing truck volumes, the states are seeking new methods such as virtual weigh enforcement and inspection practices to control violations and improve safety for all road users.

4.1 Background

In 2009, FHWA published a ConOps for VWS operations focusing on the technical and jurisdictional aspects of virtual technology implementation at commercial vehicle weigh stations. The FHWA ConOps is a comprehensive tool that can support state DOTs in planning the roadside weight enforcement programs, submitting funding requests, and communicating with the stakeholders at the federal, state and local levels.

A Concept of Operations report (ConOps) describes the objectives, key concepts, system architecture, operational scenarios, supporting policies, and the potential impacts of a proposed operation.

Many states in the NWP have already developed weight enforcement ConOps reports and laid the groundwork for virtual technology applications through statewide data collection facilitated by WIM technology deployment. For instance, Idaho, Montana, Washington, and Minnesota have actively pursued virtual technology demonstrations, data collection projects, as well as pilot programs. Overall, state DOT and highway patrol staff believe that virtual technology deployment can significantly increase efficiency and decrease the resource-intensiveness of commercial vehicle weight enforcement practices. The following table provides a list of the recent studies and weigh station ConOps done by the NWP states.

Figure 4-1: NWP State Recent Weight Enforcement Planning Reports

State	Year	Report
Montana	2014	Weigh-in-Motion (WIM) and Automatic Traffic Recorder (ATR) Strategy
Idaho	2016	Port of Entry Study
Washington	2017	Commercial Vehicle Enforcement System Strategic Plan
North Dakota	2013	Commercial Motor Vehicle Enforcement: Identifying Appropriate Levels
South Dakota	2018	Automatic Traffic Recorder Data
Minnesota	2015	Virtual Weigh Station Demonstration
Wyoming	2016	Commercial Vehicle Safety Plan

Source: CPCS Compilation of NWP State Studies Relevant to Weigh Station Operations.

In Montana, the MDT established a traffic monitoring program consisting of permanent and short-term WIM and automatic data collection sites to measure commercial vehicle volume and weight and understand the details of the nature of traffic throughout the state. With the installation of 62 ATR and 37 WIM sites, MDT directly collects data on truck VMT on the state highway system, screens the data for quality control, and then uses the information to determine various characteristics of the traffic such as AADT, VMT, ESALs, and etc.[38]

MnDOT's 2015 virtual weight station demonstration project by is another example of a starter system built around existing WIM data collection sites. The project scope included the required enhancements to the existing WIM system and development of performance measures to guide the advancement of the weight compliance program and support the planning and enforcement activities in Minnesota.

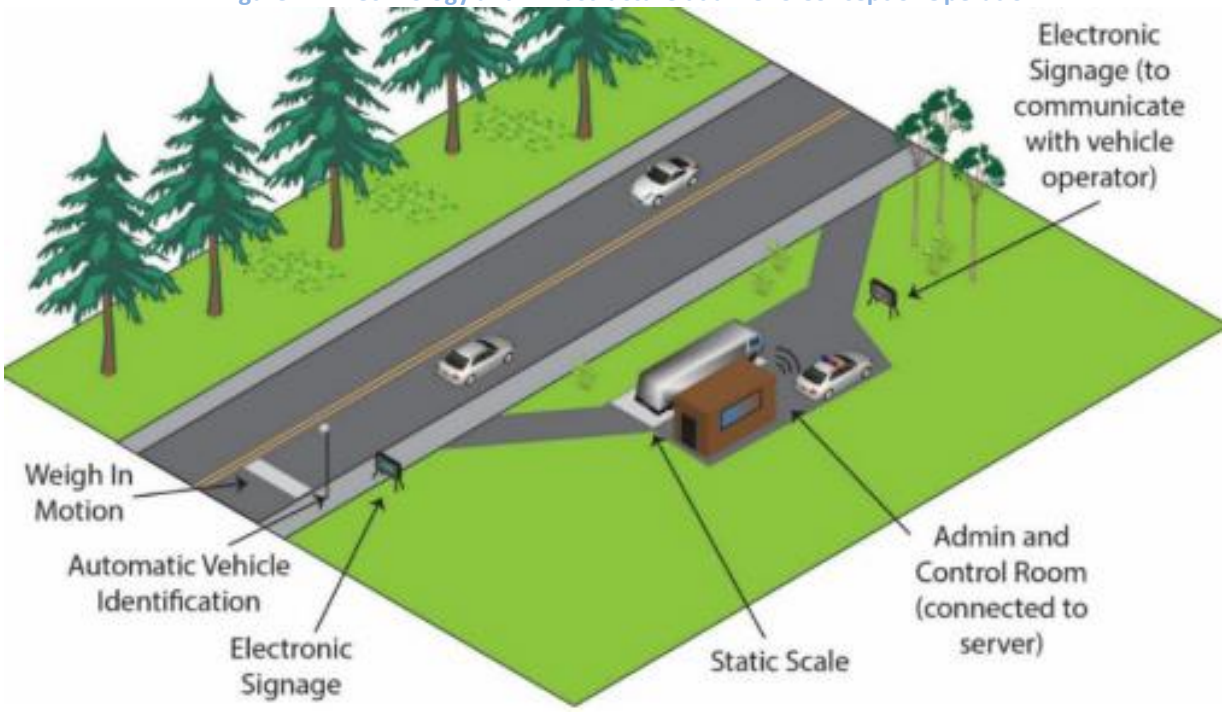
Another example is Idaho's POE study, which aimed to identify the strengths and weaknesses of the state's weight enforcement operations and develop guidelines for future program implementation. As part of the study, the state developed a ConOps for future improvements in the weight enforcement activities considering five operational tiers: three regarding the state's fixed facilities and two regarding the state's mobile facilities. The following are the five tiers for ITD's POE concept of operation:

- Tier 1: high-volume fixed facility
- Tier 2: lesser volume major roadways fixed facility
- Tier 3: periodic virtual operation fixed facility
- Tier 4: rover sites with mainline WIM technology
- Tier 5: rover sites without mainline WIM technology

The study had no concept of operation for the future of virtual facilities. However, Tier 3 presents the concept of a periodic virtual operation fixed facility which concerns the operations at low volume fixed facilities on secondary roadways. The following figure shows the concept of operation at a Tier 3 site in Idaho.

[38] MDT "Montana Weigh-in-Motion (WIM) and Automatic Traffic Recorder (ATR) Strategy" (2014).

Figure 4-2: Technology and Infrastructure at a Tier 3 Concept of Operation



Source: ITD "State of Idaho Port of Entry" (2017).

A Tier 3 facility is intended to operate with a relatively small-sized staff or virtually, through an electronic portal installed at the side of the scale. While more cost effective and less labor intensive, this concept of virtual weigh station has some limitations compared to the virtual facility defined in this present report. Overweight trucks familiar with the road can still avoid the station by taking detours or driving at times that the station is not operating. Also, the traffic flow will be disrupted as the trucks (although pre-screened), have to wait in line to be weighted on the static scale.

The ITD report also includes a list of the suggested sites for the five tiers. Now that the ITD has widely implemented WIM technology, the state's next step is towards virtualization, whether by part-virtualizing the fixed facilities or upgrading WIM sites to virtual stations, can be informed by a comprehensive ConOps for VWS technology application tailored based on the state's needs and available resources.

The Commercial Vehicle Enforcement Systems (CVES) Strategic Plan by WSDOT and the Washington State Patrol (WSP) in 2016, identified the virtual technology opportunities to expand truck operations monitoring with a reduced staff commitment. The study recommended four scenarios for virtual operations as follows:

1. **Virtual weigh-in-motion without pull-off**: a virtual facility equipped with LPR that identifies overweight trucks and informs officers through a real-time data dashboard. The officer then intercepts the potential violator and escorts the truck to a nearby parking for portable scale weighing and inspection, and (if necessary) citations.

2. **A remote site with e-screening, fixed multiplatform scale with auto weighing and kiosk – unstaffed**: a virtual facility which screens the trucks while they are directed into a roadside facility and stop on a multiplatform scale. The system checks the truck weight against the weight measured at the virtual system and informs a remote officer of potential violators.

3. **Virtual weigh-in-motion plus pull-off site with stored portable scales**: a virtual facility in which a potential overweight truck is identified. Then, the remote officer directs the truck into a nearby mobile facility for additional measurements and (if necessary) citations.

4. **24/7 staffed POE**: a fixed facility with fixed multiplatform scales and automatic weight scale, inspection building with pit, and e-screening technology.

Building from this basis of existing WIM data collection sites and previous ConOps reports, the NWP states interested in a more advanced VWS technology application will need to work with technology vendors who can provide hardware and technical expertise to equip the WIM locations with advanced weigh scales, effective digital imaging systems, and reliable remote access platform. The NWP states may also want to partner to evaluate the potential for multi-state VWS technology demonstrations along major corridors such as I-90 and I-94 and answer specific questions that apply to each state commercial vehicle weight and size regulations and relevant state legislation.

4.2 Operational Objectives

VWS ConOps are developed to meet a wide range of operational objectives. States typically develop such ConOps in order to:

- Augment commercial vehicle weight and size enforcement operations through virtual technology applications;
- Increase the consistency between different enforcement methods by improving the technical aspects of operations;
- Identify and monitor truck activity on bypass routes around fixed and mobile facilities;
- Improve highway safety through targeted commercial vehicles safety enforcement;
- Improve the balance between the growth in the truck volume and the available roadside enforcement assets;
- Reduce the costs of expanding commercial vehicle size and weight/safety enforcement programs.

4.3 Data Needs

4.3.1 Evaluation of Weight Enforcement Methodologies

According to the FHWA's ConOps for VWS deployment guide, the first step for developing a ConOps is to understand the current methods and available technologies in commercial vehicle weight enforcement practices. A review of the common weight enforcement practices across the

U.S. is presented in Chapter 2 of this working paper. In particular, the states' understanding of the current technologies and applications should cover the pros and cons of each system and practice to inform decision-making.

4.3.2 Available Technologies

Brief summaries of the current weight enforcement practices in the NWP states have been covered in this working paper (Section 2.6). In general, a review of the available weight enforcement facilities including fixed, mobile, and virtual facilities forms a basis for VWS ConOps development. The information requirements should cover the following data points:

- Location
- Hours of operation
- Layout and infrastructure
- Number of staff
- Software and systems in use
- Nearby WIM scales
- WIM data collection locations
- Digital imaging technologies
- Communication hardware and software.

In the case of the weight enforcement operations at the states' borders, the data should cover the differences in size and weight regulations and legislation to inform future decisions for initiating/expanding collaborative efforts.

4.3.3 Stakeholder Considerations

To move this potential initiative forward, the states will need to identify the needs of stakeholders and engage them in the process of developing ConOps and deploying the virtual technology.

VWS stakeholders include individuals belonging to agencies, institutions, groups, or businesses that have an interest in commercial vehicle operations, benefit from data sharing made available through virtual technologies, and can influence or contribute to the VWS deployment programs.

In general, the stakeholders' needs and challenges can be incorporated into plans for future infrastructure and technology needs. The stakeholder's expectations from virtual technologies include:

- Safety improvements due to reduction in truck-related crashes;
- Congestion and delay reduction on highways due to efficient weigh station operations;
- Reduction in fuel consumption and environmental pollution due to reductions in vehicle idling times;
- A decrease in the total logistics costs of freight companies due to fuel consumption reduction;
- Highway and bridge infrastructure protection;
- Reduction in costs of highway infrastructure maintenance and weight/size enforcement activities; and
- Commercial vehicle traffic data availability and reliability improvement.

4.4 Key Steps

4.4.1 Developing Deployment Scenarios

According to the identified needs, challenges and expectations, the states may develop a set of location selection criteria for expanding the operations at the existing weight enforcement or data collection facilities or deploying VWS at new locations. Depending on the states' available infrastructure and needs, there are two main scenarios to build the ConOps upon:

1. Developing new VWS: since the costs associated with VWS deployment is significantly lower than fixed and mobile facility deployments, the states may decide to develop a VWS at a new location.
2. Converting existing operations into VWS: the costs associated with VWS deployment are even lower when some of the required technologies and infrastructure (i.e., WIM, ESD, cameras, etc.) are available in a location. Examples of such operations include:
    - → Converting a non-operative or occasionally operative fixed facility to VWS;
    - → Converting mobile facilities with WIM technology on highways to VWS; and
    - → Converting WIM data collection sites to VWS.

4.4.2 Benefit-Cost Analysis

As is the case with any project and operation, cost-benefit analysis is an important step in developing a VWS ConOps as it enables states to make informed decisions about moving toward virtual technology deployment, prioritize needs, and plan the budget and request funds. Since VWS is still considered an emerging concept for which detailed cost-benefit data may not be thoroughly available, evaluation of the results from deployments of similar roadside applications can provide valuable information of the range of benefits and potential costs. At a high level, the benefits of VWS technology deployment include cost savings due to:

- Delay reduction
- Fuel consumption reduction which in turn, leads to less environmental impacts
- Infrastructure protection/preservation
- Truck-related accident/fatality reduction due to expanded safety inspection.

Estimating the costs associated with VWS deployments depends on the scope of the virtualization, the extent of operations, and the existing infrastructure and technology. Based on the analysis of the requests for the Federal CVISN Deployment funds, the estimated costs of a VWS deployment is between $350,300 and $1,634,840 (converted into 2018 dollars) which is significantly lower than the costs of developing a fixed facility, typically costing between $14 million (converted into 2018 dollars, without land acquisition) and $360 million (converted into 2018 dollars, with land acquisition).[39]

4.4.3 Supporting Policies and Practices

The policies affecting the VWS operations vary by the state. However, the minimum policies that support VWS deployment include:

- **Resource management policies**: such policies ensure that VWS technologies leverage the existing weight enforcement practices and resources. An example is scheduling scale calibrations in advance, based on the staff availability instead of a need-based maintenance schedule which may not encourage optimized usage of resources.
- **Data management policies**: such policies ensure that the sensitive data collected at the VWSs is protected by warehousing and anonymizing the data and controlling individuals' access.
- **Enforcement management policies**: such policies are required for virtual enforcement systems. As an example, the policies may indicate that citation issuance can only be done virtually after the measurement data is verified by the carrier or the driver.
- **Permit system policies**: such policies assist virtual enforcement by enabling the ESD to connect truck identification information to the states' permitting systems. In such upgraded permitting systems, the properly permitted trucks would be able to bypass weight and inspection facilities. In the case of multi-state operations, the state DOTs can adapt permitting systems to allow for electronic ticket/notice issuance in case a vehicle doesn't have a permit to work in a specific state.

[39] FHWA "Concept of Operation for Virtual Weigh Station" (2009). The $ values are converted into 2018 values using CPI inflation calculator provided by the Bureau of Labor Statistics.

5 Conclusions and Next Steps

5.1 Conclusions

The relatively lower costs of deployment and the promise of increased efficiency and safety make emerging VWS technology an attractive option for state DOTs and public safety agencies. Overall, state DOT and highway patrol staff believe that shifting towards virtual technology implementation can significantly increase efficiency and decrease the resource-intensiveness of commercial vehicle weight enforcement practices.

Many states across the U.S., including some of the NWP states, have laid the groundwork for virtual technology applications through statewide data collection facilitated by WIM technology deployment and VWS pilot programs. Building from the basis of existing WIM data collection sites and previous ConOps reports, the NWP states interested in a more advanced VWS technology application will need to work with technology vendors who can provide hardware and technical expertise to equip the WIM locations with advanced weigh scales, effective digital imaging systems, and reliable remote access platform.

The NWP states may also want to partner to evaluate the potential for multi-state VWS technology demonstrations along major corridors such as I-90 and I-94. Such collaborations would inform future enforcement plans and help the states answer specific questions that apply to commercial vehicle weight and size regulations and relevant legislation.

Appendix A: Weight Enforcement Profiles

The purpose of this Appendix is to provide a background for the weight enforcement infrastructure and practices in non-NWP states that were selected for stakeholder consultations.

A.1 Arkansas Weight Enforcement Facilities

Arkansas has 12 fixed facilities located at major highways including I-30, I-40, and I-55. The facilities are all equipped with WIM and ESD technology for pre-screening of the trucks about 150 yards ahead of the fixed facility entrance. Six of the fixed facilities in the State operate 24/7 while the rest are only staffed at specific times of day and days of the week. Arkansas Highway Police operates the commercial vehicle weight enforcement activities across the State, while the State DOT is in charge of facility deployment, calibration, and maintenance.[40]

In addition, Arkansas has 66 staffed mobile facilities that are equipped with portable scales as well as advanced infrared brake inspection technology which enables the officers at the mobile facility to electronically monitor truck safety.

Currently, Arkansas has one virtual weigh station. Plans for implementing the virtual weigh station technology in Arkansas started in 2008. In 2009, the State DOT identified a location for the WIM scales on Route 64, near Alma, AR. This specific location was selected to decrease the probability of violators bypassing the fixed facility in Alma on I-40 by taking a 4-mile detour on Route 64. The station started operation in mid-2017, and to this day is the State's only virtual facility.

The virtual facility measures trucks' weight, speed, and class, records license plates and registration numbers and takes a photo of the potential violators. Arkansas Highway Police officers use real-time information to identify the overweight trucks and flag them to stop at the nearest fixed or mobile facility for follow-on actions. The following figure provides a summary of the current weigh station operations in Arkansas.

Figure A-1: Summary of Weigh Station Operations in Arkansas

Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	12	66	1
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Prescreening
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	✓

Source: CPCS Analysis of Information Provided on ARDOT and State Highway Police Websites

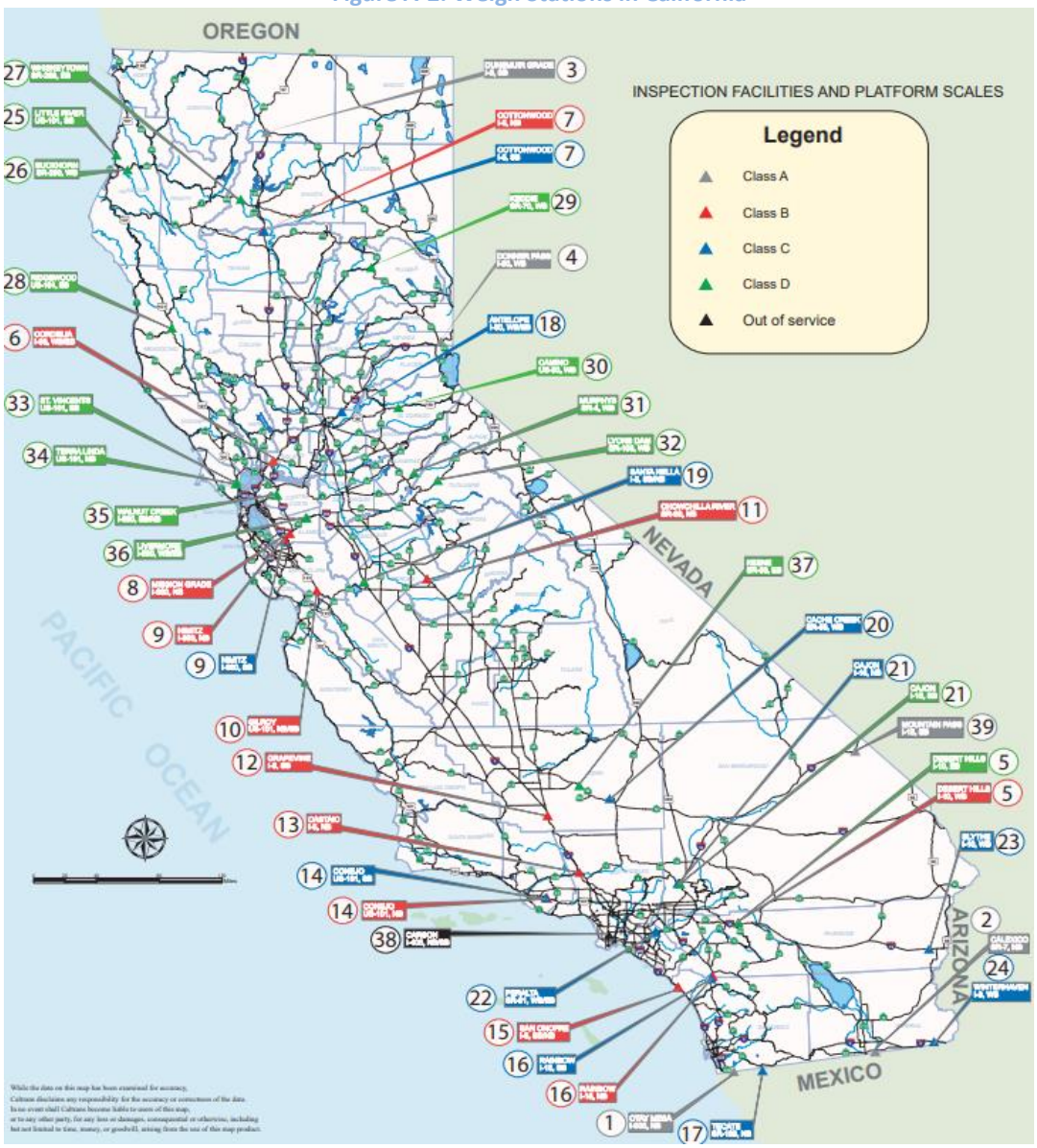
[40] Arkansas Highway Police "AHP Mission Statement" (2012). https://www.arkansashighways.com/PowerPoints/2012/082312_RB_sagacomm.pdf

Based on consultation with the State Highway Police, the only virtual facility in Arkansas is temporarily out of service due to the hacking of the system and camera problems. However, the stakeholders unanimously believed that if well implemented, virtual weigh stations increase safety and provide better management of staff time and availabilities.

A.2 California Weight Enforcement Facilities

There are 39 fixed facilities in California, of which 35 are equipped with WIM and ESD technology for pre-screening of the trucks. Five of these fixed facilities are located at the State's borders (POEs), operating 24/7 and fully staffed while the rest of facilities have changing hours of operation. The state also has 73 mobile facilities (known as mini-site weigh station in California).

Figure A-2: Weigh Stations in California



Source: Caltrans "Inspection facilities and platform scales" (August 2018). http://www.dot.ca.gov/trafficops/trucks/docs/weigh-sta-map.pdf

Caltrans is in charge of deploying, operating and maintaining the stations as well as periodic calibration of the weigh scales but the State Highway Patrol is in charge of enforcing commercial vehicle weight requirements.

The State also has 110 WIM data collection locations which record commercial vehicle travel data to support planning, operation management, and infrastructure maintenance activities of Caltrans.[41] The following figure provides a summary of the current weigh station operations in California.

Figure A-3: Summary of Weigh Station Operations in California

Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	39	73	0
Staffing Status	Staffed	Staffed	-
Primary Purpose	Enforcement	Enforcement	-
Legal Bypass Option	✓	-	-
Camera and LPR	✓	-	-

Source: CPCS analysis of Caltrans data and information provided by Drivewyze, NORPASS, and PrePass websites

In 2006, Caltrans deployed a VWS prototype in Cordelia to test the concept but decided to expand the fixed stations and WIM technology instead of VWS deployment due to the right of way issues and lack of funding. Currently, the WIM data collection sites are positioned at the proximity of fixed weighing facilities to sort out the violators from the law-abiding truckers. The information obtained from the stations has screening use only, and the electronic images cannot be used to issue notices and tickets for the violators. Due to privacy concerns and limiting legislation, the trucks should be weighed again in the presence of highway patrol officers or State DOT agents for enforcing commercial vehicle weight regulations.

A.3 Florida Weight Enforcement Facilities

Florida has 20 fixed facilities, 10 of which are equipped with WIM and ESD technologies as well as USDOT number readers and LPRs and are located at interstates. These facilities use WIM data to stop the potential violators for follow-on operations. The remaining 10 fixed facilities are non-interstate stations that operate without WIM or ESD technology. In addition to fixed facilities, Florida has a limited number of mobile facilities that operate in designated locations across the State.

22 virtual facilities support the fixed and mobile weigh enforcement operations in Florida. Other than the WIM technology, the majority of these facilities have LPRs and overhead cameras. Virtual facilities enable the officers in nearby fixed facilities or State highway patrol vehicles to monitor the traffic by logging into their portable devices or subscribe to certain cameras and receive emails a few seconds after a potential violator has passed the virtual facility. The following figures provide a summary of the current weigh station operations in Florida.

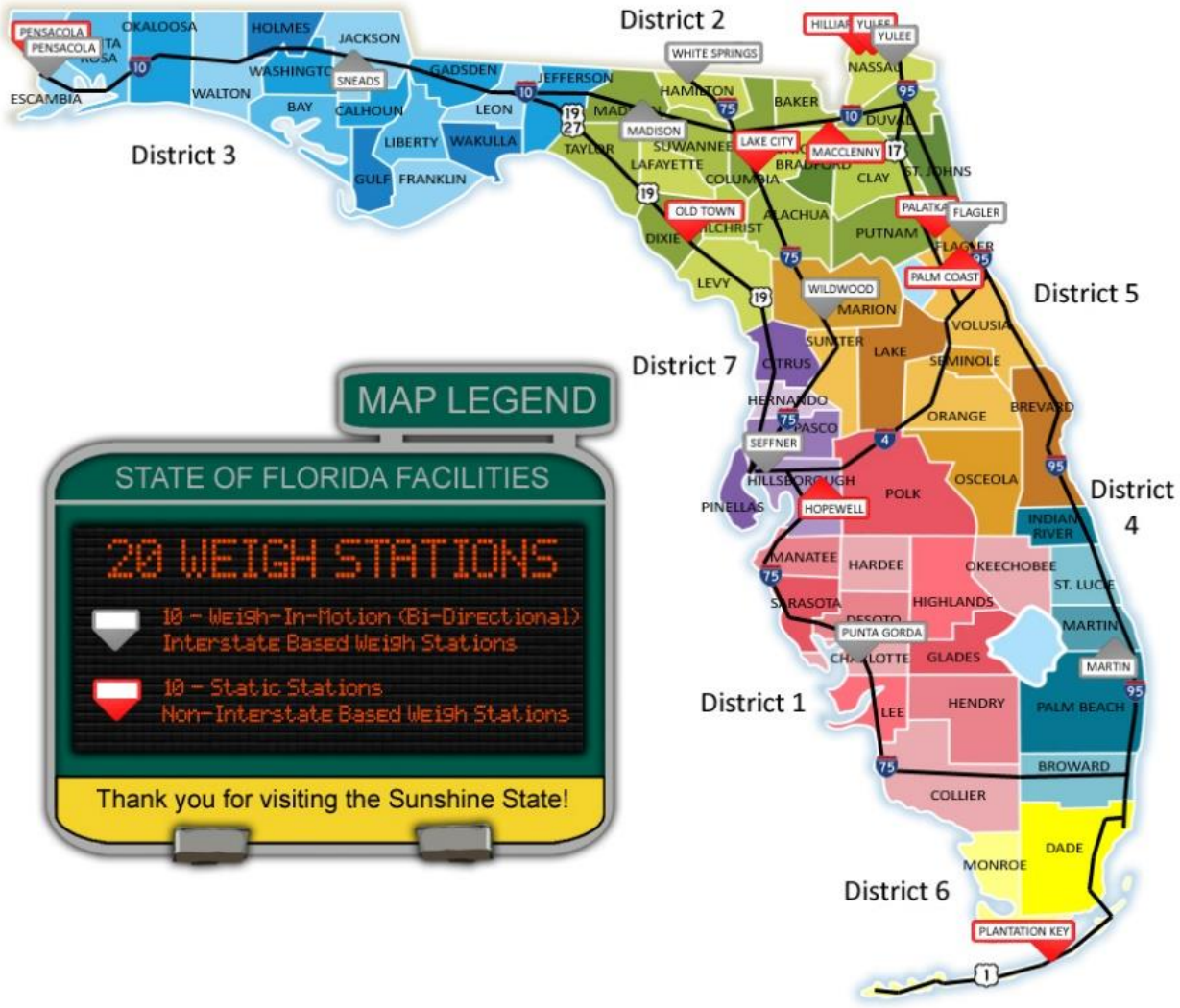
[41] Caltrans "The Requirements and Recommendations for Development of a California Weigh-in-Motion Technology Test Facility".
http://caltrans.ca.gov/research/researchreports/reports/2014/final_report_task_1798.pdf

Figure A-4: Summary of Weigh Station Operations in Florida

Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	20	Limited[42]	22
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Screening
Legal Bypass Option	✓	-	-
Camera and LPR	✓	-	✓

Source: FDOT, "Florida Weigh Station Information" (2018). http://www.fdot.gov/maintenance/WeighStationListing.shtm

Figure A-5: Weigh Stations in Florida



Source: FDOT "Weigh Station Map" (2018). http://www.fdot.gov/maintenance/WeighStationMap.shtm

[42] The exact number of mobile facilities in Florida is stated as limited both in available documents and reports as well as during the consultations.

In 2007, FDOT tested the feasibility of virtual facilities by installing two prototype virtual sites near existing fixed facilities. The technologies deployed at the two sites included WIM, cameras, LPRs, and ultrasonic, laser, and infrared sensors to measure weight, size, speed, axle number, class, and brake functioning. The results of this test proved that virtual facilities could capture reliable data and send it to nearby fixed facilities or roving vehicles for follow-up operations. The virtual facilities currently operating in Florida all have screening application, meaning that they send the data (in real-time) to nearby fixed facilities to inform the officers of potential violators.

The results of deploying virtual facilities in Florida showed that when embedded in the elastic pavement (asphalt surface), the WIM sensors show higher fluctuation in presented weights compared to the scales embedded in the rigid pavement (concrete surface). Therefore, rigid pavements are better candid for WIM scale installation, resulting in more reliability in the reported weights.

Although FDOT constantly calibrates the WIM scales at the fixed facilities, the scales at virtual facilities are only calibrated on an annual basis. Reducing the time between periodic calibrations can improve the reliability of reported results at the virtual facilities. Also, highway patrol officers confirm that LPRs and cameras are essential features of the virtual facilities that help the officers in getting detailed information about violating vehicles.

A.4 Indiana Weight Enforcement Facilities

Indiana has ten fixed facilities for monitoring commercial vehicle activity at the State's POEs, of which, five are equipped with WIM and ESD technologies. Indiana DOT uses the data stream from the WIM sites as a screening tool to identify and sort out the potential violators. In addition to the facilities at the State's borders, Indiana has 46 mobile facilities to monitor truck size and weight compliance on interior highways. Officers serving the mobile facilities rely on their own experience in identifying the potential violators and flag them to stop at the facility.

In 2016, Indiana DOT started a virtual weigh station pilot program in collaboration with the State Police, the Department of Revenue, and Perdue University. The initial plan was to upgrade three of the 41 WIM data collection sites existing in Indiana to three virtual facilities, but due to pavement conditions, only one WIM data collection site was selected for the pilot program. The following figure summarizes the weigh station operations in Indiana.

Figure A-6: Summary of Weigh Station Operations in Indiana

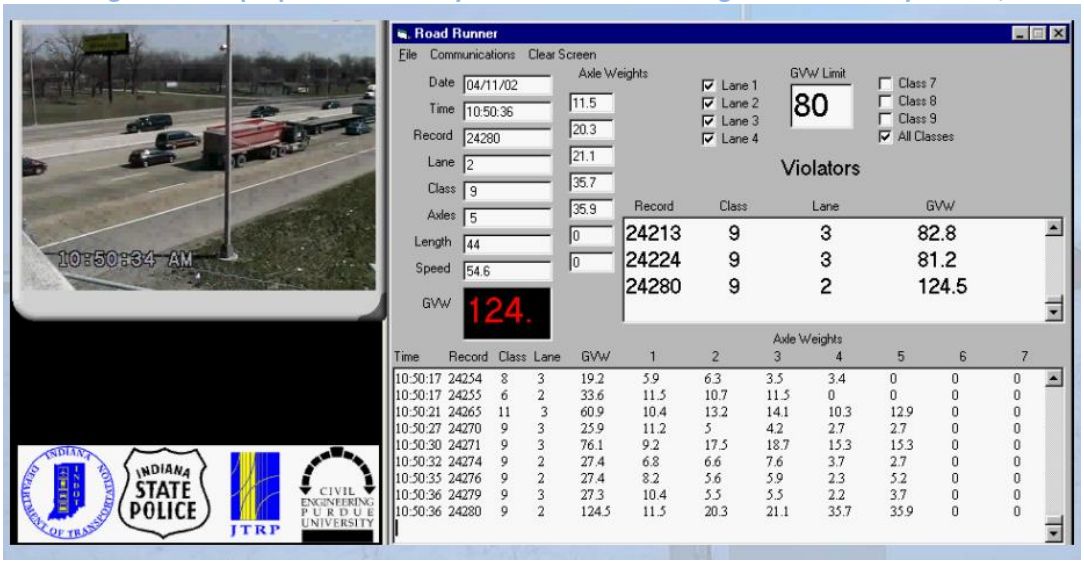
Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	10	46	1
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Notification
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	✓

Source: CPCS analysis of INDOT data and information provided by Drivewyze, NORPASS, and PrePass websites

The virtual site at I-94 uses a combination of camera, USDOT number reader, and LPR to identify the carriers that are violating the State's size and weight laws and inform the officers at nearby fixed facilities (Figure A-7) and notify the carriers through the mail. The results would help the

Indiana DOT to enhance the commercial vehicle weight enforcement and to recommend changes in legislation to support the virtual weigh enforcement through electronic citation.[43]

Figure A-7: Laptop Screen Seen by the Officers Monitoring a Virtual Facility on I-94, IN



Source: Overdrive "Indiana starts virtual weigh station pilot program along I-94" (June 2016). https://www.overdriveonline.com/indiana-begins-no-stop-wireless-inspection-pilot-program/

The lessons learned from INDOT's pilot program proved the necessity of involving the stakeholders from the very first stages of virtual weigh enforcement operations. The DOTs should determine from the beginning, who should expect what from the new technology deployment. Ongoing collaboration between the State DOT and Highway Police Department is the key to successful virtual operations, especially in the presence of laws that dismiss the electronic citation.

On the maintenance and calibration of the sensors and scales at the virtual facilities, INDOT's experience showed that repeatable calibration based on truck re-identification data obtained from the virtual facility and nearby fixed facilities would improve the reliability and enforce stakeholders' confidence in virtual operations. The results of the pilot program also showed that using cameras in combination with USDOT number readers and LPRs ensures carrier identification even in the face of challenges such as in inclement weather or when other vehicles block the camera view on multi-lane highways.

On the trucking association side, the stakeholders believe that although WIM technology improves the efficiency of trucking operations by sorting out the potential violators for stopping at weigh stations, electronic citation raises concerns related to due diligence and privacy.

A.5 Maryland Weight Enforcement Facilities

The Maryland Truck Weigh and Inspection Station system includes 13 fixed facilities and 4 mobile facilities for monitoring and weighing commercial vehicles. Seven of the 13 fixed facilities in the state use WIM technology to pre-screen the commercial vehicles. Maryland State Highway Administration (MSHA) is deploying additional screening devices (such as automatic safety

[43] INDOT "Overweight Vehicle Enforcement Pilot Program" (2018). https://www.in.gov/indot/3415.htm

inspection devices) for at these sites to increase their efficiency. The state has seven WIM sites that are located on bypass routes or at the vicinity of fixed facilities to support fixed and mobile operations.

Maryland Motor Carrier Division will add six WIM sites to the system by the end of 2018 to further improve commercial vehicle weight enforcement and screening operations. The locations of these WIM sites have been selected based on the results of a joint study by the MSHA, the State Police, and the State Transportation Police. The study included the use of public outreach, enforcement data, and traffic counts, as well as information on road surface condition, cellular/solar power availability, land acquisition, and staff availability. The following figure provides a summary of the current weigh station operations in Maryland.

Figure A-8: Summary of Weigh Station Operations in Maryland

Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	13	4	2
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Test sites
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	✓

Source: CPCS analysis of information provided by RITIS, Drivewyze, NORPASS, and PrePass websites.

All of the WIM scales in Maryland (deployed and currently under development) work with quartz sensors and are equipped with loop detectors, roadside and above the road cameras. The weigh stations send the image, number of axles, and weight information of the violators to nearby fixed stations or roving officers. The potential violators will then get flagged by a patrolling officer downstream who will send the truck to a fixed station or mobile station for weight and safety inspection. The WIM stations also provide weight, speed, classification, and violation data which is integrated into the University of Maryland Regional Integrated Transportation Information System (RITIS).

Evaluation of WIM scales data in Maryland shows that since the technology deployment, the number of violations has decreased, but one can argue that the number of trucks on the monitored routes might have decreased as well because the violating drivers use other routes to avoid the weigh stations.

Although it is legal in Maryland to issue citations based on electronic imaging technologies, MSHA is currently using the WIM technology for screening and monitoring commercial vehicle activities and not for enforcement. The main concern for deploying fully virtual facilities is the accuracy of WIM results.

In 2009, MSHA conducted a practical study of the methods and resources required for VWS deployment in Dayton, Maryland. The following are the lessons learned from statistical analysis of test VWS sites in Dayton, and the consultations with commercial vehicle weigh enforcement stakeholders in Maryland:

- For WIM technology location selection, the quality of pavement surface, access to power, proximity to a cell tower, and availability of safe pull-off sites should be considered,

- The timing of the periodic scale calibration is a function of mainline volume as well as the scale type,
- Equipping the WIM cabinets with monitors and keyboards will make the cabinet self-contained and improve calibration and maintenance process,
- The addition of a license plate reader or USDOT reader will further facilitate virtual law enforcement actions.

A.6 Nevada Weight Enforcement Facilities

In the state of Nevada, the Motor Carrier Safety Assistance Program (MCSAP) office of the state highway patrol operates and oversees the commercial vehicle enforcement activities. As the major population areas in the state are clustered around Las Vegas and Reno, the weight station facilities are located around those two cities. The state has a total of 7 fixed facilities located north and south of Las Vegas, east of Elko, east and west of Reno, and at the state's border with California on I-80. All of the fixed facilities in Nevada are equipped with WIM technology.

In addition, the state has 68 mobile weight enforcement operation sites and 34 WIM data collection locations that support the weight enforcement practices of the fixed and mobile sites. In 2006, the state implemented the VWS technology in 2 sites. However, the data obtained from those facilities were only used to inform planning and not enforcement activities.[44] The following figure provides a summary of the current weigh station operations in Nevada.

Figure A-9: Summary of Weigh Station Operations in Nevada

Weigh Station Type	Fixed Facility	Mobile Facility	Virtual Facility
Quantity	7	68	2
Staffing Status	Staffed	Staffed	Unstaffed
Primary Purpose	Enforcement	Enforcement	Screening
Legal Bypass Option	✓	✓	-
Camera and LPR	✓	✓	-

Source: CPCS analysis of information provided in the highway patrol portal, Drivewyze, NORPASS, and PrePass websites.

[44] AASHTO Presentation "Virtual Weigh Virtual Weigh-In-Motion, a "WIM-win" for transportation agencies" (2006).