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COMMERCIAL VEHICLE INFORMATION SYSTEMS AND NETWORKS (CVISN) PROGRAM, CENTER FOR ADVANCED TRANSPORTATION TECHNOLOGY (CATT), UNIVERSITY OF MARYLAND

# Maryland Virtual Weigh Station

## Final Report

Dongwoon Hahn, Manoj Pansare
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**16. Abstract:**

A Virtual Weigh Station (VWS) is a new approach to CMV weight, height, and safety enforcement that can help monitor statewide compliance rates and provide a deterrent to CMVs that use bypass routes for the purposes of violating state weight and safety laws. Occasional and habitual offenders can be identified remotely and pulled over for targeted inspections. It is expected that this weight and height pre-screening approach will provide advantages over a traditional random selection approach by providing law enforcement officers the necessary information to target inspection efforts. Various high speed WIM technologies were considered and investigated. Research and production deployments in other states were investigated. Based on national and Maryland experience, the quartz sensor was selected and deployed for the pilot VWS. The area chosen for the pilot VWS was Dayton, MD on Rte 32 in the southeast direction. Full construction took approximately four weeks, with the sensor and loop installation being completed in less than a day. Sensor calibration was completed thereafter, and working in conjunction with MSP-CVED, results were formulated from two sets of tests. Phase 1 had a predefined set of SHA vehicles and Phase 2 utilized a random sampling of CMVs. These results are presented and analyzed in the report. A set of recommendations and suggestions are provided, along with a guideline for calibration of the WIM sensor periodically. Suggestions for future research studies and potentials are also provided.

It was demonstrated that the VWS improved the effectiveness of CMV selection methods significantly over a traditional method relying on random selection. It was also demonstrated that the quartz sensor is able to achieve an accuracy level that is sufficient for pre-screening of CMVs. We developed a practical test, calibration and maintenance methodology for the VWS. We were also able to develop a flexible, cost-effective, and rapid deployment model for future planned VWS deployments in the state.

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# MARYLAND VIRTUAL WEIGH STATION

**Final Report**
**August 2009**

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## EXECUTIVE SUMMARY

All goods that are consumed within the United States and exported outside the United States are carried by trucks or Commercial Motor Vehicles (CMVs) at some point in their journey. The volume of goods moved by CMVs is expected to increase significantly by 2015. Goods are moved by large, heavy CMVs that travel at highway speeds for very long distances. Movement of goods is most efficient when motor carrier operations experience the least amount of downtime. Necessary downtime, when incurred to ensure the safety of the traveling public, can be made more efficient and effective when conducted in conjunction with electronic screening tools and technologies that support motor carrier operations by reducing unsafe CMV practices.

In Maryland, there exists a set of CMV safety guidelines and regulations (The Maryland Vehicle Law) that need to be enforced consistently and equitably. Regulation and enforcement work in conjunction to create a road system that is safe for the traveling public. Regulations are necessary for safety, security, and the environment. They include vehicle weight, height, speed, operation of lights, brakes, steering, tires, suspension, emissions, and multiple other systems designed to operate a CMV. Special regulations govern CMV drivers. These include work hours, health, and licensure. Enforcement is necessary to ensure that all CMVs stay within regulations to provide an acceptable margin of safety for the traveling public.

Excessive CMV loads on state roads can cause a lot of road damage. Over weight vehicles are also likely to cause other problems such as crashes and other unsafe road conditions such as hazardous spills, lost loads, etc. It is not possible for enforcement to stop, weigh and inspect every CMV that travels through the state. Traditional enforcement processes focus on selecting a random set of CMVs for inspections at Maryland's CMV weigh and inspection stations. These CMVs are then inspected to state and federal standards using inspection methods that require a fair amount of time. This model is fairly inefficient, since a substantial amount of time is lost in the inspection process, including a significant amount of inspection personnel time.

Maryland currently has thirteen fixed CMV weigh and inspection stations with permanent static scales. Six of these stations are located on Interstate highways, and the remaining seven are located on Maryland and U.S. highway routes. Some of these fixed weigh and inspection stations are operational in both directions. In addition, Maryland has ten paved pull-off mobile enforcement areas for CMV inspections. The locations and descriptions of these fixed sites and paved pull-off areas are shown in Figure 1. As can be seen from the figure, existing stations provide reasonably good coverage of this road network. However, the Interstates, Maryland routes, and U.S. highway routes make up a small portion of Maryland's overall road network. Hence, the vast majority of road mileage in the state is not monitored by fixed CMV enforcement facilities. A number of fixed weigh and inspection stations can be easily avoided by taking alternate routes to 'bypass' the weigh and inspection station.


**Figure 1. Maryland CMV Weigh and Inspection Station Facilities**

To augment fixed facilities and to provide coverage of otherwise unmonitored routes, Maryland State Police – Commercial Vehicle Enforcement Division (MSP-CVED) and Maryland Transportation Authority Police – Commercial Vehicle Safety Unit (MdTAP-CVSU) conduct mobile enforcement operations. These operations extend enforcement coverage throughout the state.

An efficient law enforcement pre-screening tool is needed in order to select and target CMVs with over weight violations for inspections, in conjunction with mobile enforcement units, on known CMV bypass routes within the state. With additional inspections, these over weight CMVs can also be scrutinized for other unsafe operating conditions and put out of service before these operating conditions cause a significant problem.

By increasing the effectiveness of target inspections, more CMVs will abide by the weight regulations. Since it is suspected that CMVs with weight and height violations are more likely to have safety issues, targeted inspections could also increase the level of safety on the roads by putting higher risk vehicles Out-of-Service (OOS).

In Maryland, the goal of the VWS pilot project is to provide a platform for law enforcement to target their enforcement activities at CMV violators using Route 32 southbound as a potential bypass route between two fixed weigh and inspection station sites in close proximity (West Friendship and New Market). Another key goal is to develop a stable, accurate, and standard platform for rapid deployment at other statewide locations. A research goal of the pilot project is to determine if there is a relationship between weight and safety. The research is also expected to provide practical recommendations and guidelines in expanded deployment of the VWS concept in the state.

The area chosen for the first pilot deployment is Dayton on Maryland Route 32 in the southeast direction, starting near West Friendship (exit off I-70) and ending in Columbia (near exits for Route 29). Two phases of tests, one with a predefined set of vehicles, and the other with a variety of CMVs on the road were performed in conjunction with MSP-CVED.

The first phase of tests concluded that the VWS met the functional and technical requirements for a high speed WIM application as defined by our test plan (Appendix C), as well as the ASTM 1318-09 standard. All axle weights, bridge formula weights, axle spacing and axle lengths met the ASTM requirements. 95% of gross weights met the ASTM 1318-09 requirements.

The second phase of tests concluded that the VWS met the functional and technical requirements specified by the ASTM 1318-09 standard. The gross weight requirement as specified in the ASTM standard was not met completely because of a negative calibration adjustment factor (-2%) used in the computation and display of axle and gross weight readings, and the inherent calibration factor of the portable scales used as reference scales (introduced and explained in 2.6.1). A number of observations were made suggesting clues for CMV pre-screening violations, including over speed, unbalanced loads (suggesting possible intentional driver maneuvers to avoid a consistent weight reading), and other visual cues that could assist law enforcement in making effective and objective pre-screening decisions to maximize their mobile weigh and inspection efforts.

Data from the WIM sensors and CMV images, in conjunction with targeted inspections by MSP-CVED improved the inspection effectiveness in targeting not only vehicles with weight violations but also vehicles with other safety issues. We observed that pre-screening methods based on WIM selection (such as unbalanced loads) are more effective in locating over weight and high risk vehicles. A relationship between weight and safety was not observed, potentially due to the limited sample set gathered in the second phase of tests.

CMV statistics at the pilot VWS location have been analyzed and presented in Section 11. These include general statistics and more detailed breakdown by volume and hour. These statistics are also available from detailed reporting functions on the VWS thin client application. These reports can provide valuable clues for law enforcement to focus their inspection efforts during time periods that suggest more over weight and/or over height violations.

A number of guidelines related to site selection, including road surface topology and cellular communications, as well as components of the VWS, including the WIM sensor, camera, IR illumination, and other components have been provided. They include guidelines for periodic WIM sensor calibration (Section 12).

In conclusion, it was demonstrated that the VWS improved the effectiveness of CMV selection methods significantly over a traditional method relying on random selection. It was also demonstrated that the Quartz sensor is able to achieve and maintain an accuracy level that is sufficient for pre-screening of CMVs. We developed a practical test, calibration and maintenance methodology for the VWS. We were also able to develop a flexible, cost-effective, and rapid deployment model for future planned VWS deployments in the state.

The results of this research are expected to serve as a model in the future deployment of VWS in Maryland. This application will serve as an efficient tool to aid law enforcement in CMV enforcement.

## ACRONYMS AND ABBREVIATIONS

| Abbreviations or Acronyms | Definition |
|---|---|
| AASHTO | American Association of State Highway Transportation Officials |
| ASTM | American Society for Testing and Materials |
| CDL | Commercial Driver's License |
| CGI | Common Gateway Interface |
| CMV | Commercial Motor Vehicle |
| CONOPS | Concept of Operations |
| CVISN | Commercial Vehicle Information Systems and Networks |
| DOT | Department of Transportation |
| ESAL | Equivalent Single Axle Loads |
| EVDO | Evolution-Data Optimized or Evolution-Data only |
| FHWA | Federal Highway Administration |
| GNP | Gross National Product |
| GUI | Graphical User Interface |
| IIS | Internet Information Services |
| IP | Internet Protocol |
| IR | Infra-Red |
| ISP | Internet Service Provider |

| | |
|---|---|
| ISS | Inspection Selection System |
| MdTAP-CVSU | Maryland Transportation Authority Police – Commercial Vehicle Safety Unit |
| MOT | Maintenance of Traffic |
| MSP-CVED | Maryland State Police – Commercial Vehicle Enforcement Division |
| NCHRP | National Cooperative Highway Research Program |
| NTP | Network Time Protocol |
| OOS | Out-of-Service |
| QoS | Quality of Service |
| QWIM | Quartz Sensor-Based Weigh In-Motion |
| SHA | State Highway Administration |
| TCP | Transmission Control Protocol |
| TWIS | Truck Weigh and Inspection Stations |
| UDP | User Datagram Protocol |
| UPS | Uninterruptible Power Supply |
| USDOT | United States Department of Transportation |
| VWS | Virtual Weigh Station |
| WIM | Weigh-in-Motion |

# 1. INTRODUCTION TO VIRTUAL WEIGH STATION

Excessive CMV loads on state roads cause a lot of road damage. The ESAL (Equivalent Single Axle Loads) model is developed from the American Association of State Highway Transportation Officials (AASHTO) Road Tests, and provides information about the relative damage to a pavement structure compared to a standard axle. It is intended to compare the effects of axles carrying different loads. The reference standard is an 18,000 lbs. single axle load with dual tires. The effect of a single axle on flexible or rigid pavement increases about a fourth power function of the axle load. For example, a 36,000 lbs. single axle load is twice as large as an 18,000 lbs. load, but it causes 17 times more loss in pavement life. (Kwon & Aryal, 2007) Therefore it is very important to make sure that CMVs meet the federal and state mandated weight regulations. Because it is not possible to stop every vehicle to ensure that it abides by the relevant state regulations such as weight and safety regulations, efficient pre-screening tools to aid law enforcement in CMV enforcement actions are required. It typically takes thirty minutes to conduct a level two inspection of a vehicle; hence, only a small portion of the traffic can be inspected by the CMV inspectors. Therefore, efficient tools and smarter methodologies are needed to enhance the effectiveness of the target inspection.

A Virtual Weigh Station (VWS) is a new approach to CMV weight, height, and safety enforcement that can help monitor statewide compliance rates and provide a deterrent to CMVs that use bypass routes for the purposes of violating state weight and safety laws. Occasional and habitual offenders can be identified remotely and pulled over for targeted inspections. It is expected that this weight and height pre-screening approach will provide advantages over a traditional random selection approach by providing law enforcement officers the necessary information to make an informed decision about additional inspection for a targeted CMV.

## 1.1. Concept of Operations (CONOPS):

According to (Cambridge Systematics, Inc., 2009), the concept of a VWS is very flexible. At a minimum, the VWS has to include the following technologies: WIM scales, camera system, screening software and communication infrastructure. The typical physical layout of a VWS is given by (Cambridge Systematics, Inc., 2009) and is presented in Figure 2.

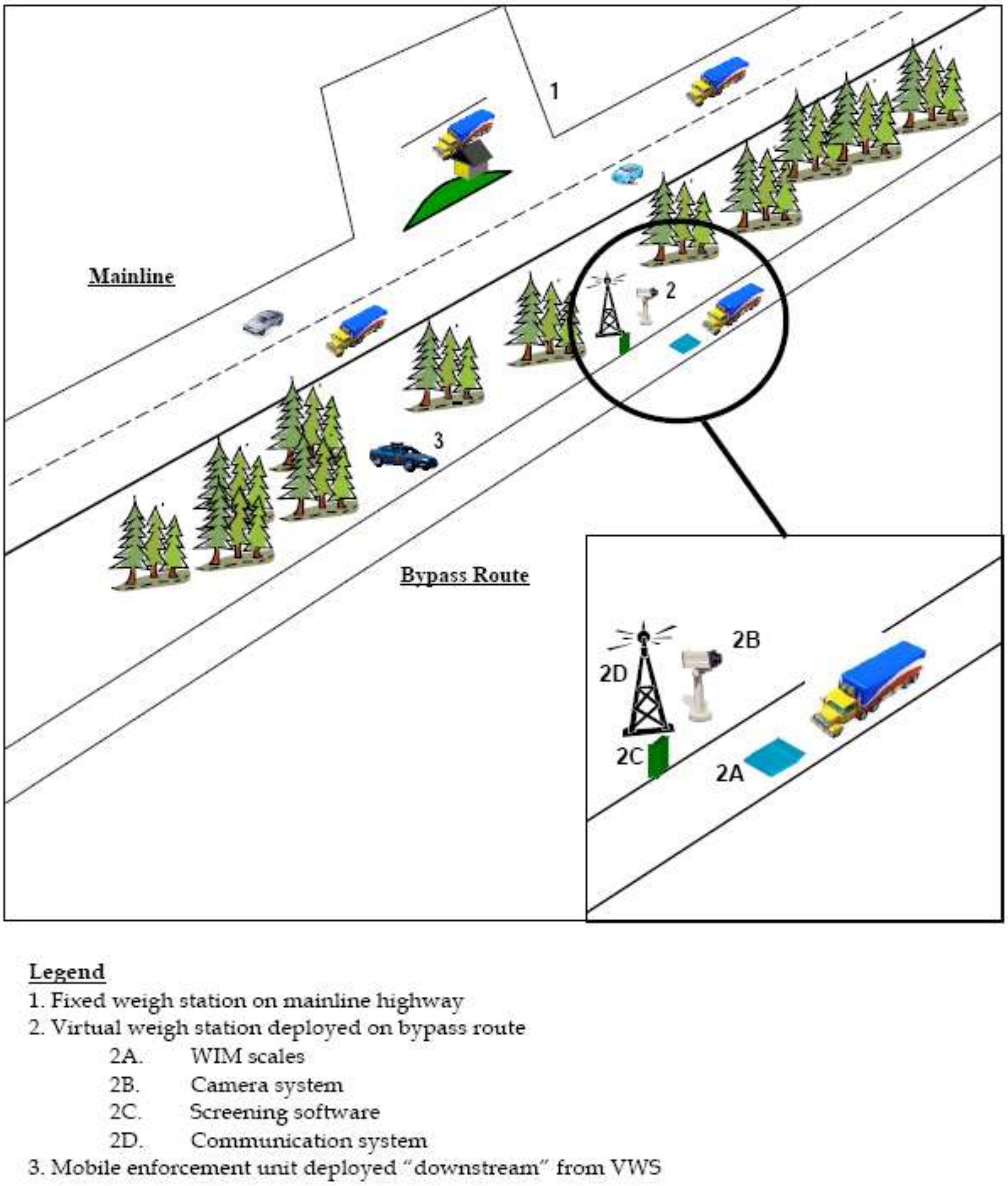



**Figure 2. Physical Layout of a Basic Virtual Weigh Station [Source: (Cambridge Systematics, Inc., 2009)]**

Mainline Weigh-in-Motion (WIM) scales (such as Quartz Sensors) are used as weight pre-screening tools, along with a loop and an over height detector for distinguishing CMVs from other vehicles. A high resolution, high shutter speed pole mounted camera is used to capture images of over weight or over height CMVs, and the information is collected in a roadside cabinet with the appropriate computer and communications hardware and software. The captured information includes the vehicle's image, axle and gross weights, height, speed, date and timestamp, and a summary display of the violation conditions observed. These are core features. In addition, other custom features such as tailgating (following too close) and wrong direction can also be tailored to state or location specific requirements. An Infra-Red (IR) illuminator can be used to enhance image visibility at night time and in adverse weather conditions. A roving enforcement vehicle equipped with a laptop, an Internet browser and a broadband communications card with any acceptable broadband communications technology to access the required information securely over the Internet would have timely access to this information to make informed decisions about pulling offenders over and conducting a more thorough inspection.

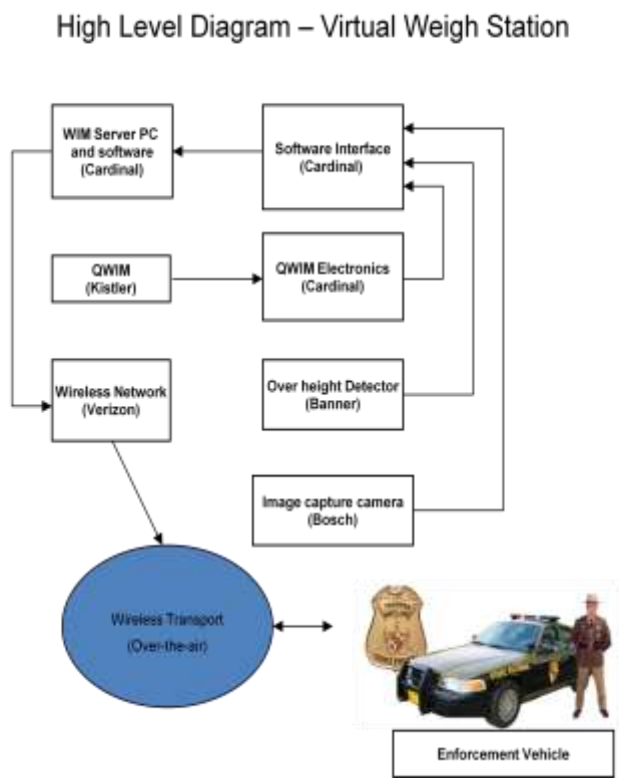



**Figure 3. High Level Diagram of Virtual Weigh Station**

A Virtual Weigh Station (VWS) is expected to be a more efficient law enforcement tool than the traditional inspection method such as random selection or selection by visual cue. The need for a VWS can be emphasized based upon the following reasons:

- **US freight volume is increasing exponentially.**

  The freight volume moving within the United States has nearly doubled the rate of population growth over the past three decades and exceeded the growth rates in disposable income and GNP. It is estimated that the volume of goods moved by CMV will increase approximately 45 percent between now and 2015 (Oloufa, 2007).

- **CMVs are moving most of the freight on US roads.**

  CMVs are moving 70% of all freight on US roads. (Mettler Toledo) Therefore it is important to monitor CMVs in order to avoid potential problems such as CMV safety and road damage.

- **The over weight violation rate is expected to decrease when enforcement is visible.**

  When enforcement is visible, the violation rate is maintained at a low percentage. As enforcement level increases, the violation rate decreases exponentially. In Maryland, the over weight violation rate is about 1% at the high enforcement level while it is 34% at the low enforcement level. (B.H. Cottrell, 1992)

- **Over weight CMVs are the major cause of road damage.**

  It is estimated that overloaded CMVs cause road damage in excess of $600 million per year. (Mettler Toledo)

  It has also been known that a slight increase in CMV loading may result in significantly more damage to the roads. Research in the area of mechanistic-empirical pavement performance predictions indicate that damage is particularly significant in adverse climate conditions such as freeze-thaw. The increased pavement damage incurred is in the order of 57% more than originally accounted for in design projections. (Taylor, Bergan, Lindgren, & Berthelot, 2000). 34% violation (violation rate at low enforcement level in Maryland) translates to a 20% decrease in the lifetime of the pavement.

- **CMVs are avoiding fixed weigh and inspection station sites taking alternate routes.**

  Up to 14% of CMV traffic avoids a fixed weigh and inspection station site when open. It was found that operators would travel up to 160 miles to avoid a weigh and inspection station. (B.H. Cottrell, 1992). By avoiding the weigh and inspection station, illegal CMV operators derive economic benefits, but the damage to the pavement far exceeds this economic benefit to the operator. It has been shown that when a CMV is traveling 300 miles with an overload condition of 10,000 lbs., there is a 50% higher cost in pavement damage compared to the economic benefit enjoyed by the CMV operator (Taylor, Bergan, Lindgren, & Berthelot, 2000).

- **Overloading and safety deficiencies are correlated.**

In 2005, 5,212 people were killed and approximately 114,000 were injured in crashes involving approximately 441,000 large CMVs. (Brown, Anderson, Balducci, Orban, Kiefer, & Desautels, 2009). If target inspections were more efficient, we could avoid more crashes and penalties by putting more unsafe vehicles out-of-service.

Random selection is only responsible for avoiding 3,139 CMV related crashes (including 818 injuries and 38 deaths) which is about 0.7% of the total CMV related crashes using a baseline year of 2005. (Brown, Anderson, Balducci, Orban, Kiefer, & Desautels, 2009).

- **VWS can detect a variety of violations other than over weight violations.**

  Previously it was argued that the VWS can potentially detect unsafe CMVs. The Maryland pilot VWS can detect other violations using WIM and over height detection. These violations include tailgating (following too closely), speeding and bridge and tandem weight violations as specified under the FHWA classification and weight tables.

  With tailored classification rule sets, the VWS can also detect other illegal operators such as unlicensed commercial operations that register the vehicle as a personal vehicle, and then use the vehicle for commercial purposes with no CDL or no DOT number with a single axle trailer carrying equipment on the trailer. This is accomplished by filtering vehicles using class and weight (class 3, under 10,000 lbs.).

- **VWS Monitors traffic 24 hours a day, 7 days a week**

  Data from the VWS could be used in monitoring commercial vehicle traffic and violation statistics at the time law enforcement personnel are not available (e.g. night time, holidays, other periods, etc.). The VWS also provides classification, speed and volume data to road planners and designers to assess volume, pavement, and speed information on any given road artery where it is installed.

The current method of law enforcement on the roadside being used widely is random selection or selection by visual cue. It is expected that filtering by the VWS should enhance the effectiveness of targeting efforts or roving enforcement operations by selecting vehicles with more potential for violations using the information from the VWS.

There have been a number of research and pilot projects by many states using the VWS concept. To repeat - in Maryland, the goal of the VWS pilot project is to provide a tool for Maryland State Police (MSP) to target their enforcement activities at CMV violators using Route 32 southbound as a potential bypass route for two fixed weigh and inspection station sites in close proximity (West Friendship and New Market). Another key goal is to develop a stable, accurate, and standard platform for rapid deployment at other statewide locations. This project is a collaborative agreement between the University of Maryland, State Highway Administration and

Cardinal Scale Manufacturing Company, in conjunction with evaluation and test assistance for production deployment by MSP-CVED.

The objectives of this VWS research paper are as follows:

- **Gather metrics for the effectiveness of VWS in targeting habitual and non-habitual offenders.**

  Determine the inspection rate and metrics on Out-of-Service (OOS) rates using the VWS as a pre-screening tool. Statistical analysis will attempt to show the correlation between OOS rates and the violations detected at the VWS. Inspection effectiveness with or without using VWS will be provided.

- **Gather data on accuracy, reliability and serviceability of Quartz Sensors as a tool for flexible and quick VWS deployment.**

  Many states have traditionally utilized analog or digital load cells as a more reliable and accurate tool for VWS deployment. However, the cost and maintenance of traffic outages associated with initial deployment of a load cell based VWS, and associated long-term maintenance may not work in all situations where extended lane closures create a problem. Quartz Sensors have recently started coming into the VWS mainstream, and there is growing acceptance of this sensor in the transportation and enforcement community.

- **Develop a flexible, cost effective and rapid deployment model for future planned VWS deployments in the state.**

  This project does not intend to end up at the research level. The ultimate goal is to provide practical recommendations for future deployment of VWS in Maryland.

- **Provide a test methodology for the VWS.**

  Determine acceptable and cost effective test methodology and plans to install VWS components, validate the construction, calibrate the WIM and provide guidelines for WIM accuracy via periodic calibration.

- **Provide a guideline for inspection methodology.**

  Utilizing test results, a guideline to achieve targeted inspection is validated by showing how to focus on over weight and potentially unsafe vehicles using information provided by the VWS.

## 2. COMPONENTS OF VWS

A VWS is composed of the following software and hardware components:

### 2.1. Weigh-In-Motion Sensor

The Kistler Lineas® quartz weigh-in-motion sensor type 9195E is used to measure the wheel and axle loads and to determine the vehicle gross weight under rolling traffic conditions. This is a core component of the VWS system.

**Figure 4. Weigh-In-Motion (WIM) Sensor: The Kistler Lineas® Quartz Weigh-In-Motion Sensor Type 9195E**

**Figure 5. Weigh-In-Motion (WIM) Sensor at the Pilot VWS (Two Sets)**

It consists of a light metal profile in which quartz disks are fitted under preload.

*2.1.1. Loop Detector*

A loop detector, in conjunction with the WIM sensor is used to identify and classify CMVs and perform the initial sorting to distinguish them from other vehicles.

The sensitivity level of the loop detector is adjusted so that vehicular traffic traveling in the opposite lane does not trigger the loop detector.

**Figure 6. Loop Detector at the Pilot VWS**

**Figure 7. Loop Detector and Quartz Piezo WIM Sensor Layout at the Pilot VWS**

## 2.2. Over height Detector

The height detector is mounted on both sides of the road way. It consists of one emitter and one reflector. Potential height violators will trigger the camera image. A Banner Engineering Q45 sensor is used for over height detection.

This detector has an analog signal strength display to assure correct alignment and reduce intermittent trips due to borderline adjustments. It also helps to adjust the detector avoiding excess gain. The beam pattern is smaller providing an accurate cut-off height of detection (at 30 feet revealed a ¼ inch threshold to trip.). The beam is strong enough to penetrate fog and light rain. Using the detector and just a reflector up to a 40 meter distance eliminates the need for power on the opposite pole. The mounting bracket has 3 axis micro adjustments for precision aiming. This detector is totally solid state with no mechanical relays. Quick connect cable allows field replacement without killing power or re-terminating wires. It also has a beam inhibit function that extends the life of the unit.


**Figure 8. Over height Detector: Banner Engineering Q45 sensor**

**Figure 9. Over height Detector at the Pilot VWS**

### 2.3. Camera

A Bosch NWC-0495 Dinion XF Day/Night IP camera is used to capture vehicle images from the front. Potential weight or height violations, per set thresholds, will trigger the camera. In the test phase, every CMV passage can trigger the camera, but only those of class 3 vehicles and above are stored at the WIM server PC.

This camera was chosen because of its excellent image quality under a variety of situations. The 15-bit digital signal is automatically processed to produce images of good quality in high and low light areas. In night mode, low light viewing can be enhanced by switching the IR illumination (still in evaluation). By sensing the illumination level, this camera automatically switches to monochrome mode. When the IR illumination is dominant, the camera is prevented from returning to color mode.

This camera cannot be configured remotely. MSP-CVED assisted in validating the angle, frame view, and images during the initial setup of the camera.


**Figure 10. Camera: Bosch NWC-0495 Dinion XF Day/Night IP camera**

### 2.4. IR illuminator

A Bosch AEGIS UFLED Intelligent-IR is used to enhance night time, early morning and late evening performance of image capture. This IR was designed so that it maintains a constant level of infrared performance throughout the life of the illuminator and at varying ambient temperatures. A number of beam patterns are available: 10, 20, 30, 60, 95 and 120.

***Note:*** *As of August 21, the performance of IR is quite satisfactory. After additional testing and further consultation with Bosch, Cardinal determined that a different (high intensity) IR illuminator model was needed. Installation and testing was completed in conjunction with Bosch technical support. An additional high intensity IR illuminator was installed at the WIM cabinet. This illuminator faces the road directly. It is in much closer proximity and is placed parallel to the exposed surface of the CMV tractor and trailer. The result is a fairly consistent illuminated CMV surface. It should be noted that results, while not perfect, yield sufficient detail to identify the CMV profile during night time enforcement, when CMV volume is low. Vehicle detail also depends on the amount of reflected light energy from the CMV. A lighter colored CMV provides very good detail. A darker color CMV may not provide the same amount of detail. In many cases, the reflected profile of vehicle lights along the side of the truck also provides sufficient detail to determine the CMV profile. MSP-CVED concluded that night time truck images after the high intensity IR illuminator was added provided enough detail for CMV identification.*

*Very careful attention needs to be placed on the geographic topology of the site, including ambient light, angle of reflectivity, distance to target, and IR beam surface area and light pattern. A 'one size fits all approach' cannot work in most cases.*


**Figure 11. IR: Bosch AEGIS UFLED Intelligent-IR**

**Figure 12. Camera and IR at the Pilot VWS**

### 2.5. Cell Router

A Proxicast cell router with a Verizon Sierra EVDO card is used to transmit data and captured images from the WIM computer to MSP-CVED laptops and other PC clients. PC clients use a

Java Thin Client in conjunction with a standard web browser (Internet Explorer 7) to access the data and images. A 9 dBi External Multi-band antenna is used with this cell router to enhance the cell signal. The router also has a built-in firewall. This firewall can be configured for a number of intrusion detection scenarios, including denial of service attacks. In our case, we are using a default configuration which automatically rejects and drops sessions if they begin to exceed 100 sessions a minute. In addition, firewall rules allow ftp, PCAnywhere, the Java Thin Client, and direct TCP login on the WIM Server using password authentication.

A persistent connection to the thin client is required. The application on the WIM computer will not send any real-time information 'over the air' until a connection is established. The size of each image and data overlay is not expected to be greater than 150KB including compression. A latency factor of 10 seconds worst case was considered to get this information to the MSP-CVED officer's laptop.

The cell router is paired with a Verizon EVDO Rev A compatible aircard. An ISP enabled Verizon static IP address has been assigned so that it can enable the router to work on Verizon Broadband access remotely. The static IP address is visible to login to the applications on the server PC using a Java thin client and other applications such as an ftp client and PC Anywhere on other terminals (remote access). The router is configured for secure password protected remote access from the Java thin client.

***Note:*** *It is believed that the limitation of bandwidth at the EVDO link and QoS (Quality of Service) priority handling by the Verizon network at busy hours sometimes prevents intermittent images from the server being delivered to the Java thin client particularly when three or more Java thin clients are active. All of our data is being passed over the cellular network. We have confirmed with Verizon that voice receives first priority, followed by data, images and video. As a result, depending on local cell tower traffic load, (there are multiple tower handoffs depending on distance; at our location between West Friendship scale house and the VWS site there is one handoff occurring), an occasional issue with dropped images is observed.*

The cell router is housed in the WIM cabinet.

**Figure 13. WIM Cabinet**

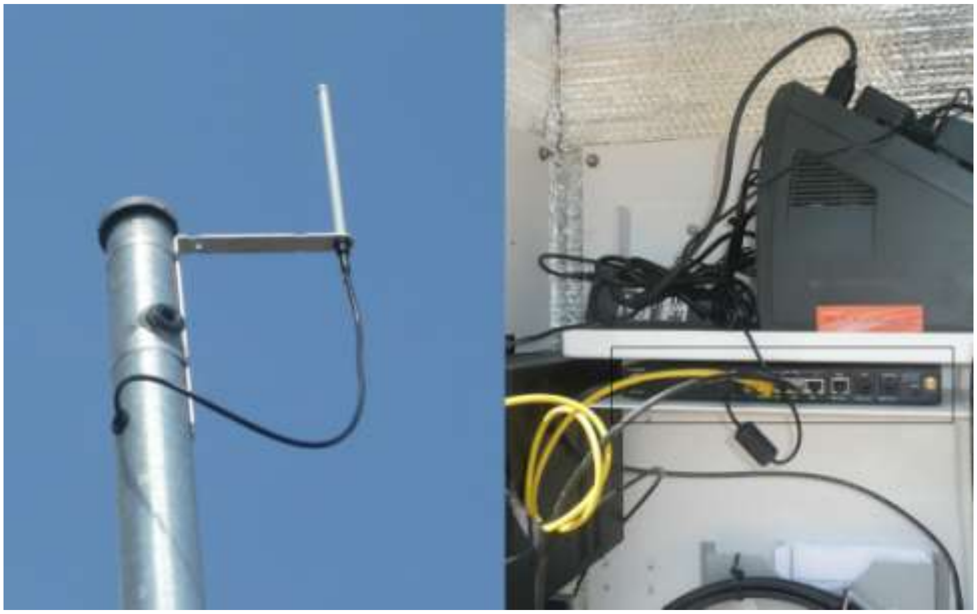


**Figure 14. Cell Antenna and Proxicast Cell Router at the Pilot VWS**

### 2.6. WIM Server PC

WIM Reader Server Software runs on the WIM Server PC. It is used to control other hardware components as part of a decision making system. This software includes the Windows operating system and related VWS applications which are composed of camera image capture, WIM data, over height data and image review software. PCAnywhere is also running on the WIM Server PC for remote access.

The WIM server PC is configured with the following software packages:

- IIS service: This will allow the Cardinal provided CGI executables for web reporting or configuration to run.

- Microsoft SQL Server 2005 Express and Management Studio Express: A database used for the system.

- Cardinal WIM Reader 2 (Cardinal WIM Classifier) software: Software developed by Cardinal Scale used to display vehicle records, configure calibration settings and setting up the WIM scale.

- WIM-Clean: A utility program performing data clean up based on a user defined configuration

The WIM Server PC is housed in the WIM cabinet. This PC is linked to the CVM unit through its serial port.

### *2.6.1. Data Filtering*

In order to facilitate the tests and production deployment, image and data traffic transferred to the thin client needs to be managed so that the application does not send excessive traffic 'over the air' and adheres to Verizon monthly bandwidth guidelines for data access. The data filtering option can be configured at the WIM reader application on the WIM server. WIM Reader is configured to send class 3 and above vehicles to the client. All measurement data for class 2 vehicles is stored at the WIM server; however, the images are not stored since they are not needed by law enforcement.

The filtering rules for the WIM server are as follows (See Appendix D):

- All class 2 vehicles are filtered.

  Since most of the traffic on Route 32 is traffic from class 2 vehicles, this decreases the amount of 'over the air' data and image traffic fundamentally.

- 2 axle vehicles of class 3 or 5 that fall under 10,000 lbs. are filtered.

This rule set is used to decrease data and image traffic as well. Technically, all class 3 or 5 vehicles less than 10,000 lbs. are classified to class 2, since law enforcement is not interested in enforcement action for these vehicles.

- Any 3 axle vehicles will not be filtered: Vehicles such as a small pickup towing a single axle trailer will not be filtered.

  This rule set is configured specifically for law enforcement action, in order to screen vehicles with certain types of violations. Examples are unlicensed commercial operations that register the vehicle as a personal vehicle, and then use it for commercial purposes with no CDL or no DOT with a single axle trailer and equipment sitting on the trailer. Technically all 3 axle vehicles less than 10,000 lbs. are classified to class 3.

- Initial gross and axle weight calibration: a slightly negative calibration bias (-2%) is applied to the reference weights displayed by the thin client in order to ensure the validity of over weight gross and axle weights during pre-screening. Note that all weight values as displayed by the thin client contain this intentional bias. This adjustment was performed to ensure the pre-screening confidence level for MSP-CVED officers in making an over weight pre-screening decision.


**Figure 15. WIM Server PC and UPS at the Pilot VWS**

## 2.7. Java Thin Client

This Java web based client application running on an Internet browser on any client PC connects to the WIM Server software to retrieve weight measurement data, over height detection data and images stored on the WIM Server PC. It provides the Graphical User Interface (GUI) to the user to view the stored data and images. Java Runtime Engine is required to run the WIM Thin Client on the MSP laptop or other fixed or mobile PC terminals. Microsoft Internet Explorer 7 was used as the reference Internet browser for developing the application. It has been observed that the client also runs on other browsers such as Mozilla Firefox v3.x and Google Chrome; however these browsers are not supported.

The Java client was tested and validated for secure access on Panasonic ToughBooks deployed and used by MSP-CVED. These laptops already have existing Verizon EVDO Rev A aircards installed and provisioned for Verizon broadband access.

The WIM server provides a basic navigation page for accessing the thin client. In order to access data on the WIM server PC, a username/password combination must be entered.

The front navigation page provides the user with several choices as shown below. Reports can be also accessed from the Java Thin client.

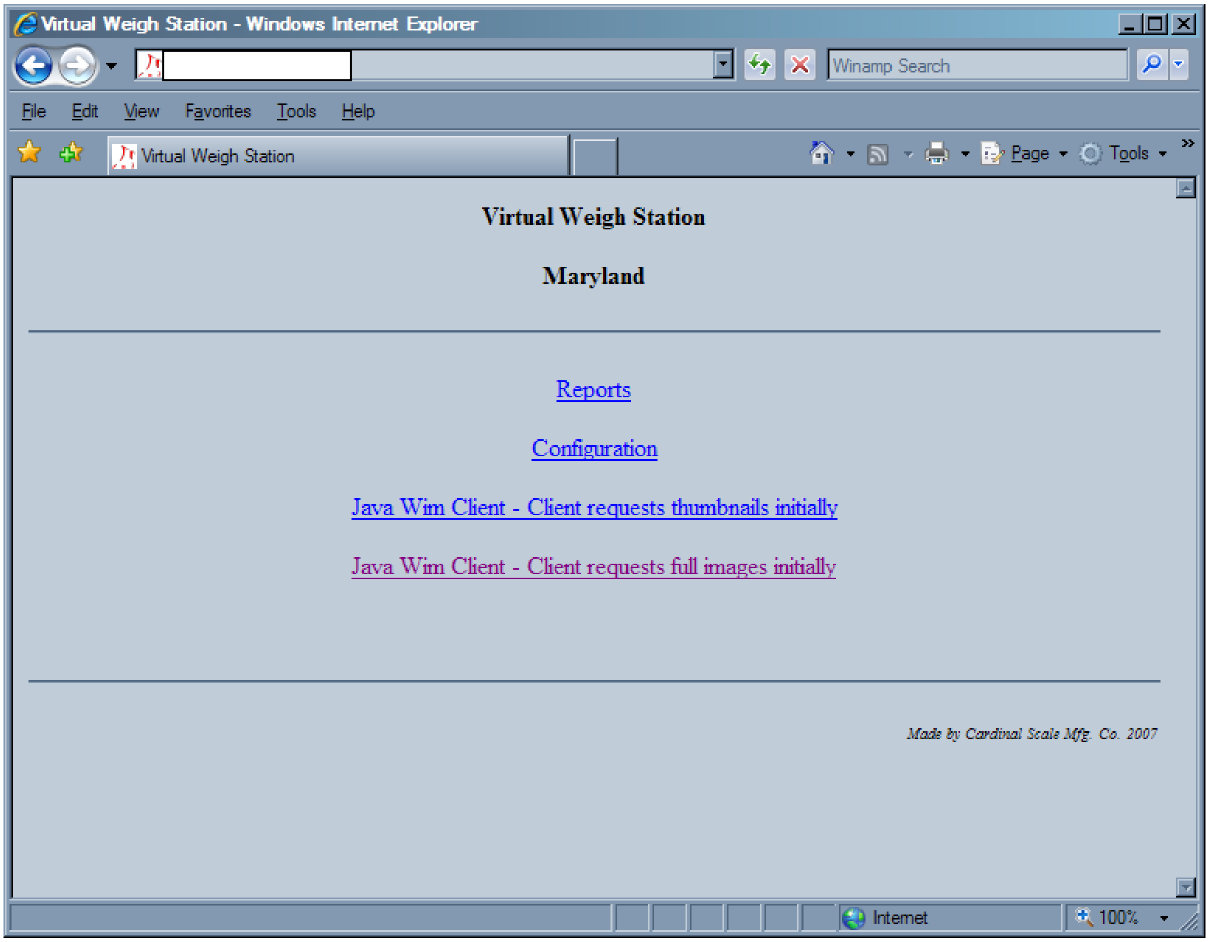



**Figure 16. Front Navigation Page for Accessing the Java Thin Client**


**Figure 17. Java Thin Client**

The Thin client has the following functionalities:

- The left hand panel displays a list of vehicles that are passing over the sensors. If the Violations tab is selected, the list is filtered to only display vehicles that have violations associated with the image.
- The upper right hand image is the full image from the list view item that was selected. Directly below the image is general information about the selected vehicle including time stamp, gross weight (blue for non-violation, red for violation), speed (red for violation), length, and vehicle class. Also depicted is a list of the violations for the selected vehicle.
- Below this is a graphical representation of the axles and axle weights.
- At the bottom of the right hand side there is a tabbed area for notes and information logs.

### *2.7.1. The Configuration Page:*

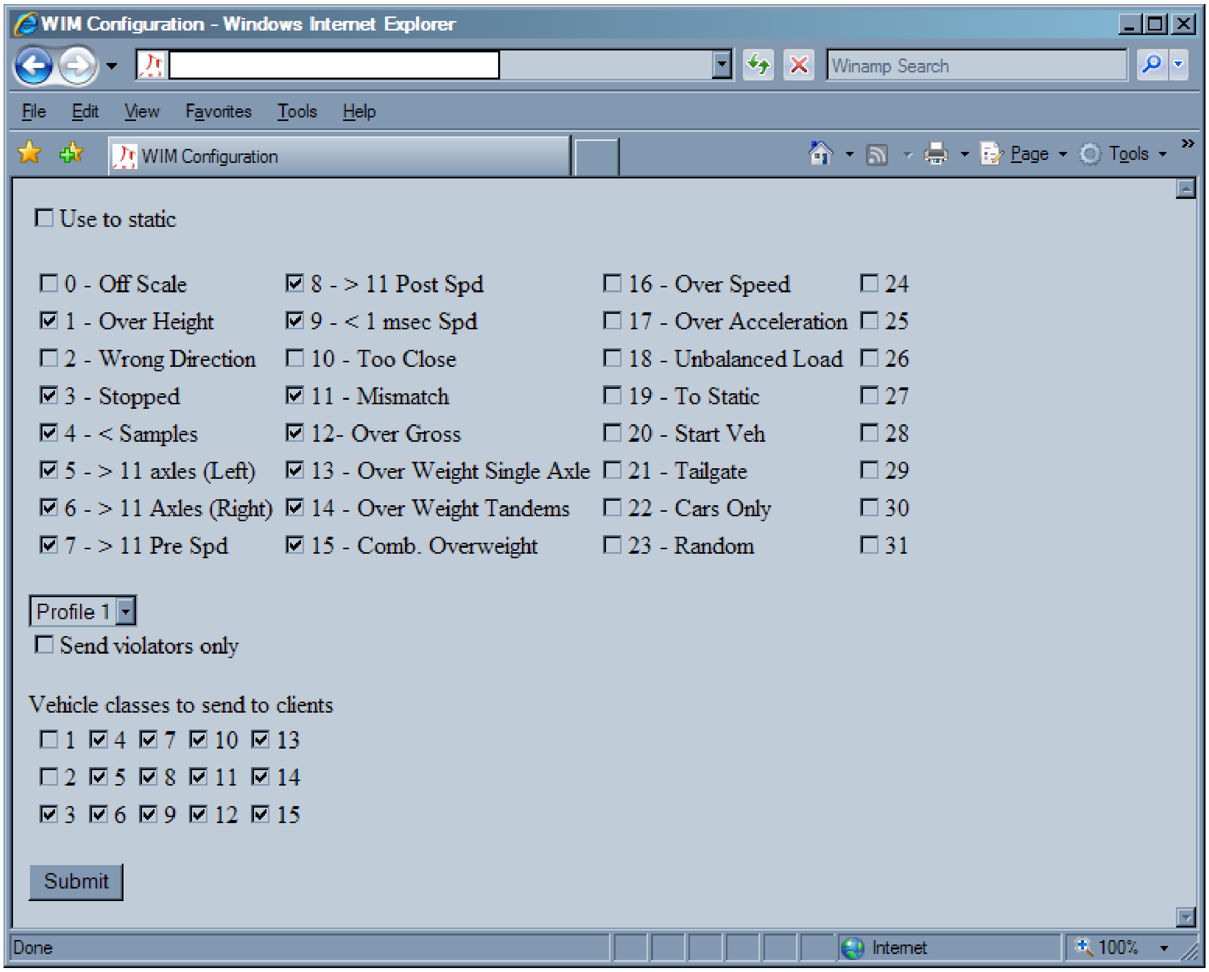



**Figure 18. Java Thin Client Configuration Page**

- The first block of check boxes can be configured to setup violations that are being sent to the thin client.

- Below the violations check boxes is a drop down menu where users can select a profile to save the current configuration to. These profiles are configurable to select a predetermined set of profiles for special enforcement actions (these can be configured to MSP-CVED requirements).

- Below the profile drop down list is a check box labeled “Send violators only”. If checked, this will cause the server to only send information about vehicles which have been flagged with violations.

- The “Vehicle classes to send to clients” check box can be seen below the “Send violators only”. These check boxes control which classes of vehicles are being sent to the client for display.

*2.7.2. The Report Pages:*

The report pages enable users to retrieve information about the last 10 vehicles summary, detailed information of vehicles per time period, vehicle count by class and vehicle count by speed. The following screenshots show the menus and the different report results. *(**Note**: More reports can be added in the future as more reports are available or customized.)*


**Figure 19. Virtual Weigh Station Reports Menu**

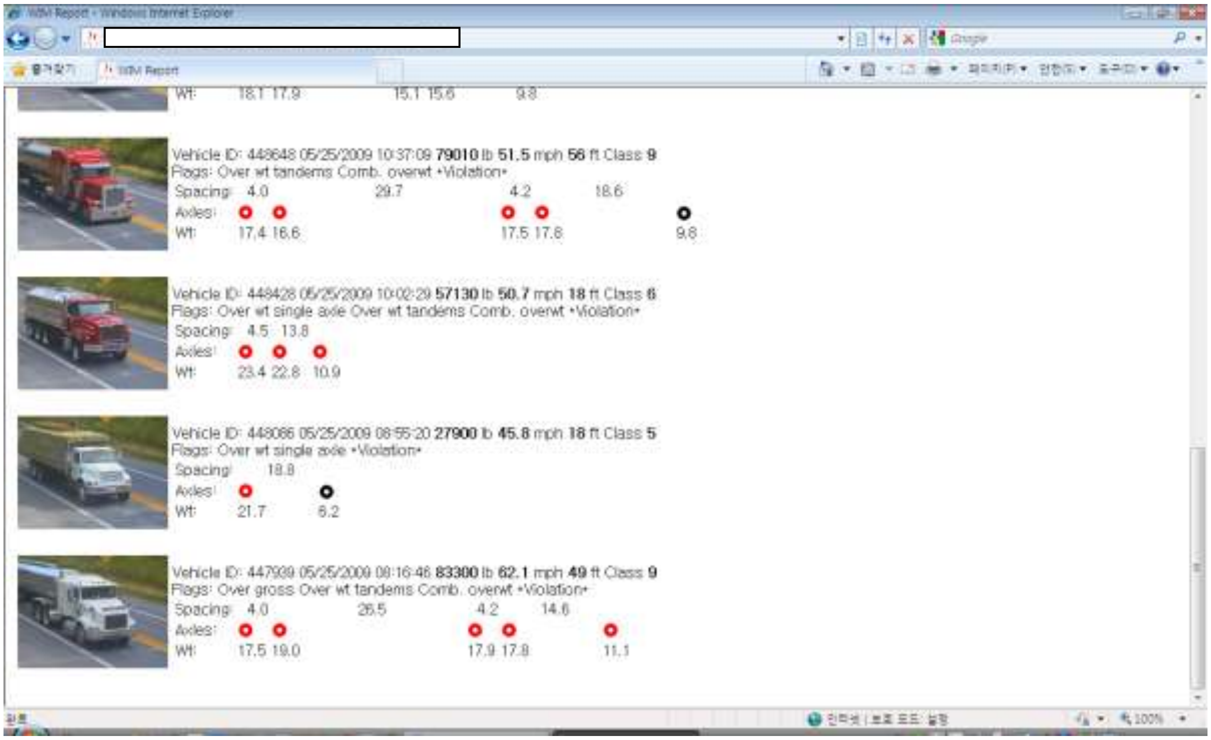
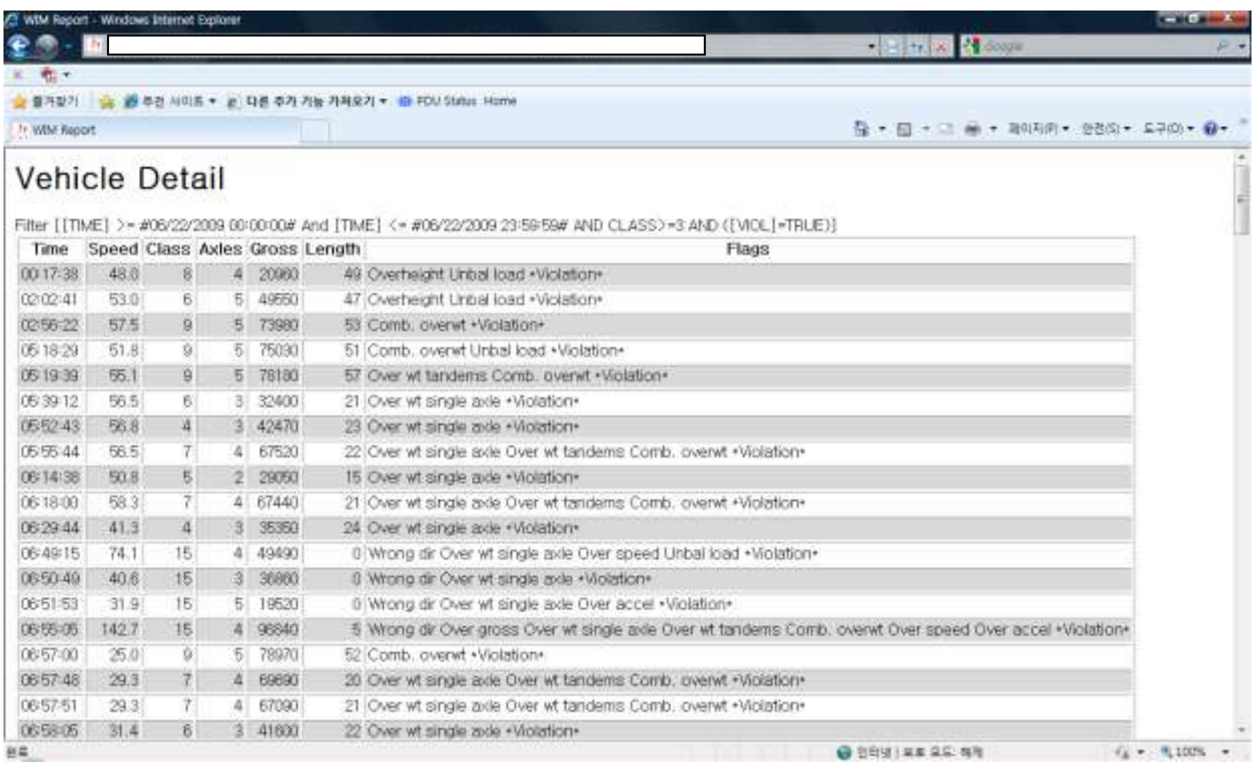



**Figure 20. Virtual Weigh Station Reports: Last Ten Vehicles**

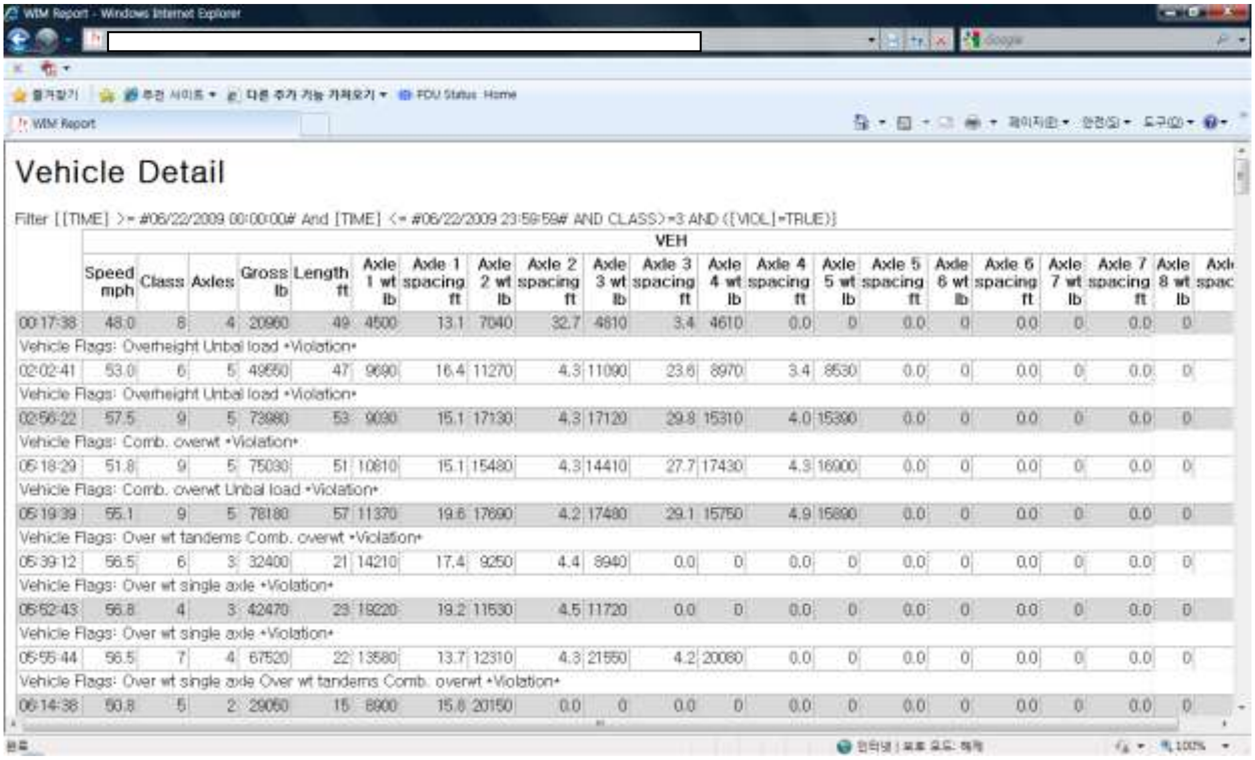


# Vehicle Detail

Filter [[TIME] >= #06/22/2009 00:00:00# And [TIME] <= #06/22/2009 23:59:59# AND CLASS>=3 AND ([VIOL]=TRUE)]

| Time | Speed | Class | Axles | Gross | Length | Flags |
|---|---|---|---|---|---|---|
| 00:17:38 | 48.0 | 8 | 4 | 20960 | 49 | Overheight Unbal load •Violation• |
| 02:02:41 | 53.0 | 6 | 5 | 49550 | 47 | Overheight Unbal load •Violation• |
| 02:56:22 | 57.5 | 9 | 5 | 73980 | 53 | Comb. overwt •Violation• |
| 05:18:29 | 51.8 | 9 | 5 | 75030 | 51 | Comb. overwt Unbal load •Violation• |
| 05:19:39 | 55.1 | 9 | 5 | 78180 | 57 | Over wt tandems Comb. overwt •Violation• |
| 05:39:12 | 56.5 | 6 | 3 | 32400 | 21 | Over wt single axle •Violation• |
| 05:52:43 | 56.8 | 4 | 3 | 42470 | 23 | Over wt single axle •Violation• |
| 05:55:44 | 56.5 | 7 | 4 | 67520 | 22 | Over wt single axle Over wt tandems Comb. overwt •Violation• |
| 06:14:38 | 50.8 | 5 | 2 | 29050 | 15 | Over wt single axle •Violation• |
| 06:18:00 | 58.3 | 7 | 4 | 67440 | 21 | Over wt single axle Over wt tandems Comb. overwt •Violation• |
| 06:29:44 | 41.3 | 4 | 3 | 35350 | 24 | Over wt single axle •Violation• |
| 06:49:15 | 74.1 | 15 | 4 | 49490 | 0 | Wrong dir Over wt single axle Over speed Unbal load •Violation• |
| 06:50:49 | 40.6 | 15 | 3 | 36880 | 0 | Wrong dir Over wt single axle •Violation• |
| 06:51:53 | 31.9 | 15 | 5 | 19520 | 0 | Wrong dir Over wt single axle Over accel •Violation• |
| 06:55:05 | 142.7 | 15 | 4 | 96840 | 5 | Wrong dir Over gross Over wt single axle Over wt tandems Comb. overwt Over speed Over accel •Violation• |
| 06:57:00 | 25.0 | 9 | 5 | 78970 | 52 | Comb. overwt •Violation• |
| 06:57:48 | 29.3 | 7 | 4 | 69690 | 20 | Over wt single axle Over wt tandems Comb. overwt •Violation• |
| 06:57:51 | 29.3 | 7 | 4 | 67090 | 21 | Over wt single axle Over wt tandems Comb. overwt •Violation• |
| 06:58:05 | 31.4 | 6 | 3 | 41600 | 22 | Over wt single axle •Violation• |

**Figure 21. Virtual Weigh Station Reports: Vehicle Detail (Simple View)**



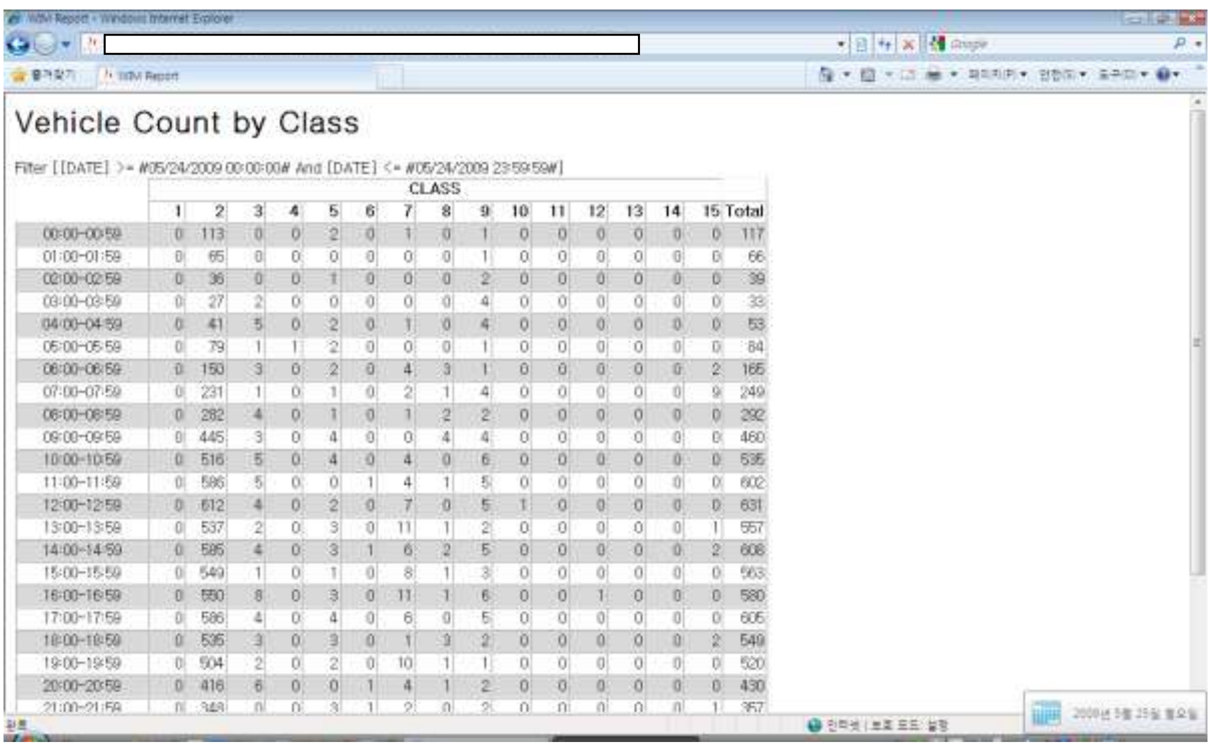
Vehicle Detail

Filter [[TIME] >= #06/22/2009 00:00:00# And [TIME] <= #06/22/2009 23:59:59# AND CLASS>=3 AND ([VIOL]=TRUE)]

| | VEH | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Speed mph | Class | Axles | Gross lb | Length ft | Axle 1 wt lb | Axle 1 spacing ft | Axle 2 wt lb | Axle 2 spacing ft | Axle 3 wt lb | Axle 3 spacing ft | Axle 4 wt lb | Axle 4 spacing ft | Axle 5 wt lb | Axle 5 spacing ft | Axle 6 wt lb | Axle 6 spacing ft | Axle 7 wt lb | Axle 7 spacing ft | Axle 8 wt lb | Axl spac |
| 00:17:38 | 48.0 | 8 | 4 | 20960 | 49 | 4500 | 13.1 | 7040 | 32.7 | 4810 | 3.4 | 4610 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Overheight Unbal load •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 02:02:41 | 53.0 | 6 | 5 | 49550 | 47 | 9690 | 16.4 | 11270 | 4.3 | 11090 | 23.6 | 8970 | 3.4 | 8530 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Overheight Unbal load •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 02:56:22 | 57.5 | 9 | 5 | 73980 | 53 | 9030 | 15.1 | 17130 | 4.3 | 17120 | 29.8 | 15310 | 4.0 | 15390 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Comb. overwt •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 05:18:29 | 51.8 | 9 | 5 | 75030 | 51 | 10810 | 15.1 | 15480 | 4.3 | 14410 | 27.7 | 17430 | 4.3 | 16900 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Comb. overwt Unbal load •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 05:19:39 | 55.1 | 9 | 5 | 78180 | 57 | 11370 | 19.6 | 17690 | 4.2 | 17480 | 29.1 | 15750 | 4.9 | 15890 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Over wt tandems Comb. overwt •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 05:39:12 | 56.5 | 6 | 3 | 32400 | 21 | 14210 | 17.4 | 9250 | 4.4 | 8940 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Over wt single axle •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 05:52:43 | 56.8 | 4 | 3 | 42470 | 23 | 19220 | 19.2 | 11530 | 4.5 | 11720 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Over wt single axle •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 05:55:44 | 56.5 | 7 | 4 | 67520 | 22 | 13580 | 13.7 | 12310 | 4.3 | 21550 | 4.2 | 20080 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |
| Vehicle Flags: Over wt single axle Over wt tandems Comb. overwt •Violation• | | | | | | | | | | | | | | | | | | | | | |
| 06:14:38 | 50.8 | 5 | 2 | 29050 | 15 | 8900 | 15.8 | 20150 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | |

**Figure 22. Virtual Weigh Station Reports: Vehicle Detail (Grid View)**


**Figure 23. Virtual Weigh Station Reports: Vehicle Detail (Wheel Graphic View)**

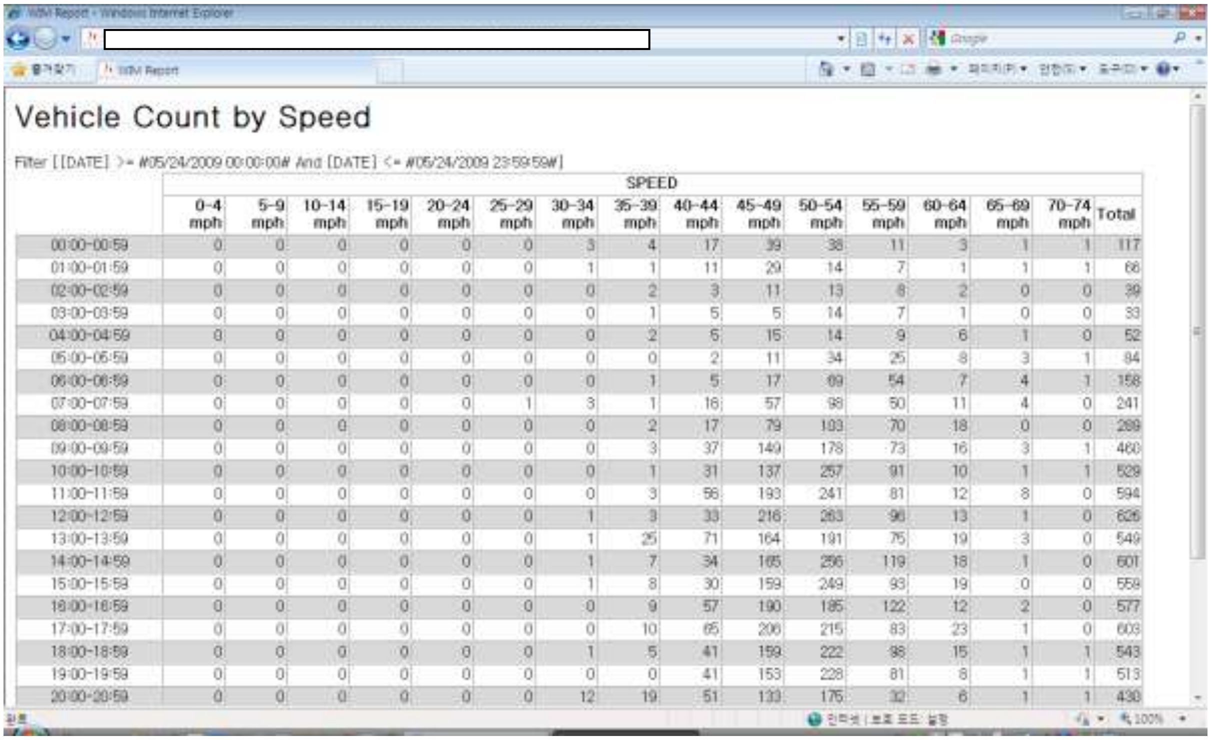


Vehicle Count by Class

Filter [[DATE] >= #05/24/2009 00:00:00# And [DATE] <= #05/24/2009 23:59:59#]

| | CLASS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
| 00:00-00:59 | 0 | 113 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 117 |
| 01:00-01:59 | 0 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 66 |
| 02:00-02:59 | 0 | 36 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 39 |
| 03:00-03:59 | 0 | 27 | 2 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 33 |
| 04:00-04:59 | 0 | 41 | 5 | 0 | 2 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 53 |
| 05:00-05:59 | 0 | 79 | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 84 |
| 06:00-06:59 | 0 | 150 | 3 | 0 | 2 | 0 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 165 |
| 07:00-07:59 | 0 | 231 | 1 | 0 | 1 | 0 | 2 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 9 | 249 |
| 08:00-08:59 | 0 | 282 | 4 | 0 | 1 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 292 |
| 09:00-09:59 | 0 | 445 | 3 | 0 | 4 | 0 | 0 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 460 |
| 10:00-10:59 | 0 | 516 | 5 | 0 | 4 | 0 | 4 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 535 |
| 11:00-11:59 | 0 | 586 | 5 | 0 | 0 | 1 | 4 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 602 |
| 12:00-12:59 | 0 | 612 | 4 | 0 | 2 | 0 | 7 | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 631 |
| 13:00-13:59 | 0 | 537 | 2 | 0 | 3 | 0 | 11 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 557 |
| 14:00-14:59 | 0 | 585 | 4 | 0 | 3 | 1 | 6 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 2 | 608 |
| 15:00-15:59 | 0 | 549 | 1 | 0 | 1 | 0 | 8 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 563 |
| 16:00-16:59 | 0 | 550 | 8 | 0 | 3 | 0 | 11 | 1 | 6 | 0 | 0 | 1 | 0 | 0 | 0 | 580 |
| 17:00-17:59 | 0 | 586 | 4 | 0 | 4 | 0 | 6 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 605 |
| 18:00-18:59 | 0 | 535 | 3 | 0 | 3 | 0 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 549 |
| 19:00-19:59 | 0 | 504 | 2 | 0 | 2 | 0 | 10 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 520 |
| 20:00-20:59 | 0 | 416 | 6 | 0 | 0 | 1 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 430 |
| 21:00-21:59 | 0 | 348 | 0 | 0 | 3 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 357 |

**Figure 24. Virtual Weigh Station Reports: Vehicle Count by Class**



# Vehicle Count by Speed

Filter [[DATE] >= #05/24/2009 00:00:00# And [DATE] <= #05/24/2009 23:59:59#]

| | SPEED | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-4 mph | 5-9 mph | 10-14 mph | 15-19 mph | 20-24 mph | 25-29 mph | 30-34 mph | 35-39 mph | 40-44 mph | 45-49 mph | 50-54 mph | 55-59 mph | 60-64 mph | 65-69 mph | 70-74 mph | Total |
| 00:00-00:59 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 17 | 39 | 38 | 11 | 3 | 1 | 1 | 117 |
| 01:00-01:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11 | 29 | 14 | 7 | 1 | 1 | 1 | 66 |
| 02:00-02:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 11 | 13 | 8 | 2 | 0 | 0 | 39 |
| 03:00-03:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 5 | 14 | 7 | 1 | 0 | 0 | 33 |
| 04:00-04:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 15 | 14 | 9 | 6 | 1 | 0 | 52 |
| 05:00-05:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 34 | 25 | 8 | 3 | 1 | 84 |
| 06:00-06:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 17 | 69 | 54 | 7 | 4 | 1 | 158 |
| 07:00-07:59 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 16 | 57 | 98 | 50 | 11 | 4 | 0 | 241 |
| 08:00-08:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 17 | 79 | 103 | 70 | 18 | 0 | 0 | 289 |
| 09:00-09:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 37 | 149 | 178 | 73 | 16 | 3 | 1 | 460 |
| 10:00-10:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 31 | 137 | 257 | 91 | 10 | 1 | 1 | 529 |
| 11:00-11:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 56 | 193 | 241 | 81 | 12 | 8 | 0 | 594 |
| 12:00-12:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 33 | 216 | 263 | 96 | 13 | 1 | 0 | 626 |
| 13:00-13:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 25 | 71 | 164 | 191 | 75 | 19 | 3 | 0 | 549 |
| 14:00-14:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 34 | 165 | 256 | 119 | 18 | 1 | 0 | 601 |
| 15:00-15:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 30 | 159 | 249 | 93 | 19 | 0 | 0 | 559 |
| 16:00-16:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 57 | 190 | 185 | 122 | 12 | 2 | 0 | 577 |
| 17:00-17:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 65 | 206 | 215 | 83 | 23 | 1 | 0 | 603 |
| 18:00-18:59 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 41 | 159 | 222 | 98 | 15 | 1 | 1 | 543 |
| 19:00-19:59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 153 | 228 | 81 | 8 | 1 | 1 | 513 |
| 20:00-20:59 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 19 | 51 | 133 | 175 | 32 | 6 | 1 | 1 | 430 |

**Figure 25. Virtual Weigh Station Reports: Vehicle Count by Speed**

## 3. PILOT VWS SITE SELECTION AT DAYTON, MARYLAND

This section summarizes the location selection for the first pilot Virtual Weigh Station (VWS) in Maryland. The general area chosen for the first pilot deployment is a suitable location on Maryland Route 32 in the southeast direction, starting near West Friendship (exit off I-70) and ending in Columbia (near exits for Route 29). The location selection takes into consideration a variety of factors, including but not limited to:

- Surface topology, elevation and condition of the existing single lane road in the southeast direction

- Proximity to available 110-220V AC power without significant cable runs and power loss

- Proximity to Verizon Wireless Cell Tower

- General road approach prior to and after the proposed WIM sensor location

- Availability of a safe and effective pull-off site sufficiently upstream of the WIM to flag down, stop, and inspect non-compliant or suspect CMVs and perform weight measurement with portable certified scales, or allow for an escorted turnoff site upstream of the WIM to escort suspect CMV back to a local static scale site (in this case, the West Friendship Truck Weigh and Inspection Station location off I-70).

- Consideration of future phased Route 32 dualization projects over the next several years - minimize operational impact to the chosen location during road construction, and allow future expansion into north and southbound lanes (assuming the pilot is successful) once route dualization is complete.

**Location selection:** Route 32, southeast direction, approximately 200 feet east of the Triadelphia Road overpass.


**Figure 26. Location of the Pilot VWS**

This location is deemed appropriate for the following reasons:

- Surface topology, elevation, approach and general condition of the road surface in both directions is excellent, with no observed bumps, road ruts, cracks, potholes, or other anomalies in the road surface. No flood plain is observed. The ground elevation on both sides of the road adjacent to the six foot shoulder is also ideal (above the road surface) to alleviate any pull box and conduit flooding issues, such as those initially encountered with an existing QWIM deployment at Perryville. There are no known plans to resurface this road in the near future. This is especially important if the system is expanded to cover additional lanes in the same location at a later date. See pictures below. No verification has been performed to validate whether the road surface meets ASTM 1318-09 specifications, though the geometric design, pavement condition, and lane width seem to meet these requirements. The horizontal and vertical profiles of the site are in Figure 27 and Figure 28.

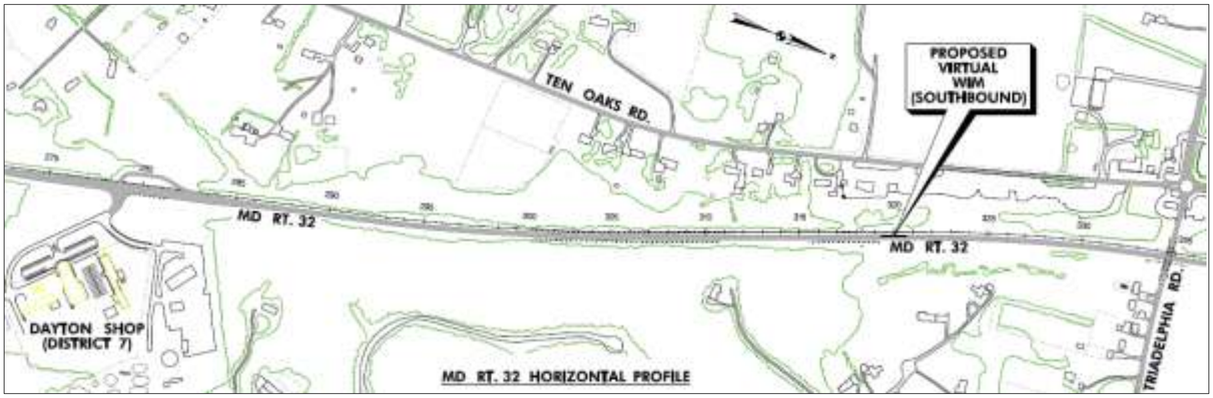



Figure 27. MD Route 32 Horizontal Profile

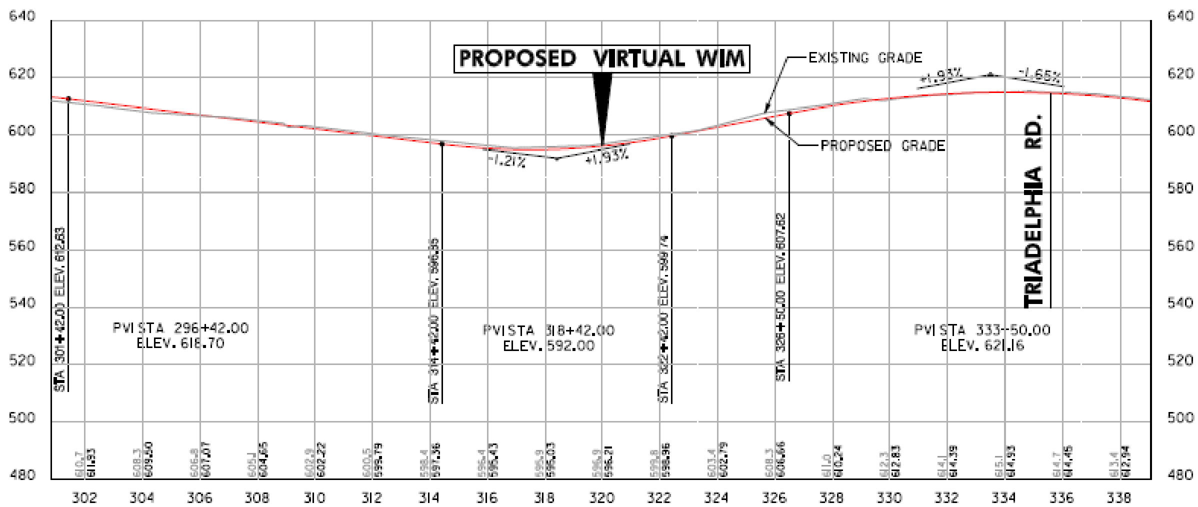



Figure 28. MD Route 32 Vertical Profile

**Figure 29. Location of the Pilot VWS (Northbound before construction.)**

**Figure 30. Location of the Pilot VWS (Northbound before construction.)**

**Figure 31. Location of the Pilot VWS (Southbound before construction.)**

- Proximity to available 110-220V AC power – SHA maintained power is available in the northeast quadrant of Triadelphia Road overpass and Route 32. This allows us to obtain buried power conduit and cable for the VWS over a worst case distance of 500 feet, resulting in minimal AC voltage drop avoiding the need for any high voltage transformer installation, and mitigating significant and expensive power runs. Soil conditions were not examined.

- Proximity to Verizon Wireless Cell Tower – This area is in close proximity to a Verizon Wireless cell tower. The EVDO Broadband signal strength on Route 32 from the pilot VWS to the pull-off area was observed to be 100%. The Verizon Wireless coverage map for the area is shown in Figure 32 (blue areas indicate 100% coverage).


**Figure 32. Coverage Map of Verizon Wireless in Dayton**

- General road approach before and after the proposed WIM location is excellent. Vehicles run at speed at approximately the 55 mph posted limit, except during rush hour traffic intermittently from 6:30 AM to 9:00AM when speeds can be much lower.

- Availability of a safe and effective pull-off site – Approximately 0.85 miles upstream of the WIM, and in direct visible access across from the SHA Dayton Maintenance Shop, is a 'jug handle' type pull-off away from the Route 32 southeast lane. This pull off seems to be remaining in place after the proposed dualization of Route 32 in this location, with the addition of an overhead access road to the Dayton shop (eliminating the flashing signal at this intersection). At 55 mph, this distance equates to approximately 50 seconds worth of travel time between the WIM and the pull off. Accounting for approximately 10 seconds of delay to overlay a camera image with weight and height information for a potential CMV violator and transmitting this image to a wireless mobile laptop PC, this allows for 40 seconds of 'visual time' for the MSP-CVED officer to identify the vehicle in the picture, flag the vehicle down, and either commence a portable weigh scale (or other) inspection, or flag the vehicle down and escort it back to the I-70 TWIS at West Friendship (approximately 8 minute drive from pull-off location). During the Phase II test (See chapter 10), the pull-off location was a location between the VWS and the proposed pull-off site. Typically, the jug handle was used.

**Figure 33. Location of Pull-off Site**


**Figure 34. MD Route 32 (From VWS to Pull-off Site)**

- Consideration of phased road dualization projects on Route 32 over the next few years – the proposed location of the VWS will allow future expansion of the program, if successful, to the newly constructed dual southeast bound lanes of Route 32, with ready access to power and communications at the Triadelphia Road overpass, minimal MOT and build out of additional VWS infrastructure at the proposed location during the construction phase, thus eliminating any major road closures at that time.

# 4. DESCRIPTION OF WIM SENSOR TECHNOLOGIES

## 4.1. Description of WIM Sensor Technologies

The most popular WIM sensor technologies today are load cell and piezoelectric (quartz, polymer and ceramic). There are other WIM sensor technologies such as bending plates, bridge and culvert WIM systems, capacitance mats, fiber-optic, subsurface strain gauge and multi-sensor systems also available, but in limited use.

The basic structural components and operating principles of each WIM sensor technology are described in this section.

### *4.1.1. Load Cell*

A typical load cell WIM system consists of a single load cell that has two in-line scales, at least one inductive loop, and one axle sensor. The load cell is placed in the travel lane perpendicular to the travel direction. The purpose of the inductive loop placed upstream of the load cell is to detect approaching vehicles and alert the system. The axle sensor is placed downstream of the load cell to determine axle spacing and vehicle speed. It utilizes technology based on the change of sensor resistance with pressure.

Load cell WIM systems utilize a single load cell with two scales to detect and weigh the right and left side of an axle simultaneously. A load cell is comprised of durable material such as steel and a strain gauge attached to it. The strain gauge consists of a wire that transmits electric current. As the cell is subjected to load, the wire under the strain gauge is compressed slightly and altered. The change in the wire results in a resistance difference to the current. Then, the system measures the variance in the current and calculates weight measured by each scale and then sums them to obtain the axle weight. A load cell is classified as an ASTM Type I, II, III, or IV system depending on site design. (Zhang, 2007)

### *4.1.2. Piezo Electric (Polymer, Ceramic and Quartz)*

A piezoelectric WIM system consists of at least one sensor and up to two inductive loops, embedded in a road saw cut or portable. The piezoelectric sensors usually are encapsulated in an epoxy-filled metal channel, such as aluminum. The sensor is placed in the travel lane perpendicular to the direction of travel enabling the wheels of one axle to hit the sensor at the same time. In the case of quartz piezoelectric sensors, one set of sensors is used for each of the two wheel paths in a lane. Kistler recommends the installation of two sets of sensors to provide weight averaging for more accurate weights, and to provide a redundant set of sensors should one pair of sensors in the configuration fail; in a failure scenario, the system can be manually re-configured to detect weights from a single sensor set. One or two inductive loops are placed upstream or downstream from the sensor to detect an approaching vehicle and to trigger a sequence of events: WIM sensor signal detection, amplification, and collection, vehicle speed and axle spacing based on the time it takes the vehicle to traverse the distance between the sensors. Axle spacing, number of axles, vehicle length and weight enable the system to classify vehicles.

When a mechanical force is applied to a piezoelectric sensor, it generates a voltage that is proportional to the force or weight of the vehicle. As a vehicle passes over the piezoelectric sensor, the system records the electrical charge generated by the sensor and calculates the dynamic load. Static load is estimated from the measured dynamic load with appropriate calibration parameters. (Zhang, 2007)

### 4.2. Comparison study

There has been some research by universities (e.g. University of Waterloo) and states (e.g. Connecticut, and more recently, a new, as yet unpublished study by New York State DOT) comparing various WIM sensor technologies for virtual weigh stations. Particularly, the result of comparison study was performed in (Hallenbeck & Weinblatt, 2004), (Pines & Fang, 2008) and (Zhang, 2007).

The summary of the findings from previous research is provided in this section.

Comparison studies have been made between single load cell sensors, piezoelectric sensors and quartz piezoelectric sensors. Other sensor technologies are not considered because they are not widely used these days (e.g. bending plates) or they are very new to the market and have not been proven enough (e.g. bridge WIM). Quantitative and qualitative comparisons are made in determining the technology. It is worthwhile to mention that site conditions such as temperature and roughness, driver behavior and the CMV configuration affects the accuracy of the WIM sensor.

Whatever sensor technology is chosen, it is known that the accuracy of all WIM sensors decreases with decreasing pavement conditions. Unstable speeds, which are common in urban areas, result in significant decreases in WIM accuracy, regardless of the technology chosen. (Hallenbeck & Weinblatt, 2004)

Briefly, the pros and cons of each sensor technology are as follows:

Load Cell: A single load cell provides an accurate and easily maintainable system at a higher equipment and installation cost. It is the most expensive sensor system for a high-speed weigh-in-motion installation. The installation takes multiple weeks and major consideration needs to be provided to maintenance of traffic (MOT) issues associated with this installation.

Piezo Sensors: Conventional piezoelectric sensors such as polymer and ceramic sensors provide the lowest accuracy with the lowest cost. This setup is not appropriate for law enforcement because the sensor does not provide the necessary gross and axle weight accuracy under variable conditions. The sensors are very sensitive to temperature and roughness of the pavement.

The quartz piezoelectric sensors potentially offer high accuracy at a reasonable cost, but more data is required to state this conclusively. The State of New York (NYSDOT) is currently conducting a comparison study of different sensor technologies at a WIM evaluation site in Schodack), and the result of this research is expected to provide detailed performance of each sensor technology including repeatability, maintainability, and reliability. While the results from this study have not been published as yet, it is widely expected that this study will recommend the use of quartz piezoelectric sensors as the sensor of choice for high speed WIM systems (NYSDOT, McDonogh, Galvin, unpublished paper, 2009)

These three types of WIM sensors employ different techniques and have their advantages and disadvantages depending on the requirements of different applications. Some of the factors considered for the comparison are:

- **Cost:** The purchase cost of equipment, installation, and annual operating and maintenance costs.

  For comparison, the equipment and installation costs will be for the in-road equipment only. The cost of the electronics, cabinet, power supply, telephone connection, and road preparation are assumed to be relatively constant, regardless of the technology used. The initial installation includes the equipment supplied, installation by a local contractor, and installation supervision and calibration by a vendor representative.

  In order for any WIM system to perform consistently and reliably it should be maintained. It is recommended that scheduled maintenance visits occur at least semi-annually, with calibration occurring at each visit. The cost of a calibration vehicle is not included, since all systems will require the use of a calibration vehicle. One of the semi-annual maintenance visits can be a visual inspection and calibration check. The other semi-annual visit should include an in-depth on road inspection as well as a calibration check.

  Other assumptions for the purposes of the comparison are noted for each technology. This comparison takes into account only direct costs for the work and equipment to provide the WIM data. Associated factors such as road deterioration and repair, traffic delay costs, and data reliability are not considered.

  The cost of piezoelectric sensor is compatible to that of single load cell. (Bushman & Pratt, 1998) (Zhang, 2007)

- **Accuracy:** Relative performance accuracy, tolerance for 95% confidence level. More than 95% of CMV passages have to meet this level of accuracy.(Zhang, 2007)

- **Sensitivity:** The response of sensors to various factors including pavement roughness, temperature, vehicle suspension, and vehicle speed.

  Some WIM systems are sensitive to temperature. Piezoceramic and piezopolymer sensors are both temperature sensitive (i.e., their signal strength for a given axle force changes with temperature). While some vendors have developed compensation algorithms to account for temperature sensitivity, these technologies are at a disadvantage when placed in environments that include quickly changing temperatures. Because the strength of asphalt pavements also changes as environmental conditions change, the technologies that rely on direct structural support from the pavement itself will perform less consistently in these pavements than at locations where the pavement's strength characteristics will not change (e.g., thicker asphalt and concrete sections). Also more successful will be WIM technologies whose axle sensor support is not affected by changing environmental conditions. (Hallenbeck & Weinblatt, 2004) (Zhang, 2007)

- **Expected Life:** Expected lifetime of a type of sensor.

  Single load cell has longer expected life time than polymer/ceramic piezoelectric sensors. The expected life time of quartz piezoelectric sensor is not proven but it is expected to be longer than five years.

- **Reliability:** The ability of the system to perform the required function in routine and hostile circumstances; primarily depending on performance of the sensor itself over the entire life cycle of a system, but may also include the data acquisition subsystem of a WIM system.

  The Quartz piezoelectric sensor does not fatigue quickly and is not very sensitive to temperature. (Klein, 2001) (Zhang, 2007)

- **Applicability:** The nature of sensor technologies for particular industrial application.

  The piezoelectric (polymer and ceramic) sensor was applied more in data collection than weight enforcement because of its low accuracy. Quartz piezoelectric sensor has better accuracy than other piezoelectric sensors so it can be applied to a weight enforcement application. (Zhang, 2007)

**Table 1. WIM Sensor Technologies Comparison [Source: (Zhang, 2007) and (Pines & Fang, 2008)[1]]**

| | | Single Load Cell | (Polymer/Ceramic) Piezoelectric Sensor | Quartz Piezoelectric Sensor |
|---|---|---|---|---|
| **Cost** | **Initial Installation Cost** | High (~$50,000+) | Low (~$9,000) | Medium (~$20,000 per sensor set) |
| | **Annual Life Cycle Cost** | High (~$8,000) | Low (~$5,000) | Not determined |
| **Accuracy (GVW, 95% Confidence)** | | 6%<br><br>Can Meet Enforcement Requirements | 15%<br><br>Cannot meet Enforcement Requirements | 6%<br><br>Can Meet Enforcement Requirements with 2 rows of sensors. Better accuracy can be achieved with 3 rows through averaging out of vehicle dynamics |

[1] This table is the summary from (Zhang, 2007) and (Pines & Fang, 2008). However, some content has been changed at authors' discretion.

| | | | |
|---|---|---|---|
| **Sensitivity** | Medium | High<br><br>Temperature Sensitive.<br><br>Accuracy affected by changes in pavement strength<br><br>Susceptible to lightening. | Medium-High<br><br>Accuracy affected by changes in pavement strength |
| **Expected Life** | 12 years | 4 years | > 5 years |
| **Reliability** | High | Low | Medium |
| **Applicability** | Weight Enforcement, Traffic Data Collection | Traffic Data Collection | Weight Enforcement, Traffic Data Collection |
| **Installation** | Significant Road Cut with Proper Drainage Required<br><br>Multiple Days to Complete | Small Road Cuts<br><br>Meticulous installation required | Small Road Cuts |
| **Maintenance** | Corrosion of load cell if not sealed correctly | Must maintain surface smoothness and seal properly to achieve satisfactory performance | Must maintain surface smoothness and seal properly to achieve satisfactory performance<br><br>Sensor longevity data is not proven enough. |

| | | | |
|---|---|---|---|
| **Length of traffic disruption during installation and maintenance** | Multiple Days for System Installation and During Periods of In-Road Maintenance | One Day for System Installation and During Periods of In-Road Maintenance | One Day for System Installation and During Periods of In-Road Maintenance |
| **Mature / Proven Technology** | Yes | Yes<br><br>Well-supported by industry | Yes<br><br>Growing support by industry. |

## 5. DESCRIPTION OF PREVIOUS AND ON-GOING RESEARCH CONDUCTED IN OTHER STATES

A number of states such as Connecticut, Kentucky, Florida, New York, California and Indiana have conducted research on VWS but none of them have been conclusive in adopting or recommending VWS as a law enforcement tool for pre-screening of commercial vehicles. They have utilized piezoelectric sensors, load cells or bending plates for weigh-in-motion.

### 5.1. Connecticut

The State of Connecticut has been evaluating WIM technologies since 1998. The quartz piezoelectric weigh-in-motion sensors installed in 2003 at several sites offer a practical option for collecting accurate data. The results are highly site-specific. The pavement approach is a critical component of a WIM system. Sensor response did not appear to be speed- or load-specific at the test sites in Connecticut. In general, the quartz piezoelectric sensors installed in 2003 locations have continued to perform for over five years. (Pines & Fang, 2008)

The Connecticut Department of Transportation has conducted a study and evaluation of quartz piezoelectric sensors on an in-service highway between 1998 and 2001. The Connecticut Department of Transportation was the first to install quartz piezoelectric sensors on an in-service highway in the USA. The study includes the determination of the sensor survivability, accuracy and reliability under actual traffic conditions in Connecticut's environment.

Field validations used pre-weighed vehicles following any field calibrations. Continuous traffic data was collected at the site and complete weight records for FHWA Class 4 through 13 were recorded.

It was shown that different test CMVs provided significantly different results in the calibration process and the validation test results were also different depending on which CMV was used; it should be noted these results were obtained with the first generation of Quartz piezoelectric sensors. It is advised that a complete representation of CMV population variability is needed to assess the performance.

In general the Connecticut DOT was satisfied with the accuracy and the repeatability of the sensors in comparison to other systems. The sensor longevity was based on noticeable cracking in the surrounding asphalt pavement. Poor drainage (hence, water intrusion) and infestation of mice caused failure. The sensors have shown that they can hold their calibration for long durations of time. This study supports the need to gain a better understanding of the relationship between WIM data quality and pavement profile. (McDonnell, 2002)

In 2008, the Connecticut Academy of Science and Engineering completed a report in response to the inquiry by Connecticut Department of Transportation. This study was requested in response to concerns about the operation of a weigh and inspection station in Connecticut.

This report includes description and comparison of mature WIM sensor technologies (piezoelectric, load cells, and bending plates) and a summary of a promising non-intrusive bridge WIM scale technology that has been used in Europe but not in the United States. A review of pertinent literature indicates that it is very evident that physical site conditions play a major role in the overall accuracy of WIM scales. Additionally, a description of selected best practices that have been employed using WIM scales has been provided for review and consideration.

ConnDOT, DMV, and DPS have experience using quartz, bending plates, and load cell WIM scales. Taking into account installation, maintenance, safety, and cost, it is suggested that Connecticut invest in the quartz piezoelectric technology for new and replacement WIM scale installations. Furthermore, it is suggested to consider the use of three rows of quartz piezoelectric sensors versus the standard two-row configuration.[2] The three-row configuration will initially be more expensive for purchase and installation. However it has the potential to reduce sensor life cycle cost as a result of a reduction in the highway smoothness necessary to attain the required accuracy needed for enforcement applications (i.e., Type III ASTM requirements). (Pines & Fang, 2008).

### 5.2. Florida

Florida has conducted a project that designed and implemented a virtual weigh station that can automate electronic pre-screening in a cost effective and efficient way. The project was performed by University of Central Florida and the result and findings were published in 2007. In this project, the first VWS in Florida was designed and implemented at I-10 close to Sneads WIM station. Various technologies and components of the VWS such as video, wireless, infrared, internet, database and sensor technologies were evaluated in the field. This VWS has been operating for almost one year capturing almost 700,000 records.

This VWS used two sets of two Kistler Lineas® quartz piezo sensors and an inductive loop detector that is installed upstream of the sensors. It also used a Cardinal in-motion scale controller and a roadside display which is a hand held pocket PC with Bluetooth interface including software to display in real time the total weight of each passing vehicle. The system was initially calibrated using static weights as a reference and 5 sets of CMVs were used in calibration. Initially the WIM sensor accuracy did not meet the manufacturer's claim (<10%), so the system had to be recalibrated. The data obtained from this station over a span of 6 months was analyzed. (Oloufa, 2007)

### 5.3. New York

In order to select the most appropriate WIM technology for integration with e-screening systems, NYSDOT is researching, procuring, installing and field testing several available WIM technologies, including piezoelectric, quartz piezoelectric and single load cell, for integration with roadside electronic safety and screening operations. These selected WIM technologies are

[2] This suggestion is made with the first generation of quartz piezoelectric sensors

installed at the Schodack, NY site and will be subjected to similar weather and traffic conditions over an extended period to allow for an engineering- and statistics-based evaluation and comparison. Additional factors to be evaluated include weather impacts and WIM field performance on standard, asphalt-based pavement.

While there may have been individual studies on the various types of high-speed WIM use and accuracy involving high cost, specialized concrete pavement, there is very little, if any, data available for a comparative analysis under field conditions at a specific, integrated site where pavement conditions are less than ideal. It is anticipated that this research effort will address many of these issues and provide comprehensive, field-based data and information that will help transportation agencies decide the most appropriate WIM technology for electronic safety and screening integration and asset management. (Pines & Fang, 2008) The result of the NYSDOT research is not yet available as of June 2009. It is expected to be published in late 2009.

NYSDOT's goal was to pick the "best" WIM technology that can be used in the field for pre-screening, not necessarily the most accurate. They would like to balance accuracy versus cost, installation, etc. since they are attempting to use the mainline WIM to screen compliant vehicles for possible bypass. (Those that do not pass the WIM threshold criteria get stopped for possible inspection and enforcement.)

NYSDOT has analyzed the WIM measurement outputs against each other on a relative basis, and have some limited static measurements to use as comparisons/baselines to the three dynamic weights of the same vehicle. The devices are operating within the vendor's stated specifications. Based on their short term analysis, the Kistler WIM seems the best choice; this is expected to be the final recommendation as part of their research. They will provide law enforcement access to the system after evaluation is complete, and NYSP is expected to start using the Schodack e-screening location for weight and safety inspections. NYSDOT also expects to obtain many more, periodic - static measurements using Haenni portable scales to continue the static vs. dynamic analyses.

In order to calibrate the Quartz Piezoelectric WIM, NYSDOT recommends checking Kistler's live traffic measurements against the outputs of the static scales for the same vehicle on a semi-annual basis.

### 5.4. Kentucky

Kentucky has developed the concept of VWS since 1997, and the first VWS was installed in 2002. This VWS could capture images of passing CMVs and transmitted those images to a nearby weigh and inspection station. This VWS was equipped with a weigh-in-motion system. The preliminary assessment was made in 2003 and the site shut down in 2005. Kentucky had problems with image capture and loss of the WIM sensor, which was paved over due to miscommunication between transportation department agencies.

The quartz piezoelectric WIM system was chosen as the weigh-in-motion technology. A single high-resolution camera with a wider field of view was used and a cable modem provided by the local cable TV provider was used for communications which provided the connection to the Internet.

Kentucky conducted a 48 hour field assessment of their VWS in June 2003. They tried to capture the image with a camera setting that can capture USDOT number from the images (no PCR, only image capture) but only 34 percent of valid transactions could capture a readable USDOT number. The performance of the Kistler WIM was not particularly addressed in their report. (Crabtree, Hunsucker, & Walton, 2005)

### 5.5. Indiana

Indiana published the result of implementation and evaluation of VWS in 2002.

Indiana used Weigh-In-Motion equipment, a laptop computer, and short range (IEEE 802.11) wireless communication equipment, to develop a virtual weigh station screening tool. The Virtual Weigh Station screening tool developed in this project allowed officers to read the weights of vehicles crossing WIM scales, in real time, in their patrol cars.

Indiana used piezoelectric sensors, bending plates and single load cells. Since their sites with piezoelectric sensors and bending plates reached end of life, they recommended abandoning the sites with piezoelectric sensors and bending plates, and recommended the use of single load cells for VWS. However, Indiana did not have any experience with quartz piezoelectric sensors when their study was published in 2002. (Green, Nichols, Allen, Nuber, & Thomaz, 2002)

### 5.6. Massachusetts

The Massachusetts Highway Department (MHD) manages and operates approximately 24 high speed WIM sites throughout the state on interstate highways. At present, they do not use any of these sites for enforcement purposes; they are used for data collection only. MHD has experienced some problems with the piezo sensors installed at many of the sites; particularly the epoxy/grout used to seal the units in the pavement saw cuts. Currently MHD is experimenting with installing these sensors “sub-surface” in the “binder” course of the roadway. Approximately 12 of the 24 WIM data collection sites are currently operational. (Pines & Fang, 2008)

### 5.7. New Jersey

The New Jersey Department of Transportation (NJDOT) maintains more than 80 WIM sites throughout the state for data collection and reporting (as of 2008). All sites use ceramic–polymer piezoelectric sensors. Their standard sensor array is loop-piezo-loop-piezo-loop (L-P-L-P-L) in each lane with the center loop redundant.

Bending plates were used at some of the earlier WIM sites with the expectation that they would be more accurate and durable. However, the bending plate systems have not produced more accurate results and have also presented much greater maintenance challenges. Therefore, New Jersey no longer uses these bending plate WIM systems and has either removed them or welded them into place in their frames. Hydraulic load cells were never utilized by New Jersey. Out of the state's 80 WIM sites, 50 are fully operable; 10 are partially operable (counting and classifying); 6 are completely out of service; 5 are in the process of being newly constructed; and 9 are in the process of being reconstructed. (Pines & Fang, 2008)

### 5.8. Rhode Island

The Rhode Island Department of Transportation (RI DOT) maintains four permanent high-speed WIM sites on I-95 and two low-speed sites on Route 146 for data collection. These WIM sites are used only for data collection, not enforcement purposes, and are usually not in close proximity to the state's enforcement sites. Five of the sites have encapsulated ceramic piezoelectric sensors while one site uses quartz piezoelectric sensors. (Pines & Fang, 2008)

# 6. FUNCTIONAL REQUIREMENTS FOR MARYLAND'S PILOT VWS SITE

## 6.1. WIM (Weigh-In-Motion) sensor

- The WIM shall be capable of performing load and length[3] measurements accurately.

  Axle load, Axle-Group load, Gross-vehicle weight, distances between axles, tandem axles and the bridge groups shall be measured.

- The drift rate of the measurements by the WIM system must be reasonably small so that the system does not have to be calibrated too frequently. This will be tested to conform to ASTM 1318-09 accuracy requirements for Type III WIMs.

  Once calibrated, the WIM system should meet the ASTM 1318-09 accuracy requirements for Type III WIMs over a 6 month period.

- The date and time of passage shall be indicated.

- The vehicle record number (sequence number) shall be indicated.

- The speed of CMV passage shall be indicated.

- The vehicle class shall be indicated.[4]

- The type of violation shall be indicated if any violations occur.

  Cardinal WIM shall detect the following violations: Over Height, Wrong Direction, Stopped, Too Close, Over Speed, Over Acceleration, Over Gross, Over Weight Single-Axle, Over Weight Tandems, Over Length, Unbalanced Load and Bridge.

- The user shall be able to choose to receive data regarding 1) every vehicle passage or 2) the vehicle passage with violations by a setting at the server PC. If the second option is used, the threshold level to define the violation shall be adjustable.

[3] Strictly speaking, the length measured by the WIM is the distance between two axles. The length of a vehicle is the distance between the first axle and the last axle.

[4] ASTM - There are currently 15 FHWA assigned vehicle classes

### 6.2. Camera

- The user shall be able to choose to capture 1) every CMV passage or 2) the CMV passage with violations with the camera.

- The camera features, such as focus, zoom, and aiming shall be configurable but fixed. Shutter speed, color enhancement, and monochrome/color switching modes shall be configurable.

- The camera shall be triggered every time a vehicle passes over the loop detector; however image capture is configurable by vehicle class and other configuration settings.

- The CMV distinguishing features such as cab and trailer color and distinguishing characteristics such as company name, graphic logos, etc to the extent possible and CMV profile shall be recognized from the captured image.

- The CMV distinguishing features, such as cab and trailer distinguishing characteristics such as company name, graphic logos, etc to the extent possible (under low light) and CMV profile shall be recognized with limited light. Adverse conditions such as rain and snow will not be considered; images are not expected to be recognized during such events.

### 6.3. IR Lamp

- IR lamp shall enhance image capture performance in the early morning and late night hours.

### 6.4. Over height Detector

- The CMV with over height characteristics over a preset threshold shall be detected.

- The CMV or other types of vehicles with height complying with relevant traffic laws shall not be detected.

- False-positives (such as birds, etc) should not trigger the over height sensor.

### 6.5. Cell Router

- Time latency from image transmit on the WIM server PC to image receipt on the MSP laptop or other PC client shall be small enough that MSP can receive images within reasonably short time (under 10 seconds). The time latency requirement has to be satisfied for a variety of captured images.

- Router access shall be controlled (secure) with username and password restrictions.

### 6.6. WIM Server PC and WIM Reader Server Software

- The terminal (the MSP laptop with Verizon dialup card) shall be able to login to the WIM Server PC via a Proxicast router pass-through with Microsoft Internet Explorer 7 with username and password restriction.

- PCs on other networks (e.g. Home PCs, SHA, University of Maryland) can log on to the WIM Server PC with username and password restriction. Verizon provided front facing fixed IP address is accessible through a variety of data networks.

- PCAnywhere shall enable secure remote computer access for administrative purposes.

- The server software shall be able to generate a report at the client PC.

- Violation, non-violation, storage and data cleanup thresholds shall be user configurable.

### 6.7. WIM Thin Client

- Graphical User Interface (GUI) shall display images and data (speed, axle and gross weight, distance between axles, vehicle class and violation types - if any) of each vehicle transmitted from the server PC. Violations shall be highlighted in Red.

- The user can note a memo on each vehicle record.

### 6.8. System

- The system can transmit data and images corresponding to 1) every CMV passage or 2) only CMV passages with violations. Required violation thresholds shall be configurable.

- The camera shall be triggered every time a vehicle passes over the loop detector; however image capture is configurable by vehicle class and other configuration settings.

- The image and measurement results of WIM sensor and over height detection shall correspond to the same vehicle.

- ***Note**: Over height spans both lanes. An over height vehicle traveling in the opposite direction, passing a legitimate vehicle detected by the WIM sensor is possible.*

# 7. TECHNICAL REQUIREMENTS

## 7.1. WIM (Weigh-In-Motion) sensor

- Accuracy of load measurements - tested against measurements by certified portable scale (tolerance for 95% compliance)

  - Accuracy of Axle Load measurements: ±15%[5]

  - Accuracy of Axle-Group Load measurements: ±10%[6]

  - Accuracy of Gross Vehicle Weight measurements: ±6%[7]

  ***Note**: Individual axle, gross weight, and height thresholds shall be set to applicable Maryland laws for passage over state roads. MSP provided upper tolerances – 1000 lbs. over for individual axle weights.*

- Accuracy of length measurements (distance between axles) – tested against manual measurements (tolerance for 95% compliance).

  - Accuracy of length between first and last axle measurements: ±0.5ft[8]

- Accuracy of bridge formula calculation: ±6%

  FMCSA regulation §658.17 states that no vehicle or combination of vehicles shall be moved or operated on any interstate highway when the gross weight on two or more consecutive axles exceeds the limitations prescribed by the following formula[9]

$$w = \mathrm{MROUND}\left(500\left(\frac{l \cdot n}{n-1} + 12n + 36\right), 500\right)$$

  where

  w = the maximum weight in pounds that can be carried on a group of two or more axles.

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[5] ASTM E 1318-09 Table 2
[6] ASTM E 1318-09 Table 2
[7] ASTM E 1318-09 Table 2
[8] ASTM E 1318-09 Table 2
[9] There are exceptions to the bridge formula.

l = spacing in feet between the outer axles of any two or more consecutive axles.

n = number of axles being considered.

MROUND (*number*, *multiple*): a function rounding the *number* to the desired *multiple*. (E.g. MROUND(4920,500) =5000)

In this report, the accuracy for the bridge formula calculation is defined in the following way. Let's define $\widetilde{w}$ and $w'$.

$$\widetilde{w} = 500 \left(\frac{\tilde{l} \cdot n}{n-1} + 12n + 36\right)$$

$$w' = 500 \left(\frac{l \cdot n}{n-1} + 12n + 36\right)$$

where

$\tilde{l}$ = spacing in feet between the outer axles of any two or more consecutive axles measured by the WIM.

The difference $D = (\widetilde{w} - w')/\,w'$ shall be within the accuracy bound ±6%.

***Note***: *Bridge formula measurements will be calculated using manual weight and length measurements against inspection report information provided by MSP. There is no bridge formula accuracy requirement for a Type III WIM as defined in the ASTM standard.*

- Drift rate of measurements
    - Drift rate of weight load measurements over 6 weeks : ±2.5 %
    - Drift rate of length measurements over 6 weeks: ±2.5 %
- The percentage of misclassifications < 5 %
- The percentage of CMV passages that is not recorded by the WIM < 5%

Exclusions: There are certain types of vehicles that cannot be verified for weight accuracy by WIM sensors in general. These include short dump trucks, car carriers, milk and other liquid load carriers, house/wide load carriers, and certain agricultural vehicles. Unbalanced loads (e.g., CMVs straddling the sensor or not passing over the WIM sensor properly) will not be considered.

### 7.2. Camera

- The percentage of CMV passages captured by the camera > 95%
- The percentage of false alarms (The number of non-CMV images/The total number of captured images) < 5%
- The percentage of images with CMV distinguishing features and CMV profile > 95%
- The percentage of images with CMV distinguishing features and CMV profile in limited light > 95%

### 7.3. Over height Detector

- The percentage of misdetections < 5%
- The percentage of false detections < 5%

### 7.4. Cell Router

- Maximum time latency between the server PC and MSP laptop at the pull-off site < 10 seconds
- The percentage of images successfully transmitted to MSP laptop within 10 sec > 95%

### 7.5. System

- The percentage of successful transmission of measurements and an image corresponding to a CMV passage > 95%

# 8. VALIDATION RESULTS

## 8.1. Calibration of the WIM

The initial calibration of the WIM was completed on April 14th, 2009, about one month from the date of sensor installation. An Advance Scale[10] weight truck was chosen as the test CMV. The truck has four axles and weighs about 55,000 lbs. The weight was measured by certified scale from Advance Scale. The length between the first and last axle was measured manually. When the truck passed the WIM, the mileage of the truck was recorded to account for the weight loss from the consumption of fuel. It was assumed that approximately one lb. is lost per mile. The mileage at the time when the truck was weighed by a certified scale was also recorded.

The test procedure was developed by modifying the procedure described in ASTM E 1318-09 Section 7.5.5. Before we recorded the values, we made several test runs and initial calibration was performed by a Cardinal engineer. Then thirteen runs in total were made and the measurements were recorded. Three runs at high speed (~60 mph), three runs at low speed (~30 mph), three runs at average speed (~45 mph), two runs at slightly below the high speed (~50 mph) and two runs at slightly above the low speed (~40 mph) were made. The driver made best effort to drive the test CMV at the given speed.

For detailed procedure of the WIM calibration, see Appendix G.

[10] Advance Scale (http://www.advancescale.com/default.htm) is a Cardinal Scale authorized value-added reseller offering sales, service and support of weighing products.

**Figure 35. Advance Scale Test CMV Used in WIM Calibration**

*8.1.1. WIM Calibration Set Up*

- Advance Scale Reference CMV loses one lb per mile.
- The length of reference CMV (from the first axle to last axle) is 22’ 8’’ (22.7 ft)
- Tests 1/2/3 correspond to the tests at high speed.
- Tests 4/5/6 correspond to the tests at low speed.
- Tests 11/12/13 correspond to the tests at average speed.
- Tests 7/10 correspond to the tests at slightly below the high speed.
- Tests 8/9 correspond to the tests at slightly above the low speed.

### *8.1.2. WIM Calibration Measurement Data*

**Table 2. Test results of WIM Calibration**

| Test | WIM Gross | Scale Gross | Lbs. Diff | WIM % | WIM % (absolute) | Mileage | Speed | WIM Speed | WIM Length |
|---|---|---|---|---|---|---|---|---|---|
| **0** | **55,780** | **55,780** | **0** | **0.0** | | **845** | **0** | | |
| **1** | 54,720 | 55,737 | -1,017 | -1.8 | 1.8 | 888 | 60 | 59.7 | 22.3 |
| **2** | 55,650 | 55,727 | -77 | -0.1 | 0.1 | 898 | 60 | 58.6 | 22.3 |
| **3** | 53,110 | 55,724 | -2,614 | -4.7 | 4.7 | 901 | 60 | 52.9 | 22.4 |
| **4** | 55,350 | 55,720 | -370 | -0.7 | 0.7 | 905 | 30 | 30.1 | 22.3 |
| **5** | 55,020 | 55,715 | -695 | -1.2 | 1.2 | 910 | 30 | 30.3 | 22.3 |
| **6** | 56,020 | 55,708 | 312 | 0.6 | 0.6 | 917 | 30 | 29.4 | 22.3 |
| **7** | 55,010 | 55,704 | -694 | -1.2 | 1.2 | 921 | 50 | 49.3 | 22.3 |
| **8** | 55,460 | 55,700 | -240 | -0.4 | 0.4 | 925 | 40 | 39.9 | 22.3 |
| **9** | 56,240 | 55,692 | 548 | 1.0 | 1.0 | 933 | 35 | 33.7 | 22.4 |
| **10** | 53,950 | 55,684 | -1,734 | -3.1 | 3.1 | 941 | 50 | 48.9 | 22.3 |
| **11** | 54,320 | 55,680 | -1,360 | -2.4 | 2.4 | 945 | 45 | 43.5 | 22.4 |
| **12** | 54,920 | 55,676 | -756 | -1.4 | 1.4 | 949 | 45 | 45.9 | 22.3 |
| **13** | 53,180 | 55,672 | -2,492 | -4.5 | 4.5 | 953 | 45 | 44 | 22.3 |

| Test | WIM Class | Axle Wt 1 | Axle Wt 2 | Axle Wt 3 | Axle Wt 4 | Axle Len 1 | Axle Len 2 | Axle Len 3 | Tandem 1-2 | Violations |
|---|---|---|---|---|---|---|---|---|---|---|
| **0** | | | | | | | | | | |
| **1** | 3 | 11.8 | 16.6 | 13 | 13.3 | 13.6 | 4.3 | 4.4 | **28.4** | Over weight Combo |
| **2** | 3 | 11.5 | 15.5 | 15 | 13.6 | 13.6 | 4.3 | 4.4 | **27** | Over weight Combo |
| **3** | 6 | 17.1 | 17.2 | 18.8 | | 18 | 4.4 | | **36** | Over weight Combo<br>Over weight Tandem<br>Unbalanced |
| **4** | 3 | 14 | 12.5 | 14.6 | 14.2 | 13.6 | 4.3 | 4.4 | 26.5 | |
| **5** | 3 | 14.2 | 11.8 | 14.4 | 14.6 | 13.6 | 4.3 | 4.4 | 26,0 | |
| **6** | 3 | 13.5 | 13.1 | 14.8 | 14.7 | 13.6 | 4.3 | 4.4 | 26.6 | |
| **7** | 3 | 13.3 | 10 | 16.1 | 15.6 | 13.6 | 4.3 | 4.4 | 23.3 | |
| **8** | 3 | 13.2 | 11.3 | 15.3 | 15.7 | 13.6 | 4.3 | 4.4 | 24.4 | |
| **9** | 3 | 14.2 | 9.2 | 17.2 | 15.6 | 13.6 | 4.4 | 4.4 | 23.4 | |
| **10** | 3 | 14.1 | 9.7 | 15.2 | 14.9 | 13.6 | 4.3 | 4.4 | 23.8 | |
| **11** | 3 | 13.9 | 10.9 | 14.4 | 15.1 | 13.6 | 4.4 | 4.4 | 24.8 | |
| **12** | 3 | 13.8 | 10.7 | 15.5 | 14.9 | 13.6 | 4.3 | 4.4 | 24.5 | |
| **13** | 3 | 13.8 | 9.2 | 15.1 | 15.1 | 13.6 | 4.3 | 4.4 | 23 | |

*8.1.3. WIM Calibration Data Analysis*

As seen in the images in Appendix B, the test result of the third run was dropped in analyzing the data. During the third run, the lift axle (the second axle from the front) was off the ground improperly so it was taking less load. Since the lift axle was raised, it transferred more load to other axles. During the test, it was observed this lift axle was not touching the ground completely.

8.1.3.1. Technical requirements (95% compliance)

The technical requirements for the WIM calibration in this project are the same as those in ASTM E 1318-09 Standard. It is expected that more than 95% of the runs will meet the accuracy requirement below.

- Gross weight : 6%
- Axle weight : 15%
- Length : 1.5ft [=0.5ft * 3 (# of axles - 1)]

8.1.3.2. Gross Weight

Average Error is defined by mean dev/average*100 (%)

- Result : Pass (100% of measurements are within 6% error)
- Average error (%) = 1.8

8.1.3.3. Axle weight

Since we do not have reference values for each axle load, the average axle load is used as the reference axle load. Therefore, the actual axle weight error may be greater than the calculated axle weight error. Average Error is defined by mean dev/average*100 (%). Result is in Table 3.

**Table 3. Statistical Analysis of Axle Weight Measurement**

| | Axle Weight 1 | Axle Weight 2 | Axle Weight 3 | Axle Weight 4 |
|---|---|---|---|---|
| **Average** | 13.44167 | 11.70833 | 15.05 | 14.775 |
| **Mean Deviation** | 0.661111 | 1.826389 | 0.683333 | 0.579167 |
| **Mean Deviation (%)** | 4.918372 | **15.59905** | 4.540421 | 3.91991 |
| **Upper Range** | 15.45792 | 13.46458 | 17.3075 | 16.99125 |
| **Lower Range** | 11.42542 | 9.952083 | 12.7925 | 12.55875 |
| **# Over 15%** | 0 | 2 | 0 | 0 |
| **# Under 15%** | 0 | 3 | 0 | 0 |
| **# Out of Range** | 0 | 5 | 0 | 0 |
| **% Out of Range** | 0 | **41.66667** | 0 | 0 |

- Axle weight 1
  - Result : Pass (100% of measurements are within 15% error)
  - Average Error (%): 4.9 (%)
- Axle weight 2
  - Result : Fail (58% of measurements are within 15% error)
  - Average Error (%): 15.6 (%)
- Axle weight 3
  - Result : Pass (100% of measurements are within 15% error)
  - Average Error (%): 4.5 (%)
- Axle weight 4
  - Result : Pass (100% of measurements are within 15% error)

- Average Error (%): 3.9 (%)

The axle weight 2 does not meet the requirement because the lift axle was not touching the ground completely. After discussion with Cardinal, we decided that we could accept the failure of axle weight 2 because of the problem with the lift axle. We validated the accuracy of axle weight measurements during phase I and phase II tests to ensure there were no issues with axle weight 2 measurements during subsequent tests.

8.1.3.4. Length

- Result: Pass (100% of measurements are within 1.5 ft error. See Table 2.)
- Average Error (%) : 0.4 (ft)

*8.1.4. Correlation between Violations and Measurements*

In order to determine if there is any correlation between the detection of violations and each type of measurement, correlation coefficients and p-values were calculated. A Matrix R of correlation coefficients was calculated from an input matrix X whose rows are from the violation results and each measurement. A matrix of p-values was also calculated for testing the hypothesis of no correlation. Each p-value is the probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero. If P (i, j) is small, say less than 0.05, then the correlation R (i, j) is significant.

**Table 4. Correlation between Violations and Measurements**

| | **WIM Gross Error** | **WIM Speed** | **WIM Length** | **Axle Weight 1** | **Axle Weight 2** | **Axle Weight 3** | **Axle Weight 4** |
|---|---|---|---|---|---|---|---|
| **Correlation Coefficient** | 0.0914 | 0.7279 | -0.2000 | -0.9299 | 0.8525 | -0.4833 | -0.8125 |
| **p-value** | 0.7775 | **0.0073** | 0.5331 | **0.0000** | **0.0004** | 0.1115 | **0.0013** |

The statistical analysis using correlation coefficients shows that the speed and the axle weight 1/2/4 are very highly correlated with the detection of violations (false alarm assuming the reference CMV is not with any violations). The following limited results were observed (small sample size).

- As speed increases, the false alarm (the detection of violations assuming that the reference CMV itself is free of violations) is likely to increase.

- With smaller axle weight 1, false alarms could be more likely.
- With greater axle weight 2, false alarms could be more likely.
- With smaller axle weight 4, false alarms could be more likely.

The inaccuracy of axle weight measurement is likely to cause false alarms. It is believed that the problem with the lift axle caused false alarms. From this result, we can observe that the axle loads of vehicles with lift axles may not be accurate while the gross weight is measured accurately.

## 8.2. Validation of Construction and Installation of Components

### *8.2.1. Construction*

Actual inspections were completed by an SHA inspector. The SHA Inspector visually verified the following.

- Pull boxes, pull string, hand holes, and conduit installed properly, with proper erosion control and sediment control where appropriate. Ground coverage (grass/seeding) completed properly.
- Cabinet foundation, cabinet apron, conduit for cabinet installed properly, with bell ends in cabinet and hand boxes.
- Poles for camera, poles for over height detector installed properly.
- Proper water/moisture isolation for WIM cable conduits – this is critical since the sensor can fail prematurely if there is water/moisture intrusion.
- Ground rod verification, cabinet seals, final as-built schematics and resolution of punch-list items.

### *8.2.2. Components (Equipment)*

Actual inspections were verified by SHA in conjunction with Cardinal.

- Power up tests for individual components in WIM cabinet.

- Over height detector: install and height setup per MSP requirement using measuring pole; calibration for beam reflection (verify using signal strength meter provided in the Banner product).

- Camera: install and angle setup, sunshield extension, and proper installation in external enclosure – verify camera images since these can only be setup on location. The camera does not have remote software setup capability; this is critical for initial setup – this was completed in conjunction with MSP-CVED. ***Note****: Camera testing was performed by SHA inspector in conjunction with SHA Radio shop, using the WIM camera inspection checklist.* No spares are provided.

- IR lamp installation on camera pole.

- WIM Server PC, Kistler charge amp, Cardinal control board, UPS, peripheral equipment installation in WIM cabinet with proper grounding. Validate installation of WIM Reader software, ftp server software, and PCAnywhere software.

- Proxicast cell router with Verizon Sierra EVDO card installation by CEI, external antenna install.

- Kistler WIM Installation – verify grout and epoxy properly sanded down to road surface and WIM level with road surface.

# 9. PHASE I TEST

The main purpose of the first phase of tests is to test the functionality of the components and the system for consistent operation. During the first stage of phase I test, the performance of system components (such as the cell router) and the performance related to misclassification, misdetection and false alarms were tested. During the second stage of phase I test, a set of known vehicles from the SHA Dayton Maintenance Shop were used to validate weight and axle measurements to ensure that the WIM is properly calibrated and functional.

## 9.1. Performance of each component

### *9.1.1. Cell Router*

The latency and the throughput of cell router were tested both manually and by a test application.

#### 9.1.1.1. Manual test – Latency

In order to test the latency between the WIM server and the MSP laptop, the WIM server needed to be synchronized to the NTP (Network Time Protocol) server. Microsoft Windows XP® provides this functionality. Since the default period of synchronization is 7 days, we have to ensure that the WIM server is synchronized to the NTP server just before the test.

On the MSP laptop, we can either use the feature of Windows XP® or we can use the official US time provided by www.time.gov. This web site provides official time from two time agencies of the United States: a Department of Commerce agency- the National Institute of Standards and Technology (NIST), and its military counterpart, the U. S. Naval Observatory (USNO). It is accurate within 0.4 sec on the laptop. NIST and USNO provide software using the Internet to automatically set computer clock time to the correct time.

On the Java thin client, there are two options. 1) Clients request thumbnails initially and 2) Clients request full images initially. In most of our tests, we used the second option. When we used the second option, the data such as time, weight and violations shows up first and the image appears later. It is observed that the data and image appear within about 4 seconds' latency.

#### 9.1.1.2. Test by QCheck – Latency and Throughput

An IP benchmarking application called QCheck (Ixia) was used to test the cell router. IxChariot is the most popular commercial network benchmarking tool widely used by certification bodies such as Wi-Fi alliance, and QCheck is a free version of IxChariot providing rudimentary functions. QCheck provides enough functionality for our purposes.

In order to avoid heavy voice traffic on the Verizon Wireless Network, the test was done at 8 PM.

The test was performed between the WIM server and an MSP-CVED laptop (Panasonic ToughBook) over Verizon EVDO and the result was satisfactory. This topology is the same as the real application scenario where the images and data are transferred from the WIM server to the Java thin client operating on the laptop. It is expected that an image of size 100 kbytes can be transmitted within 10 seconds most of the time. The performance of TCP (Transmission Control Protocol) needs to be investigated since it is expected that the traffic between the WIM server and MSP-CVED laptop is TCP traffic.

The test result of response time measurement is as follows:

- Data Size 100 bytes / 3 iterations
  - TCP : min 187 msec, average 218 msec, max 256 msec
  - UDP : min 179 msec, average 205 msec, max 244 msec
- Data Size 32 kbytes / 3 iterations
  - TCP : min 1067 msec, average 1490 msec, max 1814 msec
  - UDP : min 1484 msec, average 1758 msec, max 2116 msec

We cannot have a data size greater than 32 kbytes due to limited functionality of the freeware version. However the result shows that in case of TCP, 32 kbytes data can be transferred in 1.5 seconds. This can be roughly translated to 4.5 seconds response time when we send an image of maximum size (100 kbytes). This response time is short enough for our purposes.

The test result of throughput measurement (data size 100 Kbytes) is as follows:

- TCP : 259.733 kbps
- UDP : 134.185 kbps

The throughput tests with a data size of 100 kbytes shows that we can send 100 kbytes roughly in 3.9 sec which also meets our expectation for the performance of the cell router.

### 9.2. Performance as a system

The misclassification/misdetection/false alarm test was completed on June 3rd, 2009, between 9 AM and 12 PM. This time was specifically chosen in order to avoid heavy traffic during commuting hours. Table 5 shows that 5AM – 9AM is the time span with very heavy traffic. A known problem with any manufacturer's classifier is that it tends to be unstable during high periods of stop and go traffic. The pilot VWS classifier tends to be unstable for periods of 1~2 minutes with rapid speed transitions. This sometimes results in bad reads. For this test this rush hour is intentionally avoided.

**Table 5. Traffic by Class on the Day of Misclassification Test**

| | CLASS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **Total** |
| **00:00-00:59** | 0 | 31 | 1 | 0 | 1 | 0 | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 39 |
| **01:00-01:59** | 0 | 28 | 4 | 0 | 0 | 0 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 38 |
| **02:00-02:59** | 0 | 32 | 0 | 1 | 0 | 0 | 1 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 41 |
| **03:00-03:59** | 0 | 46 | 0 | 4 | 3 | 0 | 0 | 2 | 8 | 0 | 1 | 0 | 0 | 0 | 0 | 64 |
| **04:00-04:59** | 0 | 240 | 2 | 1 | 4 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 262 |
| **05:00-05:59** | 0 | 962 | 5 | 1 | 17 | 0 | 2 | 3 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 1004 |
| **06:00-06:59** | 0 | 1422 | 6 | 0 | 30 | 8 | 20 | 4 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 1513 |
| **07:00-07:59** | 0 | 1222 | 8 | 1 | 23 | 4 | 31 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 2 | 1303 |
| **08:00-08:59** | 0 | 1144 | 8 | 1 | 27 | 4 | 29 | 2 | 15 | 1 | 0 | 0 | 0 | 0 | 0 | 1231 |
| **09:00-09:59** | 0 | 871 | 11 | 6 | 16 | 9 | 18 | 1 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 943 |
| **10:00-10:59** | 0 | 567 | 6 | 3 | 29 | 9 | 28 | 4 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 671 |
| **11:00-11:59** | 0 | 435 | 6 | 3 | 20 | 10 | 21 | 3 | 16 | 1 | 0 | 0 | 0 | 0 | 0 | 515 |
| **12:00-12:59** | 0 | 423 | 3 | 2 | 32 | 9 | 19 | 4 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 508 |
| **13:00-13:59** | 0 | 439 | 10 | 2 | 22 | 6 | 23 | 3 | 17 | 1 | 0 | 0 | 0 | 0 | 0 | 523 |
| **14:00-14:59** | 0 | 440 | 8 | 1 | 32 | 4 | 19 | 1 | 17 | 1 | 0 | 0 | 0 | 0 | 0 | 523 |
| **15:00-15:59** | 0 | 558 | 11 | 2 | 15 | 5 | 12 | 3 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 611 |
| **16:00-16:59** | 0 | 606 | 6 | 3 | 18 | 5 | 6 | 0 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 655 |
| **17:00-17:59** | 0 | 552 | 4 | 1 | 10 | 0 | 6 | 3 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 584 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **18:00-18:59** | 0 | 481 | 3 | 0 | 7 | 2 | 7 | 0 | 10 | 0 | 0 | 1 | 0 | 0 | 0 | 511 |
| **19:00-19:59** | 0 | 338 | 0 | 1 | 6 | 1 | 0 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 353 |
| **20:00-20:59** | 0 | 284 | 2 | 0 | 2 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 294 |
| **21:00-21:59** | 0 | 206 | 0 | 1 | 3 | 0 | 1 | 0 | 5 | 0 | 0 | 2 | 0 | 0 | 0 | 218 |
| **22:00-22:59** | 0 | 150 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 154 |
| **23:00-23:59** | 0 | 54 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 58 |
| 06/03/2009 Wed | **0** | **11531** | **104** | **34** | **317** | **77** | **244** | **36** | **260** | **7** | **1** | **3** | **0** | **0** | **2** | **12616** |
| Week Total | **0** | **11531** | **104** | **34** | **317** | **77** | **244** | **36** | **260** | **7** | **1** | **3** | **0** | **0** | **2** | **12616** |

### *9.2.1. Misclassification*

Out of 256 vehicles that passed over WIM between 9AM and 12PM, 206 vehicles were observed from the thin client. There were breaks and interrupts during the test period because the software on the WIM server was being upgraded on the day of the test. As a result, 50 vehicles were not observed from the thin client.

Out of 206 images observed, there was only one occurrence of image mismatch. The percentage of mismatched images is 0.5% which is negligibly small.

It was observed when vehicles are passing too close to each other (when vehicles are tailgating), the classifier cannot differentiate the presence of a single vehicle with long axle space and the tailgating vehicle. In our test, two Class 2 vehicles were classified as a single Class 8 vehicle. This example is shown in Figure 36.

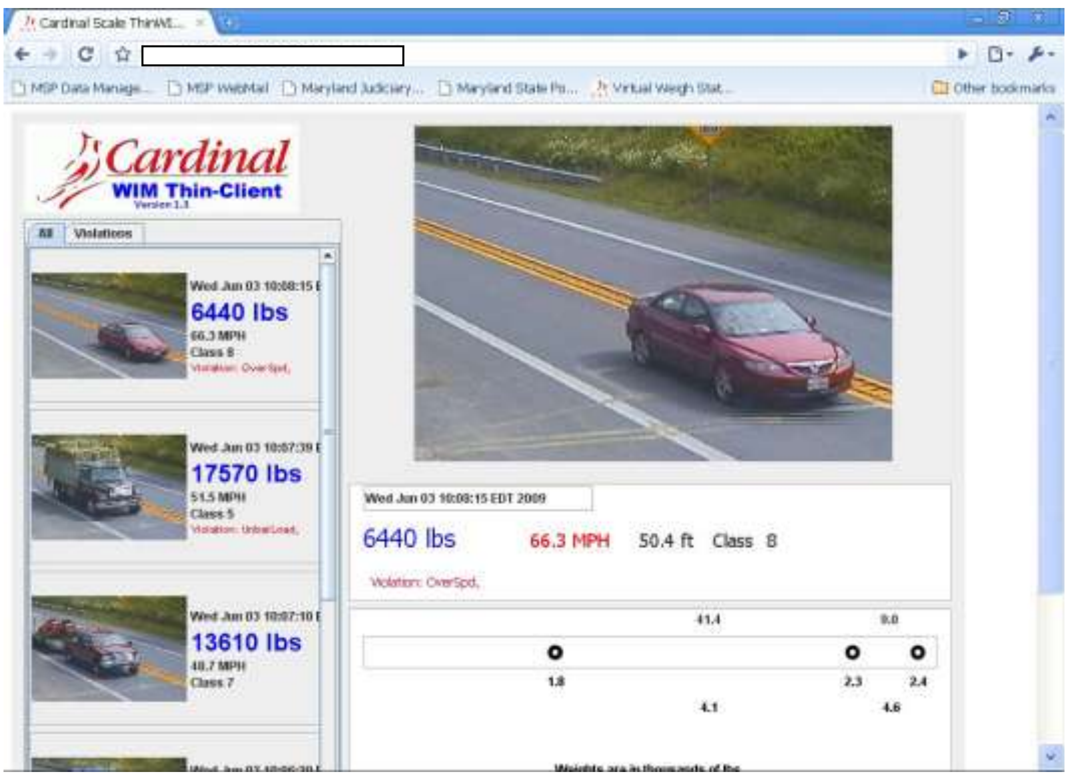



**Figure 36. A Screenshot of Misclassification during the Misclassification Test**

### *9.2.2. Misdetections*

Misdetections were not calculated while the misclassification test was being performed. In our case, we have a rule set that is specially configured for MSP; namely, two axle vehicles with a load less than 10,000 lbs are not recorded by our VWS. We cannot determine if a vehicle is not captured because of light weight or some other reasons.

### *9.2.3. False Alarms*

False alarms for our test are defined by the appearance of non-CMV images on the thin client. Out of 206 images observed, there was not a single non-CMV image. (False alarm rate is 0 %.)

When the VWS was initially installed, traffic on the opposite traveling side of the lane frequently incurred detection by the loop detector. This caused a number of false alarms. The sensitivity level of loop detector was changed from level 6 to level 4, and false alarms have been almost eliminated.

## 9.3. WIM Field Test with Predefined Set of CMVs

### *9.3.1. Summary*

We completed twenty runs with four different types of CMVs at the VWS on May 28, 2009. We verified that the VWS meets the functional performance requirements for a type III WIM as defined in the Test Plan, as well as the ASTM E 1318-09 standard.

### *9.3.2. Test Set-up*

#### 9.3.2.1. Test CMVs

Four different types of CMVs were used for Phase I tests. Three different levels of load were used for each CMV (except 2-axle bucket truck where the load level was maintained constant). During each round, each CMV made one run. There were five rounds (which makes 20 runs total).

1. 2-axle bucket truck (Class 5, 2 axles) : constant weight, 5 runs

**Figure 37. 2-axle Bucket Truck used in Phase I Test**

2. One ton dump truck (Class 5, 2 axles) : empty 1 run, 1/2 full 2 runs, full 2 runs

**Figure 38. One Ton Dump Truck used in Phase I Test**

3. 3-axle dump truck (Class 6, 3 axles) : empty 1 run, 1/2 full 2 runs, full 2 runs


**Figure 39. 3-axle Dump Truck used In Phase I Test**

4. Tractor trailer lo-boy (Class 9, 5 axles) : empty 1 run, 1/2 full 2 runs, full 2 runs

**Figure 40. Tractor Trailer Lo-boy used In Phase I Test**

- Initially all CMVs were empty. The weights were measured using the certified static scale at the West Friendship scale house on I-70 and lengths were measured manually by MSP-CVED at the scale house. For CMVs with more than three axles, we did not measure all axle loads. Only the combo loads were measured and recorded due to the weighing limits of the static scale.

- Each CMV passed over the WIM sensor at about **50 mph** on the **center.**

### *9.3.3. Target Performance*

All target performances are with 95% compliance level. Since we had 20 runs, we expected 19 runs out of 20 runs to be within error bounds to meet the requirements.

- Gross Load : 6%

- Axle Load : 15%

- Length between axles : 0.5ft

    - The performance requirement for the length between axle 3 and axle 5 of lo-boy truck is 1.0 ft rather than 0.5 ft because this length is the sum of two lengths (axle 3 & axle 4, axle 4 & axle 5).

    - The performance requirement for the overall length is 0.5 ft * (number of axles – 1).

- Bridge Formula Weight : 6% (See section 7.1)

### *9.3.4. Test Result*

#### 9.3.4.1. Load

Test result with unbalanced load is highlighted. It turned out that an unbalanced load error was not quite relevant with the load measurement error during Phase I test.

All gross weights and combo weights passed the target performance with 95% compliance (19 runs out of 20 runs passed the target performance). *(Note: All results are based upon the actual WIM reading, which includes the WIM calibration adjustment factor of -2%)*:

1. 2-axle Bucket Truck

**Table 6. Phase I Test Results for 2-Axle Bucket Truck (Weight)**

| Round | Gross weight | Axle 1 weight | Axle 2 weight | Gross Error (%) | Axle1 Error (%) | Axle 2 Error (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **23820** | **9160** | **14660** | | | |
| **Round 1 (measured)** | 23460 | 8600 | 14800 | 1.511335 | 6.113537 | 0.95498 |
| **Round 2 (ref)** | **23800** | **9160** | **14640** | | | |
| **Round 2 (measured)** | 23260 | 8400 | 14800 | 2.268908 | 8.296943 | 1.092896 |
| **Round 3 (ref)** | **23800** | **9160** | **14640** | | | |
| **Round 3 (measured)** | 21920 | 8000 | 13900 | **7.89916** | 12.66376 | 5.054645 |
| **Round 4 (ref)** | **23780** | **9140** | **14640** | | | |
| **Round 4 (measured)** | 22560 | 8800 | 13700 | 5.130362 | 3.719912 | 6.420765 |
| **Round 5 (ref)** | **23780** | **9140** | **14640** | | | |
| **Round 5 (measured)** | 23210 | 8900 | 14300 | 2.396972 | 2.625821 | 2.322404 |
| **Error (%)** | | | | ***3.841347*** | ***6.683994*** | ***3.169138*** |

- One out of five runs did not meet the gross load requirement (Marked in red). All runs meet the axle load requirement.

2. One-ton dump truck

**Table 7. Phase I Test Results for One-ton Dump Truck (Weight)**

| Round | Gross weight | Axle 1 weight | Axle 2 + Axle 3 weight | Gross Error (%) | Axle 1 Error (%) | Axle 2 + Axle 3 Error (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **10720** | **4700** | **6020** | | | |
| **Round 1 (measured)** | 10350 | 4400 | 6000 | 3.451493 | 6.382979 | 0.332226 |
| **Round 2 (ref)** | **11720** | **4720** | **7000** | | | |
| **Round 2 (measured)** | 11390 | 4400 | 7000 | 2.8157 | 6.779661 | 0 |
| **Round 3 (ref)** | **11720** | **4720** | **7000** | | | |
| **Round 3 (measured)** | 11560 | 4600 | 7000 | 1.365188 | 2.542373 | 0 |
| **Round 4 (ref)** | **13380** | **4740** | **8640** | | | |
| **Round 4 (measured)** | 13090 | 4600 | 8500 | 2.167414 | 2.953586 | 1.62037 |
| **Round 5 (ref)** | **13380** | **4740** | **8640** | | | |
| **Round 5 (measured)** | 12890 | 4300 | 8600 | 3.662182 | 9.2827 | 0.462963 |
| **Error (%)** | | | | ***2.692395*** | ***5.58826*** | ***0.483112*** |

- All runs meet the gross and axle load requirement.

3. 3-axle dump truck: Unbalanced load was observed at round 2.

**Table 8. Phase I Test Results for Three Axles Dump Truck (Weight)**

| Round | Gross weight | Axle 1 weight | Axle 2 + Axle 3 weight | Gross Error (%) | Axle 1 Error (%) | Axle 2 + Axle 3 Error (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **24740** | **11680** | **13060** | | | |
| **Round 1 (measured)** | 23410 | 11200 | 12200 | 5.375909 | 4.109589 | 6.584992 |
| **Round 2 (ref)** | **29040** | **12160** | **16880** | | | |
| **Round 2 (measured)** | 27790 | 11600 | 16200 | 4.304408 | 4.605263 | 4.028436 |
| **Round 3 (ref)** | **29040** | **12160** | **16880** | | | |
| **Round 3 (measured)** | 27920 | 11600 | 16300 | 3.856749 | 4.605263 | 3.436019 |
| **Round 4 (ref)** | **33660** | **12940** | **20720** | | | |
| **Round 4 (measured)** | 32660 | 12500 | 20200 | 2.970885 | 3.400309 | 2.509653 |
| **Round 5 (ref)** | **33660** | **12940** | **20720** | | | |
| **Round 5 (measured)** | 32570 | 12500 | 20000 | 3.238265 | 3.400309 | 3.474903 |
| **Error (%)** | | | | ***3.949243*** | ***4.024147*** | ***4.006801*** |

***Note****: Test result with unbalanced load is highlighted.*

- All runs meet the gross and axle load requirement.

4. Tractor trailer lo-boy

**Table 9. Phase I Test Results for Tractor Trailer Lo-Boy (Weight)**

| Round | Gross weight | Axle 1 weight | Axle 2 + Axle 3 weight | Axle 4 + Axle 5 weight | Gross Error (%) | Axle 1 Error (%) | Axle 2 + Axle 3 Error (%) | Axle 4 + Axle 5 Error (%) |
|---|---|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **35900** | **8300** | **16580** | **11020** | | | | |
| **Round 1 (measured)** | 35120 | 7800 | 16600 | 10600 | 2.1727 | 6.0241 | 0.1206 | 3.8113 |
| **Round 2 (ref)** | **44820** | **8180** | **18540** | **18100** | | | | |
| **Round 2 (measured)** | 43420 | 7900 | 18100 | 17400 | 3.1236 | 3.4230 | 2.3733 | 3.8674 |
| **Round 3 (ref)** | **44820** | **8180** | **18540** | **18100** | | | | |
| **Round 3 (measured)** | 42650 | 7600 | 18100 | 17000 | 4.8416 | 7.0905 | 2.3733 | 6.0774 |
| **Round 4 (ref)** | **63940** | **8760** | **23840** | **31340** | | | | |
| **Round 4 (measured)** | 61480 | 8100 | 23500 | 29900 | 3.8474 | 7.5343 | 1.4262 | 4.5948 |
| **Round 5 (ref)** | **63940** | **8760** | **23840** | **31340** | | | | |
| **Round 5 (measured)** | 60260 | 7800 | 22900 | 29500 | 5.7554 | 10.9589 | 3.9430 | 5.8711 |
| **Error (%)** | | | | | ***3.9481*** | ***7.0061*** | ***2.0473*** | ***4.8444*** |

- All runs meet the gross and axle load requirement.

9.3.4.2. Length

Every length between axles was not measured at the scale house. The following lengths were measured and used as the reference value. Each length between adjacent axles was calculated from the measured values. When the calculated value and the measured value are not the same, the measured value is used as the reference value. In all cases, the difference between calculation and measurement is negligibly small (less than 0.1 ft). The calculated value is highlighted.

**Table 10. Phase I Test Results for all CMVs (Length)**

| | # of axles | Axle 1 - Axle 2 | Axle 2 - Axle 3 | Axle 3 - Axle 5 | Total Length |
|---|---|---|---|---|---|
| **Bucket** | 2 | 14.83 | | | 14.83 |
| **One-ton Dump** | 2 | 16.5 | | | 16.5 |
| **3 axle Dump** | 3 | 13.17 | 4.33 | | 17.5 |
| **Lo boy** | 5 | 13.42 | 4.58 | 36.58 | 54.67 |

***Note***: *The calculated values are highlighted.*

All lengths passed the target performance with 100% compliance (20 runs out of 20 runs passed the target performance).

1. 2-axle Bucket Truck

**Table 11. Phase I Test Results for Bucket Truck (Length)**

| Round | Length | Length Error |
|---|---|---|
| **Round 1 (ref)** | **16.5** | |
| **Round 1 (measured)** | 16.2 | 0.3 |
| **Round 2 (ref)** | **16.5** | |
| **Round 2 (measured)** | 16.2 | 0.3 |
| **Round 3 (ref)** | **16.5** | |
| **Round 3 (measured)** | 16.2 | 0.3 |
| **Round 4 (ref)** | **16.5** | |
| **Round 4 (measured)** | 16.2 | 0.3 |
| **Round 5 (ref)** | **16.5** | |
| **Round 5 (measured)** | 16.2 | 0.3 |
| **Error (ft)** | | ***0.3*** |

- All runs meet the length requirement.

2. One-ton dump truck

**Table 12. Phase I Test Results for One-ton Dump Truck (Length)**

| Round | Length | Length Error |
|---|---|---|
| **Round 1 (ref)** | **14.83** | |
| **Round 1 (measured)** | 14.4 | 0.43 |
| **Round 2 (ref)** | **14.83** | |
| **Round 2 (measured)** | 14.4 | 0.43 |
| **Round 3 (ref)** | **14.83** | |
| **Round 3 (measured)** | 14.4 | 0.43 |
| **Round 4 (ref)** | **14.83** | |
| **Round 4 (measured)** | 14.4 | 0.43 |
| **Round 5 (ref)** | **14.83** | |
| **Round 5 (measured)** | 14.4 | 0.43 |
| **Error (ft)** | | ***0.43*** |

- All runs meet the length requirement.

3. 3-axles dump truck: Unbalanced load was observed at round 2.

**Table 13. Phase I Test Results for Three Axle Dump Truck (Length)**

| Round | Length | Length (2-3) | Length Error | Length (2-3) Error |
|---|---|---|---|---|
| **Round 1 (ref)** | **17.5** | **4.33** | | |
| **Round 1 (measured)** | 17.2 | 4.2 | 0.3 | 0.13 |
| **Round 2 (ref)** | **17.5** | **4.33** | | |
| **Round 2 (measured)** | 17.2 | 4.2 | 0.3 | 0.13 |
| **Round 3 (ref)** | **17.5** | **4.33** | | |
| **Round 3 (measured)** | 17.2 | 4.2 | 0.3 | 0.13 |
| **Round 4 (ref)** | **17.5** | **4.33** | | |
| **Round 4 (measured)** | 17.1 | 4.2 | 0.4 | 0.13 |
| **Round 5 (ref)** | **17.5** | **4.33** | | |
| **Round 5 (measured)** | 17.2 | 4.2 | 0.3 | 0.13 |
| **Error (ft)** | | | ***0.32*** | ***0.13*** |

***Note****: Test result with unbalanced load is highlighted.*

- All runs meet the length requirement.

4. Tractor trailer lo-boy

**Table 14. Phase I Test Results for Tractor Trailer Lo-boy (Length)**

| Round | Length | Length (1-2) | Length (2-3) | Length (3-5) | Length Error | Length (1-2) Error | Length (2-3) Error | Length (3-5) Error |
|---|---|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **54.67** | **13.42** | **4.58** | **36.58** | | | | |
| **Round 1 (measured)** | 53.7 | 13.2 | 4.6 | 35.9 | 0.97 | 0.22 | 0.02 | 0.68 |
| **Round 2 (ref)** | **54.67** | **13.42** | **4.58** | **36.58** | | | | |
| **Round 2 (measured)** | 53.6 | 13.2 | 4.5 | 35.9 | 1.07 | 0.22 | 0.08 | 0.68 |
| **Round 3 (ref)** | **54.67** | **13.42** | **4.58** | **36.58** | | | | |
| **Round 3 (measured)** | 53.6 | 13.2 | 4.5 | 35.9 | 1.07 | 0.22 | 0.08 | 0.68 |
| **Round 4 (ref)** | **54.67** | **13.42** | **4.58** | **36.58** | | | | |
| **Round 4 (measured)** | 53.7 | 13.2 | 4.5 | 36 | 0.97 | 0.22 | 0.08 | 0.58 |
| **Round 5 (ref)** | **54.67** | **13.42** | **4.58** | **36.58** | | | | |
| **Round 5 (measured)** | 53.6 | 13.2 | 4.5 | 35.9 | 1.07 | 0.22 | 0.08 | 0.68 |
| **Error (ft)** | | | | | ***1.03*** | ***0.22*** | ***0.068*** | ***0.66*** |

- All runs meet the length requirement.

9.3.4.3. Calculations of Bridge Formula Weights

Exterior bridge and interior bridge formula weights are calculated to see if they meet the expected level of accuracy. Since every length between axles was not measured, we can calculate the inner bridge only for the tractor trailer lo-boy CMV. For all CMVs, the exterior bridge values can be calculated. Error is calculated using the non-rounded values from the bridge formula. (See section 7.1.) All bridge formula weights passed the target performance with 100% compliance (20 runs out of 20 runs passed the target performance).

1. 2-axle Bucket Truck

**Table 15. Phase I Test Results for Bucket Truck (Bridge Formula Weight)**

| Round | Number of Axles | Exterior Bridge Formula Weight (rounded) | Exterior Bridge Formula Weight (non-rounded) | Difference (Outer Bridge Weight) | Difference (Outer Bridge Weight, with non-rounded values) | Error in the Outer Bridge Weight (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **2** | **46500** | **46500** | | | |
| **Round 1 (measured)** | 2 | 46000 | 46200 | 500 | 300 | 0.645161 |
| **Round 2 (ref)** | **2** | **46500** | **46500** | | | |
| **Round 2 (measured)** | 2 | 46000 | 46200 | 500 | 300 | 0.645161 |
| **Round 3 (ref)** | **2** | **46500** | **46500** | | | |
| **Round 3 (measured)** | 2 | 46000 | 46200 | 500 | 300 | 0.645161 |
| **Round 4 (ref)** | **2** | **46500** | **46500** | | | |
| **Round 4 (measured)** | 2 | 46000 | 46200 | 500 | 300 | 0.645161 |
| **Round 5 (ref)** | **2** | **46500** | **46500** | | | |
| **Round 5 (measured)** | 2 | 46000 | 46200 | 500 | 300 | 0.645161 |
| **Average** | | | | ***500*** | ***300*** | ***0.645161*** |

- All runs meet the accuracy requirement for bridge formula weights.

2. One-ton dump truck

**Table 16. Phase I Test Results for One-ton Dump Truck (Bridge Formula Weight)**

| Round | Number of Axles | Exterior Bridge Formula Weight (rounded) | Exterior Bridge Formula Weight (non-rounded) | Difference (Outer Bridge Weight) | Difference (Outer Bridge Weight, with non-rounded values) | Error in the Outer Bridge Weight (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **2** | **45000** | **44830** | | | |
| **Round 1 (measured)** | 2 | 44500 | 44400 | 500 | 430 | 0.959179 |
| **Round 2 (ref)** | **2** | **45000** | **44830** | | | |
| **Round 2 (measured)** | 2 | 44500 | 44400 | 500 | 430 | 0.959179 |
| **Round 3 (ref)** | **2** | **45000** | **44830** | | | |
| **Round 3 (measured)** | 2 | 44500 | 44400 | 500 | 430 | 0.959179 |
| **Round 4 (ref)** | **2** | **45000** | **44830** | | | |
| **Round 4 (measured)** | 2 | 44500 | 44400 | 500 | 430 | 0.959179 |
| **Round 5 (ref)** | **2** | **45000** | **44830** | | | |
| **Round 5 (measured)** | 2 | 44500 | 44400 | 500 | 430 | 0.959179 |
| **Average** | | | | ***500*** | ***430*** | ***0.959179*** |

- All runs meet the accuracy requirement for bridge formula weights.

3. 3-axles dump truck: Unbalanced load was observed at round 2.

**Table 17. Phase I Test Results for Three Axle Dump Truck (Bridge Formula Weight)**

| Round | Number of Axles | Exterior Bridge Formula Weight (rounded) | Exterior Bridge Formula Weight (non-rounded) | Difference (Outer Bridge Weight) | Difference (Outer Bridge Weight, with non-rounded values) | Error in the Outer Bridge Weight (%) |
|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **3** | **49000** | **49125** | | | |
| **Round 1 (measured)** | 3 | 49000 | 48900 | 0 | 225 | 0.458015 |
| **Round 2 (ref)** | **3** | **49000** | **49125** | | | |
| **Round 2 (measured)** | 3 | 49000 | 48900 | 0 | 225 | 0.458015 |
| **Round 3 (ref)** | **3** | **49000** | **49125** | | | |
| **Round 3 (measured)** | 3 | 49000 | 48900 | 0 | 225 | 0.458015 |
| **Round 4 (ref)** | **3** | **49000** | **49125** | | | |
| **Round 4 (measured)** | 3 | 49000 | 48825 | 0 | 300 | 0.610687 |
| **Round 5 (ref)** | **3** | **49000** | **49125** | | | |
| **Round 5 (measured)** | 3 | 49000 | 48900 | 0 | 225 | 0.458015 |
| **Average** | | | | ***0*** | ***240*** | ***0.48855*** |

***Note**: Test result with unbalanced load is highlighted.*

- All runs meet the accuracy requirement for bridge formula weights.

4. Tractor trailer lo-boy

**Table 18. Phase I Test Results for Tractor Trailer Lo-boy (Bridge Formula Weight)**

| Round | Number of Axles | Exterior Bridge Formula Weight (rounded) | Exterior Bridge Formula Weight (non-rounded) | Inner Bridge Formula Weight (Axle 1 - Axle 3, rounded) | Inner Bridge Formula Weight (Axle 1 - Axle 3, non-rounded) | Inner Bridge Formula Weight (Axle 2 - Axle 5, rounded) | Inner Bridge Formula Weight (Axle 2 - Axle 5, non-rounded) |
|---|---|---|---|---|---|---|---|
| **Round 1 (ref)** | **5** | **82000** | **82168.75** | **49500** | **49500** | **69500** | **69440** |
| **Round 1 (measured)** | 5 | 81500 | 81562.5 | 49500 | 49350 | 69000 | 69000 |
| **Round 2 (ref)** | **5** | **82000** | **82168.75** | **49500** | **49500** | **69500** | **69440** |
| **Round 2 (measured)** | 5 | 81500 | 81500 | 49500 | 49275 | 69000 | 68933 |
| **Round 3 (ref)** | **5** | **82000** | **82168.75** | **49500** | **49500** | **69500** | **69440** |
| **Round 3 (measured)** | 5 | 81500 | 81500 | 49500 | 49275 | 69000 | 68933 |
| **Round 4 (ref)** | **5** | **82000** | **82168.75** | **49500** | **49500** | **69500** | **69440** |
| **Round 4 (measured)** | 5 | 81500 | 81562.5 | 49500 | 49275 | 69000 | 69000 |
| **Round 5 (ref)** | **5** | **82000** | **82168.75** | **49500** | **49500** | **69500** | **69440** |
| **Round 5 (measured)** | 5 | 81500 | 81500 | 49500 | 49275 | 69000 | 68933 |

| **Round** | **Difference (Outer Bridge Weight)** | **Difference (Outer Bridge Weight, with non-rounded values)** | **Error in the Outer Bridge Weight (%)** |
|---|---|---|---|
| **Round 1 (ref)** | | | |
| **Round 1 (measured)** | 500 | **606.25** | **0.737810907** |
| **Round 2 (ref)** | | | |
| **Round 2 (measured)** | 500 | **668.75** | **0.813873888** |
| **Round 3 (ref)** | | | |
| **Round 3 (measured)** | 500 | **668.75** | **0.813873888** |
| **Round 4 (ref)** | | | |
| **Round 4 (measured)** | 500 | **606.25** | **0.737810907** |
| **Round 5 (ref)** | | | |
| **Round 5 (measured)** | 500 | **668.75** | **0.813873888** |
| **Average** | ***500*** | *643.75* | *0.783448696* |

| **Round** | **Difference (Inner Bridge Weight, Axle 1 - Axle 3, with rounded values)** | **Difference (Inner Bridge Weight, Axle 1 - Axle 3, with non-rounded values)** | **Error in the Inner Bridge Weight (%) (Axle 1 - Axle 3)** | **Difference (Inner Bridge Weight, Axle 2 - Axle 5, with rounded values)** | **Difference (Inner Bridge Weight, Axle 2 - Axle 5, with non-rounded values)** | **Error in the Inner Bridge Weight (%) (Axle 2 - Axle 5)** |
|---|---|---|---|---|---|---|
| Round 1 (ref) | | | | | | |
| Round 1 (measured) | 0 | **150** | **0.303030303** | 500 | **440** | 0.633640553 |
| Round 2 (ref) | | | | | | |
| Round 2 (measured) | 0 | **225** | **0.454545455** | 500 | **506.6666667** | 0.729646697 |
| Round 3 (ref) | | | | | | |
| Round 3 (measured) | 0 | **225** | **0.454545455** | 500 | **506.6666667** | 0.729646697 |
| Round 4 (ref) | | | | | | |
| Round 4 (measured) | 0 | **225** | **0.454545455** | 500 | **440** | 0.633640553 |
| Round 5 (ref) | | | | | | |
| Round 5 (measured) | 0 | **225** | **0.454545455** | 500 | **506.6666667** | 0.729646697 |
| error (%) | ***0*** | ***210*** | ***0.424242424*** | ***500*** | ***480*** | ***0.69124424*** |

- All runs meet the accuracy requirement for bridge formula weights.

### *9.3.5. Phase I Test Conclusions*

Phase I tests were successfully completed verifying that the pilot VWS meets the requirements set by our test plan and the ASTM 1318-09 industry standard.

It was observed that all errors for gross weight were negative (the reference value is larger than the measured value) and 22 out of 25 axle weight errors were negative. The length measurement shows that about 2% positive bias (the reference value is about 2% smaller than the measured value) exists in most of the cases.

## 10. PHASE II TEST

The second phase of tests is intended to test the functionality of the system against a variety of CMVs and validate its operation as an effective law enforcement tool for CMV weight and height pre-screening, as well as targeted safety inspections. We will also attempt to determine a correlation between weight and safety from this limited sample set. It is important to emphasize that the system as currently configured is a weight and height pre-screening tool; it is the trooper that performs the safety inspection and issues any resulting Out of Service (OOS) order. The second phase will also evaluate weight measurement drift over time in order to provide guidance for a calibration period. A separate memo may be released after a six month period to determine any additional drift after long term analysis.

Phase II tests began on June 8th, 2009 and continued until July 8th, 2009. The goal was to measure the effectiveness of the system as a pre-screening tool against a variety of CMVs. Over weight as well as normal weight (non-violation) conditions were considered. This assisted in determining the consistency of the WIM sensor to weigh a wide variety of CMVs with multiple axle configurations.

### 10.1. Phase II Test Process

The process for Phase II test is as follows. The following process was repeated for 85 vehicles.

1. MSP-CVED officers make a CMV selection based on weight violation or non-violation criteria, to provide a mix of vehicle weights for the purposes of enforcement, as well as to ensure the consistency of vehicle weights being recorded by the WIM for a variety of axle configurations. Visual cues from images were not heavily considered.

2. Capture the image of the selected vehicle on the MSP-CVED laptop (Panasonic ToughBook).

3. Proceed to pull the CMV over.[11]

4. Complete a level 2 inspection. Record weights using certified portable Haenni scales.

5. Attach a copy of the inspection report with corresponding CMV image and WIM information.

6. If other defects are found, record them as necessary. If CMV is put OOS, provide the inspection detail/violation that resulted in the OOS condition.

[11] The location of the pull-off site was chosen at MSP-CVED discretion. The pull-off location for the Phase II test was a location between the VWS and the proposed pull-off site shown in Figure 33. Typically, the jug handle was used. In other instances, the Dayton Shop parking lot was used.

The time for Phase II tests was selected at MSP-CVED discretion, avoiding rush hour traffic (typically 6AM-9AM from Monday to Friday) at the location. During rush hour, the classifier tends to become unstable for periods of 1-2 minutes with rapid speed transitions (stop and go traffic), since the classifier cannot determine the end of the preceding vehicle and the start of the following vehicle. This results in bad reads.

### 10.2. Vehicle Selection Criteria

The MSP–CVED troopers made the selection based on weight violation or non-violation (random) criteria, to provide a mix of vehicle weights for the purposes of enforcement, as well as to ensure the consistency of vehicle weights being recorded by the WIM for a variety of axle configurations. Visual cues from images were not considered very heavily.

#### *10.2.1. Random*

This is to ensure that a variety of CMVs (i.e. different types of axle configurations/class types and speed) is providing reasonable results on the WIM.


**Figure 41. An Example of CMVs Screened by Random Selection**

*10.2.2. WIM*

This is to enforce local laws (Motor Vehicle Administration, 2008) for weight and to ensure the WIM is providing consistent results on violations.

- Over weight[12]

  The gross weight of any vehicle or combination of vehicles may not exceed the following limits shown in Table 19. For dump service, the maximum gross weight limitations for a dump service vehicle are as follows:

  - · Two axles = 40,000 pounds
  - · Three axles = 55,000 pounds or 65,000 pounds
  - · Four axles = 70,000 pounds

**Table 19. The Limit of Gross Weights in Maryland**

| Number of Axles | Gross Weight (in pounds) |
|---|---|
| **Three or less** | 55,000 |
| **Four** | 66,000 |
| **Five and above** | 80,000 |

Although the WIM reports violations such as Over weight Gross, Over weight Single, Over weight Tandem and Over weight Combo, it may not be consistent with local laws and exceptions on State highways; the FHWA Class tables are used to provide weight thresholds for violation conditions. Therefore the MSP-CVED troopers use best judgment for weight violations from a combination of weight readings, classifications and CMV images.

If the gross weight is close to or over 80,000 lbs, this provides a clue that this vehicle is likely to be over weight.[13] If the gross weight of a four-axle short dump truck is close to

12 Note that the weight information is based upon the actual WIM reading, which includes the WIM calibration adjustment factor of -2%.

or over 70,000 lbs, this provides a clue that this vehicle is likely to be over weight. MSP-CVED troopers selected a vehicle if the weight read from the WIM is greater than the threshold values by approximately 1,000 lbs.

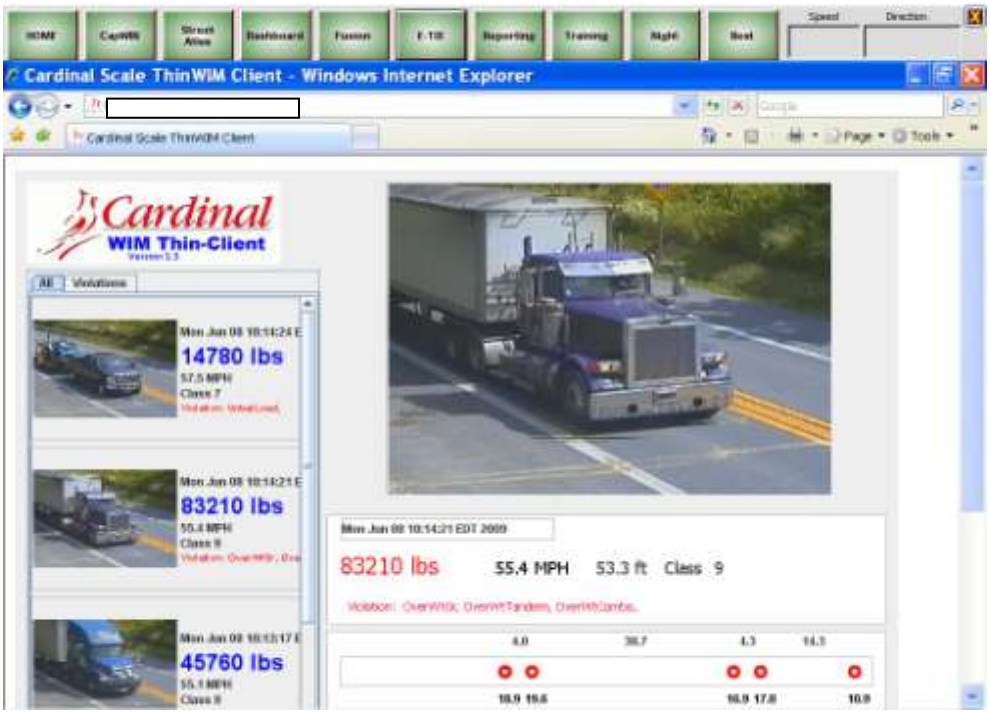



**Figure 42. An Example of CMVs Screened by Over weight Indication**

- Unbalanced Load

The WIM reports unbalanced load violation indicating that the weight on one side of the vehicle differs by more than a preset amount from the weight on the opposite side of the vehicle. This condition can also be caused by failing to drive fully across the sensor array when there are no off-scale sensors present. The unbalanced load violation usually causes bad reads on the WIM. The example in Figure 43 shows that the CMV with weight read at 40,590 lbs actually weighed 73,100 lbs.

[13] The maximum gross vehicle weight shall be 80,000 pounds except where lower gross vehicle weight is dictated by the bridge formula or by special circumstances and permits.

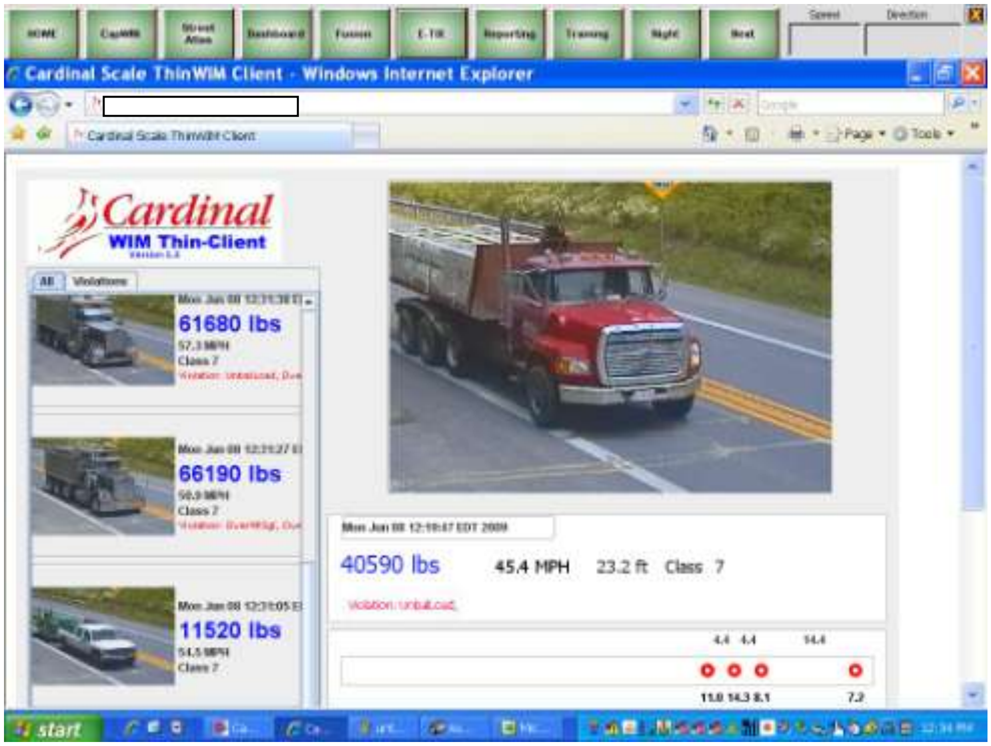



**Figure 43. An Example of CMVs Screened by Unbalanced Load Indication**

It was observed that some drivers intentionally avoid driving fully across the WIM sensor array. Some drivers even drive over the shoulder in order to avoid running over the WIM completely. Therefore, unbalanced loads can be a clue for weight violations.


**Figure 44. An Example of CMVs Running over the Shoulder**

- Other types of WIM violations

  Other types of violations reported by the WIM reader application can be clues for the following conditions:

  - Over Height Violation: This violation takes place when the over height detector senses a portion of the vehicle that exceeds the height setting of the over height sensors (13ft 9 inches). This provides a clue for an over height violation.

  - Over Speed Violation: This violation is an indication that the speed of the vehicle as it crosses the sensor array is greater than the preset limit (65 mph). This offers a clue for speed violation. (***Note:*** *MSP-CVED troopers have verified that speed calculations by the WIM sensor are generally within +/- 1 mile of radar speed units mounted on the back of the MSP-CVED roving enforcement vehicles.)*

*10.2.3. Visual Cue*

It may be possible to stop vehicles with visual cues (this method has not been proven in our case). Such visual cues can include, but are not limited to:

- Dirty Hubs

Sometimes, dirty wheel hubs may indicate defective brakes or leaking fluids, etc.

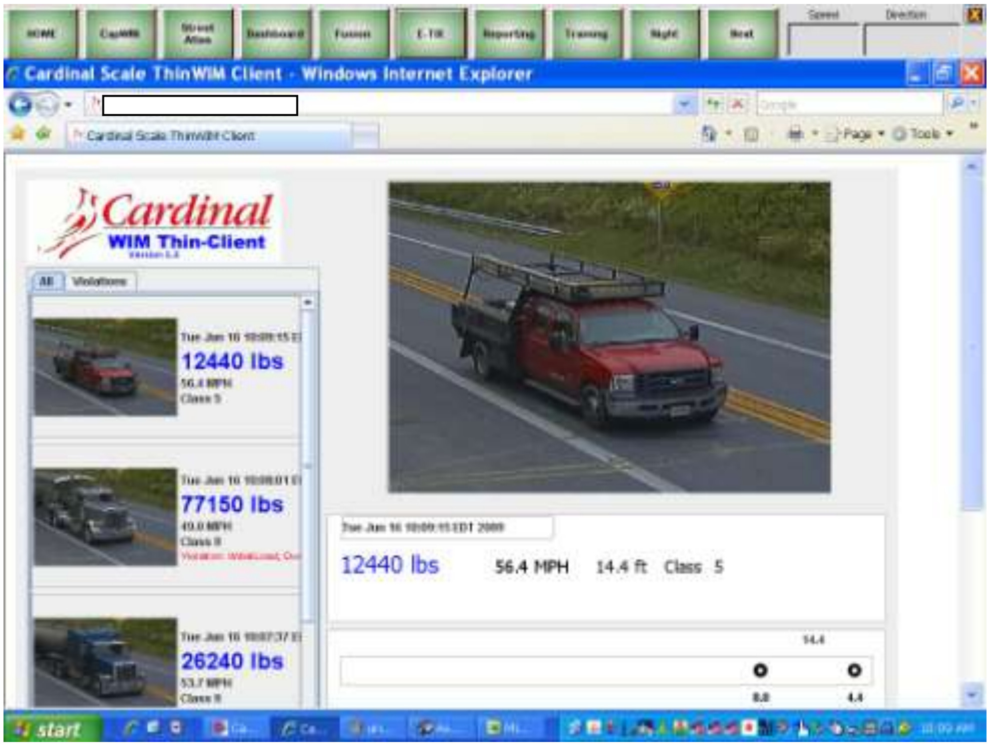



**Figure 45. An Example of CMVs Screened by Visual Cue (Dirty Hub)**

- Milk Trucks

Although milk trucks can apply for an annual special over weight hauling permit with a fixed fee, many milk trucks run overloaded without getting the required permits. During initial Phase II tests, enforcement efforts included the pre-screening of a few milk trucks based on anecdotal evidence of frequent violations as initially observed using the Java thin client. Eventually, targeted enforcement will be performed in conjunction with classification/violation reports which will provide time of day violation clues for law enforcement.


**Figure 46. An Example of CMVs Screened by Visual Cue (Milk Truck)**

- Oversize and Over Weight Signs

  Permits for oversize and over weight vehicles are issued. When vehicles with the ‘oversize load’ signs are observed, MSP-CVED may elect to screen them to verify that they have the relevant permits to travel on Route 32.


**Figure 47. An Example of CMVs Screened by Visual Cue (Over Size Load)**

- Other Visual Cues

  On occasion, MSP-CVED troopers may elect to stop vehicles from other visual cues (e.g. seat belts, etc – this is entirely up to the visual acuity of the trooper performing the initial pre-screening).

### 10.3. Performance of WIM during Phase II Tests

The WIM performance is calculated during Phase II tests to determine if the WIM sensor meets the expected accuracy level for a variety of axle configurations and speeds.

During the period from June $8^{th}$, 2009 to July $8^{th}$, 2009, 85 vehicles were screened. As in the Target Performance defined for the Phase I test, the gross weight is expected to meet 6% accuracy and axle weight is expected to meet 15% accuracy with 95% compliance. The measurement results from the vehicles with ‘unbalanced’ violations are disregarded in this calculation because vehicles with this type of violation do not provide accurate WIM readings.

There are 72 vehicles without unbalanced violations out of a total of 85 vehicles. The results are as follows *(Note: All results are based upon the actual WIM reading, which includes the WIM calibration adjustment factor of -2%)*:

- Gross Weight Error: 6% accuracy requirement was confirmed for 83% CMVs[14]

- Axle Weight Error: 15% accuracy requirement was confirmed for 97% CMVs

Gross weight errors not meeting the 95% confidence level in the ASTM 1318-09 specification for Type III WIMs could be due to a variety of factors:

1. Initial gross weight calibration was performed and a slightly negative calibration adjustment factor (-2%) was applied to the reference weight. This was done to ensure the credibility of over weight gross weights during pre-screening and increase user confidence. Essentially, the trooper relies on the visual weight violations provided by the tool for the purposes of weight pre-screening. It was determined that a slightly negative weight bias would ensure that the trooper could be absolutely sure an over weight condition existed, so the offending vehicle could be inspected for a weight violation. No adjustment factor would be more likely to cause a false alarm for the trooper, thus reducing their confidence level in the practical use of the tool.

2. The portable Haenni scales are calibrated against a reference weight. These scales have their own calibration weight tolerance thresholds. In addition, there is a small weight bias that would need to be considered during the placement of the scales underneath the vehicle for weight enforcement. If the scales are not correctly offset and positioned under each tire, weights could vary. It is impossible to determine this bias, but a correction factor may need to be assumed.

3. It was observed from Phase I tests that CMVs running at higher speeds tended to be weighed lighter than those same CMVs running at the posted speeds.

***Note**: The gross weight calibration adjustment factor needs to be considered for future VWS deployments. We could continue to use this approach, which the troopers seem to prefer, or trim the calibration factor closer to reference calibration level and increase the threshold levels for each of the weight violation criteria [For example, depending on the violation threshold setting, a vehicle weighed by the unadjusted WIM at exactly 82,000 lbs gross weight may be flagged as a potential violator. Using the negative calibration factor, it is not]. Either approach will work. This bias can be discussed further with MSP-CVED for additional deployments.*

The change in gross weight errors observed during Phase II tests can also be used to determine the calibration maintenance period of the WIM. Generally it is expected that the WIM is calibrated every six months.

[14] If we adjust the WIM reading taking the calibration adjustment factor into account, 90% CMVs meet the 6% accuracy requirement.

### 10.4. Summary of Law Enforcement Results

From June 8th, 2009 to July 8th, 2009, 85 vehicles were screened. The results are provided in Table 20.

**Table 20. Summary of Law Enforcement Results during Phase II Tests**

| | **Number of vehicles with violations** | **Percentage of vehicles with violations** |
|---|---|---|
| **Any Violations (Warnings + Citations)** | 59 | 69 (%) |
| **Weight-related Violations (Warnings + Citations)** | 29 | 34(%) |
| **OOS** | 9 | 11 (%) |
| **Violations with Citations** | 38 | 45 (%) |

### 10.5. Inspection Effectiveness

In this report, the inspection effectiveness of a vehicle selection method is defined as follows:

1. The percent of a certain condition (any violations, weight violations and non-weight violations or OOS orders) resulting from CMVs inspected under a vehicle selection method.

   *Inspection Effectiveness (%) = {Number of vehicles with a certain condition resulting from the inspections of vehicles selected by this selection method} / {Number of the inspections of vehicles selected by this selection method} * 100*

2. The percent of high-risk CMVs selected for inspection under a vehicle selection method. The high-risk vehicles are defined as CMVs with an ISS score over 75.

   *Inspection Effectiveness (%) = {Number of vehicles with ISS score over 75 resulting from the inspections of vehicles selected by this selection method} / {Number of the inspections of vehicles selected by this selection method} * 100*

### 10.6. Analysis of Phase II Test Results

The following selection methods are considered in this analysis – "Random" and "WIM". The selection method based upon WIM weights alone has two sub-methods – "Over weight" and "Unbalanced Load". These sub-methods are not mutually exclusive in the sense that some vehicles may be selected because of their over weight and unbalanced load condition. Other selection methods described before are not considered in this analysis because it was undetermined if MSP-CVED officers could use visual cues and WIM-based data in order to pre-screen a vehicle. Hence, any selection that could have used a combination of visual cues and other non-violation criteria is categorized as "Random".

*10.6.1. Inspection Effectiveness for Detecting Violations and OOS*

Inspection effectiveness for each selection method is calculated and presented in Table 21. This is based on a very limited sample set, and results may vary widely with a larger sample set.

**Table 21. Inspection Effectiveness by Selection Method**

| Vehicle Selection Method | Number of Vehicles Selected for Inspections | Vehicles with Any Violations (Warnings + Citations) | | Vehicles with Weight Violations (Warnings + Citations) | | Vehicles with OOS | | Vehicles with Citations | |
|---|---|---|---|---|---|---|---|---|---|
| | | Number | Percent (%) | Number | Percent (%) | Number | Percent (%) | Number | Percent (%) |
| **Random** | 46 | 26 | 57 | 5 | 11 | 7 | 15 | 12 | 26 |
| **WIM** | 39 | 33 | 85 | 24 | 62 | 2 | 5 | 26 | 67 |
| **Over weight** | 28 | 24 | 86 | 10 | 71 | 1 | 4 | 20 | 71 |
| **Unbalanced** | 13 | 10 | 77 | 4 | 31 | 1 | 8 | 6 | 46 |

***Note:*** *"over weight" and "unbalanced" are sub-methods of "WIM". They are not mutually exclusive methods since a CMV can trigger an over weight violation and unbalanced condition at the same time.*

In detecting violations, the WIM selection method outperforms the Random selection method. In detecting any types of violations, the inspection effectiveness of WIM is better than that of Random by 28%. In detecting weight violations, the inspection effectiveness of WIM is better than that of Random by 51%. However, in detecting OOS conditions, the inspection effectiveness of Random is better than that of WIM by 10%, but it is noted that the sample size of vehicles with OOS condition is very small – nine cases in total. It is also noted that unbalanced load condition can be an efficient clue for locating vehicles with violations as it achieves 77% inspection effectiveness in detecting any type of violations, and 31% in detecting weight violations which outperforming Random selection methods by 20%.

This result is illustrated in Figure 48.

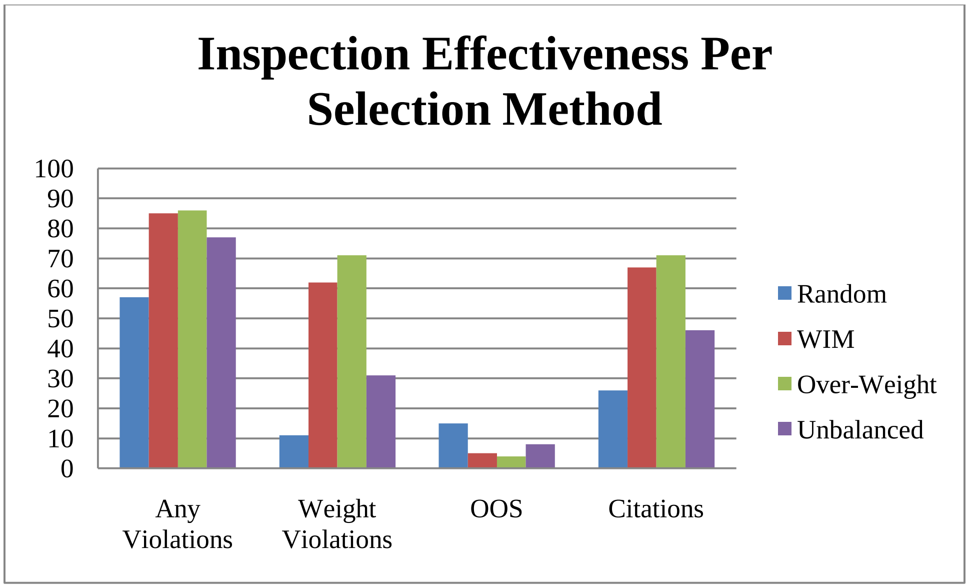



**Figure 48. Inspection Effectiveness per Selection Method**

*10.6.2. Inspection Effectiveness for Detecting High Risk Vehicles*

In (Brown, Anderson, Balducci, Orban, Kiefer, & Desautels, 2009), ISS scores were used to assess the safety risk of vehicles being screened at the static scale. The ISS provides a three-tiered recommendation as shown in

Table 22.

**Table 22. ISS Scores and Recommendations [Source: (Brown, Anderson, Balducci, Orban, Kiefer, & Desautels, 2009)]**

| Recommendation | ISS Inspection Value | Risk Category |
|---|---|---|
| **Inspect** | 75-100 | High |
| **Optional** | 50-74 | Medium |
| **Pass** | 1-49 | Low |

In this test, the ISS score was recorded for each screened vehicle. As in

Table 22, high risk vehicles are defined as vehicles with an ISS score greater than 75. The percentage of high risk vehicles screened by each selection method is calculated. The average and median ISS scores for the vehicles screened by each selection method are also calculated.

It turns out that the methods based upon WIM selection are more efficient in locating high risk vehicles than Random selection. If we take a look at selection sub-methods, it turned out that the WIM-Unbalanced achieves the highest inspection effectiveness which is 69%. Since unbalanced violations are likely to be incurred by a drivers' intentional maneuver, this is a good clue for high risk vehicles (drivers of high risk vehicles are more likely to intentionally avoid passing over the WIM correctly).

**Table 23. Inspection Effectiveness for Detecting High Risk Vehicles**

| | **Number of Vehicles Screened** | **High Risk Vehicles** | | **Average ISS Score** | **Median ISS Score** |
|---|---|---|---|---|---|
| | | Number | Percent | | |
| **Random** | 46 | 20 | 43 | 51 | 46 |
| **WIM** | 39 | 21 | 54 | 57 | 58 |
| **Over weight** | 28 | 13 | 46 | 53 | 41 |
| **Unbalanced** | 13 | 9 | 69 | 67 | 78 |

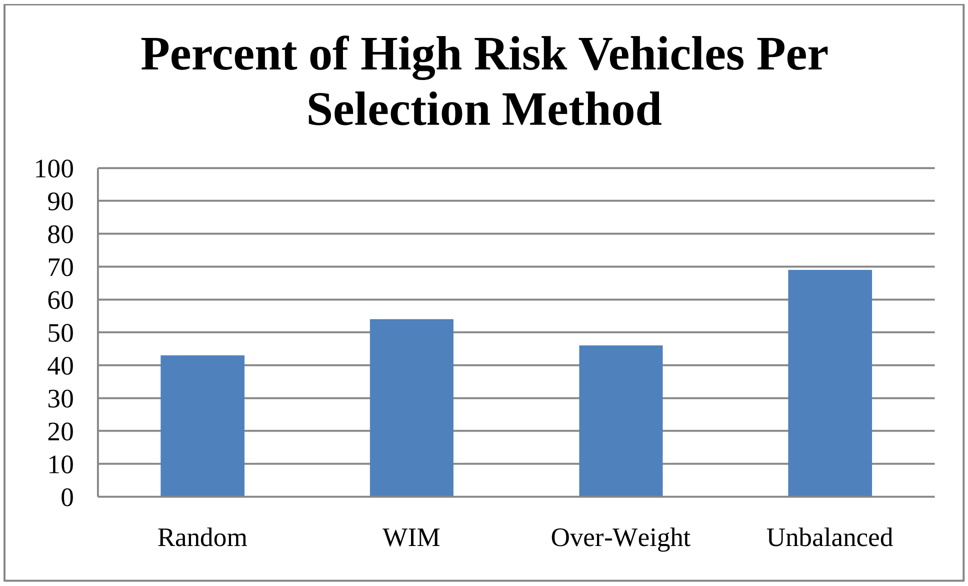


**Figure 49. Percent of High Risk Vehicles per Selection Method**

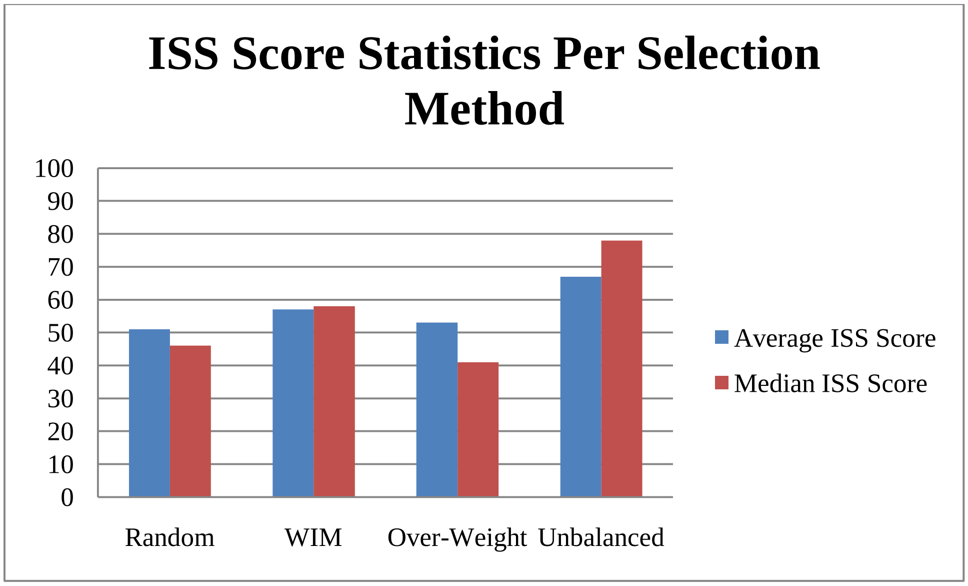



**Figure 50. ISS Score Statistics per Selection Method**

*10.6.3. Correlation Analysis for Violations and OOS*

The correlation analysis for the following pairs has been performed.

- OOS and any violations
- OOS and weight violations
- OOS and non-weight violations
- Weight violations and non-weight violations

In order to perform the correlation analysis, a comprehensive table containing OOS, any violations, weight violations and non-weight violations was built from the inspection results. Each row corresponds to a sample observation (See Table 24). One or zero is entered into each cell of this table. A value of one corresponds to the presence of the condition (OOS or violations) and a value of zero corresponds to the absence of the condition.

**Table 24. A Table for Correlation Analysis**

| Inspection Report Number | Speed | OOS | Any Violations | Weight Violations | Non-weight Violations | Citations |
|---|---|---|---|---|---|---|
| 2546 | 53.8 | 0 | 1 | 0 | 1 | 1 |
| 2547 | 49.9 | 0 | 0 | 0 | 0 | 0 |
| 2548 | 55.4 | 0 | 1 | 1 | 1 | 1 |
| 2549 | 60.1 | 0 | 1 | 1 | 1 | 1 |
| 2550 | 45.4 | 0 | 1 | 1 | 0 | 1 |
| 2551 | 35.6 | 0 | 1 | 1 | 1 | 1 |
| 2552 | 53.3 | 0 | 1 | 1 | 0 | 1 |
| 2553 | 52.2 | 0 | 0 | 0 | 0 | 0 |
| 2554 | 48.2 | 0 | 1 | 1 | 0 | 1 |
| 2555 | 50.9 | 0 | 1 | 1 | 1 | 1 |
| 2556 | 50.5 | 1 | 1 | 0 | 1 | 0 |
| 2557 | 55.4 | 1 | 1 | 0 | 1 | 0 |
| 593 | 58.4 | 0 | 1 | 1 | 0 | 1 |
| 594 | 51.8 | 0 | 1 | 0 | 1 | 0 |
| 595 | 48.3 | 0 | 0 | 0 | 0 | 0 |
| 596 | 50.4 | 0 | 1 | 0 | 1 | 1 |
| 597 | 52.6 | 0 | 1 | 0 | 1 | 0 |
| 598 | 57.2 | 0 | 0 | 0 | 0 | 0 |
| 599 | 52.8 | 0 | 1 | 1 | 1 | 1 |
| 600 | 38.7 | 0 | 1 | 0 | 1 | 0 |
| 2558 | 46.8 | 0 | 1 | 0 | 1 | 0 |
| 2559 | 56.6 | 1 | 1 | 0 | 1 | 1 |
| 2560 | 51.5 | 0 | 1 | 0 | 1 | 0 |
| 2561 | 49.8 | 0 | 1 | 1 | 0 | 0 |
| 2562 | 54.9 | 0 | 0 | 0 | 0 | 0 |
| 2563 | 56.4 | 0 | 1 | 0 | 1 | 1 |
| 2564 | 52.1 | 0 | 1 | 0 | 1 | 0 |
| 2565 | 54.1 | 0 | 1 | 1 | 1 | 1 |
| 2566 | 54.8 | 0 | 1 | 0 | 1 | 0 |
| 2568 | 49 | 1 | 1 | 0 | 1 | 0 |
| 2569 | 44.7 | 0 | 1 | 0 | 1 | 1 |
| 2570 | 50.5 | 0 | 1 | 0 | 1 | 0 |
| 2571 | 52.4 | 0 | 1 | 1 | 0 | 1 |
| 2572 | 49.2 | 0 | 0 | 0 | 0 | 0 |
| 2573 | 58.9 | 0 | 1 | 1 | 1 | 1 |
| 2574 | 59 | 0 | 1 | 1 | 0 | 1 |
| 2575 | 54.1 | 0 | 1 | 1 | 0 | 1 |
| 2576 | 49.7 | 0 | 0 | 0 | 0 | 0 |
| 2577 | 48.1 | 0 | 1 | 0 | 1 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2578 | 52.9 | 0 | 1 | 0 | 1 | 0 |
| 2579 | 50.1 | 0 | 1 | 0 | 1 | 1 |
| 2580 | 49.7 | 0 | 1 | 0 | 1 | 0 |
| 2581 | 56.3 | 1 | 1 | 0 | 1 | 1 |
| 2582 | 50.7 | 0 | 1 | 1 | 1 | 1 |
| 2897 | 53.3 | 0 | 1 | 0 | 1 | 0 |
| 2900 | 52.9 | 0 | 0 | 0 | 0 | 0 |
| 2901 | 55.5 | 0 | 1 | 1 | 1 | 1 |
| 2902 | 52.9 | 0 | 1 | 0 | 1 | 1 |
| 2903 | 46 | 0 | 1 | 0 | 1 | 1 |
| 2904 | 59.2 | 0 | 0 | 0 | 0 | 0 |
| 2908 | 47.6 | 0 | 1 | 1 | 0 | 1 |
| 2909 | 50.7 | 1 | 1 | 1 | 1 | 1 |
| 2910 | 61.6 | 0 | 1 | 1 | 0 | 1 |
| 2911 | 53.5 | 0 | 1 | 1 | 1 | 1 |
| 2913 | 49.8 | 0 | 1 | 1 | 0 | 1 |
| 2915 | 52.8 | 0 | 1 | 1 | 0 | 1 |
| 2916 | 50.3 | 0 | 1 | 0 | 1 | 1 |
| 2917 | 53.8 | 1 | 1 | 0 | 1 | 1 |
| 2918 | 51.1 | 0 | 0 | 0 | 0 | 0 |
| 2919 | 58.9 | 0 | 1 | 1 | 0 | 1 |
| 2923 | 53.4 | 0 | 1 | 1 | 0 | 1 |
| 2925 | 52.6 | 0 | 1 | 1 | 0 | 0 |
| 2930 | 51.4 | 1 | 1 | 0 | 1 | 0 |
| 2932 | 56.5 | 0 | 1 | 0 | 1 | 0 |
| 2933 | 57.2 | 0 | 0 | 0 | 0 | 0 |
| 2934 | 50.2 | 0 | 0 | 0 | 0 | 0 |
| 2935 | 45.8 | 0 | 0 | 0 | 0 | 0 |
| 2936 | 53.9 | 0 | 0 | 0 | 0 | 0 |
| 2939 | 58.6 | 0 | 0 | 0 | 0 | 0 |
| 2940 | 57.4 | 0 | 0 | 0 | 0 | 0 |
| 2941 | 55.4 | 0 | 1 | 0 | 1 | 0 |
| 2984 | 44.1 | 0 | 0 | 0 | 0 | 0 |
| 2985 | 56.3 | 0 | 0 | 0 | 0 | 0 |
| 2986 | 51.8 | 0 | 1 | 1 | 0 | 1 |
| 2987 | 50.3 | 0 | 0 | 0 | 0 | 0 |
| 2988 | 46.7 | 0 | 1 | 1 | 1 | 1 |
| 2989 | 43.1 | 0 | 0 | 0 | 0 | 0 |
| 2990 | 52.6 | 0 | 0 | 0 | 0 | 0 |
| 2991 | 55.2 | 1 | 1 | 0 | 1 | 0 |
| 2992 | 57.1 | 0 | 1 | 1 | 1 | 1 |
| 2993 | 56.3 | 0 | 0 | 0 | 0 | 0 |
| 2994 | 58.6 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2995 | 52.9 | 0 | 0 | 0 | 0 | 0 |
| 2996 | 50.1 | 0 | 0 | 0 | 0 | 0 |
| 2997 | 49.5 | 0 | 0 | 0 | 0 | 0 |

Correlation coefficients and p-values between columns are calculated. The hypothesis that we want to test is, for example, "The correlation between OOS and any violations is significant". If the p-value is smaller than 0.05, we will accept this hypothesis. If it isn't, we will reject this hypothesis.

The results of the correlation analysis are provided in Table 25.

**Table 25. Results of Correlation Analysis for Violations and OOS**

| | **Correlation Coefficient** | **p-value** | **Is Correlation Significant?** |
|---|---|---|---|
| **OOS and any violations** | 0.2284 | 0.0355 | Yes |
| **OOS and weight violations** | -0.167 | 0.1266 | No |
| **OOS and non-weight violations** | 0.3401 | 0.0014 | Yes |
| **Weight violations and non-weight violations** | -0.0829 | 0.4506 | No |

The OOS condition and any violations also have a positive correlation and the level of correlation is significant. However, no correlations are observed for other pairs. Negative correlation is observed between OOS and weight violations. Thus, in the scope of this limited sample size, there appears to be no correlation between weight and safety. Weight violations and non-weight violations also have a negative correlation. Since the sample size is very small, these results need to be interpreted taking this limit into account. They may vary significantly with a much larger sample size.

A possible explanation for not observing correlations between the weight violations and the OOS is that level 2 inspections were performed during Phase II tests. Level 2 inspections are not comprehensive inspections of brakes and other mechanical or service conditions which may result in unsafe CMV conditions, thus leading to an OOS violation. Based on 2008 VOLPE data for vehicle violations based on Level 1 inspections, approximately 30% of the top vehicle violations, including brake defects, resulted from a condition not evident in Level 2 inspections. Hence, performing additional Level 1 inspections in a larger, well controlled study with an emphasis focused on brake violations could show a correlation between weight and safety. Looking at gross weight violations may be valuable as these are less likely to be indicative of an inadvertent loading condition and more indicative of an intentional violation that potentially indicate additional violations.

*10.6.4. Correlation Analysis for Speed*

Correlation analysis for speed has been performed to examine if any dependency between speed and inspection results (e.g. speed and weight violations) exists. This is to examine if weight violations are more frequent with high-speed vehicles. According to this analysis, no observable correlation between speed and inspection results exists. As in correlation analysis for OOS and violations (Table 25), these results need to be interpreted accordingly, considering the small sample size. The results of correlation analysis are provided in Table 26.

**Table 26. Results of Correlation Analysis for Speed**

| | **OOS** | **Any Violations** | **Weight Violations** | **Non-weight Violations** |
|---|---|---|---|---|
| **Correlation Coefficient** | 0.0737 | -0.0188 | 0.0885 | -0.0861 |
| **p-value** | 0.5029 | 0.8644 | 0.4205 | 0.4331 |
| **Is Correlation Significant** | No | No | No | No |

*10.6.5. Drift Analysis*

After the WIM was initially calibrated on April 14th, 2009 the WIM accuracy was evaluated during Phase I (May 28th, 2009) and Phase II (from June 8th, 2009 to July 8th, 2009) tests. The average error, average deviation and compliance level are calculated to see if any system drift is present. The gross weights are used to perform this drift analysis since axle weights and lengths were not measured every time. *(Note: All results are based upon the actual WIM reading, which includes the WIM calibration adjustment factor of -2%)*

The result is provided in Table 27.

**Table 27. Results of Drift Analysis**

| | Date(s) | Number of Samples | Average Error (%) | Mean Deviation (%) | Compliance Level (%)[15] |
|---|---|---|---|---|---|
| **Calibration** | April 15th, 2009 | 13 | -1.55 | 1.35 | 100 |
| **Phase I Tests** | May 28th, 2009 | 19 | -3.57 | 1.22 | 95 |
| **Phase II Test** | June 8th, 2009 to July 8th, 2009 | 72 | -3.15 | 2.33 | 83 |

The trend of change in average errors, mean deviations and compliance levels is provided in Figure 51 and Figure 52.

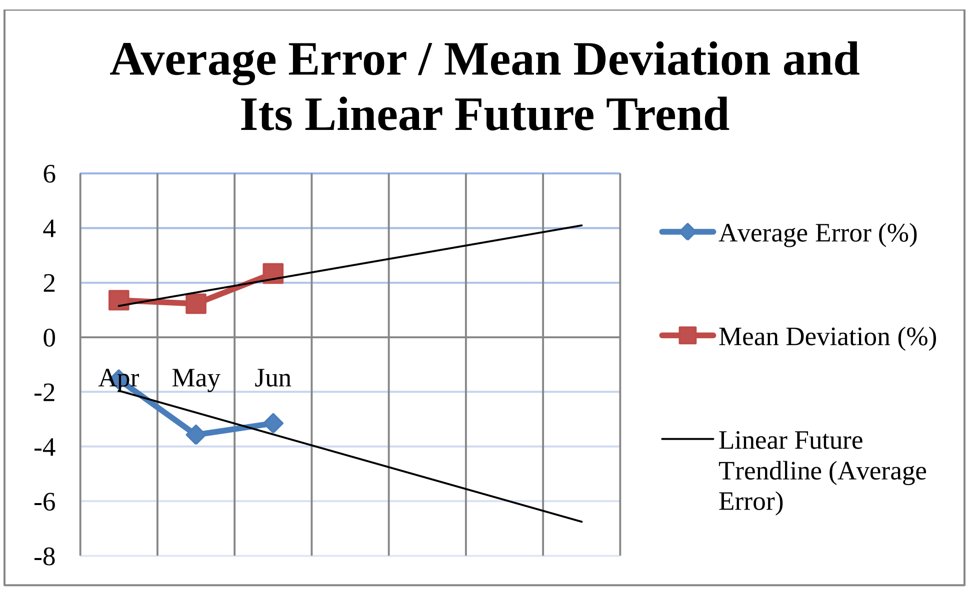



**Figure 51. Average Error / Mean Deviation and Its Linear Future Trend**

[15] Percentage of samples meeting accuracy level of 6%.

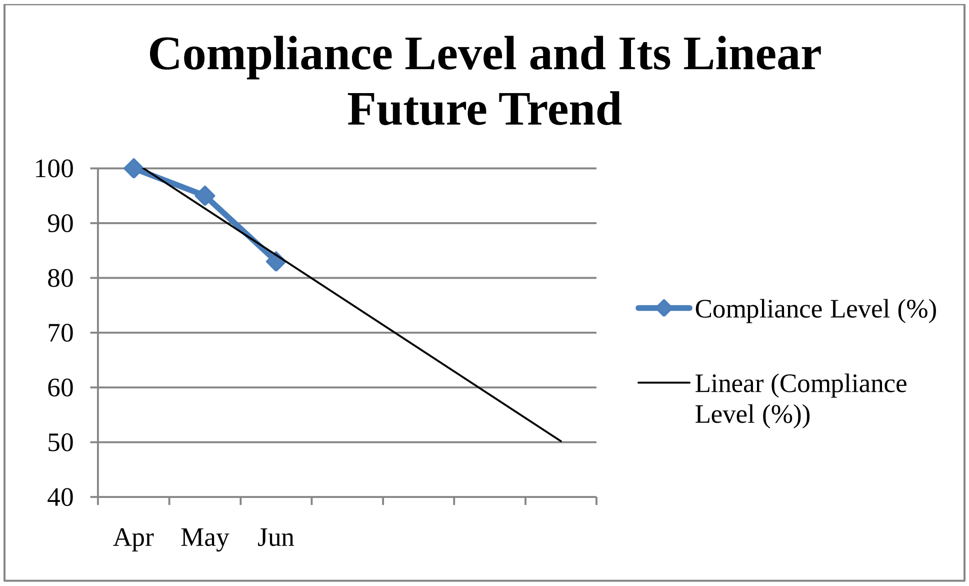



**Figure 52. Compliance Level and Its Linear Future Trend**

During these tests, it is observed that WIM accuracy is affected by the choice of test CMVs. Since CMVs used for calibration process and Phase I tests are not identical, and an uncontrolled (i.e., random) collection of CMVs were selected for Phase II tests, in addition to small sample size, there is a limit in performing the drift analysis.

As expected, the accuracy level achieved during the calibration process was the best. While the average error is smaller during Phase II tests compared to Phase I tests, the mean deviation and the compliance level of the Phase I test are better than those of Phase II tests. Although this may imply a drift in WIM, calibration, it cannot be stated conclusively due to the small sample size. In Figure 51, it is implied that the WIM may need to be calibrated every six months since its linear future trend predicts that it will reach about - 6% average error. Even with a small sample size, this relates well with the conclusion that other states have reached, implying that a high speed WIM (such as the Kistler Lineas sensor) needs to be calibrated once every six months. The weights generated by properly calibrated and certified portable scales can be used regularly to gauge the calibration and the drift.

## 11. CMV STATISTICS AT THE PILOT VWS

One of the important advantages obtained at the Pilot VWS location is its ability to monitor the traffic seven days a week twenty four hours a day. The statistics for the period from May 24th, 2009 to June 6th, 2009 is provided. This period was selected since there have not been any interruptions in the operation of the pilot VWS during this period spanning two weeks.

The total traffic volume per week is about 78,000. 93% of the total traffic is by Class 2 vehicles, and 7% of the traffic is by vehicles Class 3 and above. The traffic volume by class for two weeks is provided in Figure 53. The traffic volume by Class 3 and above is provided in Figure 54. Class 5, Class 7 and Class 9 have more traffic on Route 32 (each with more than 1,200 per week).

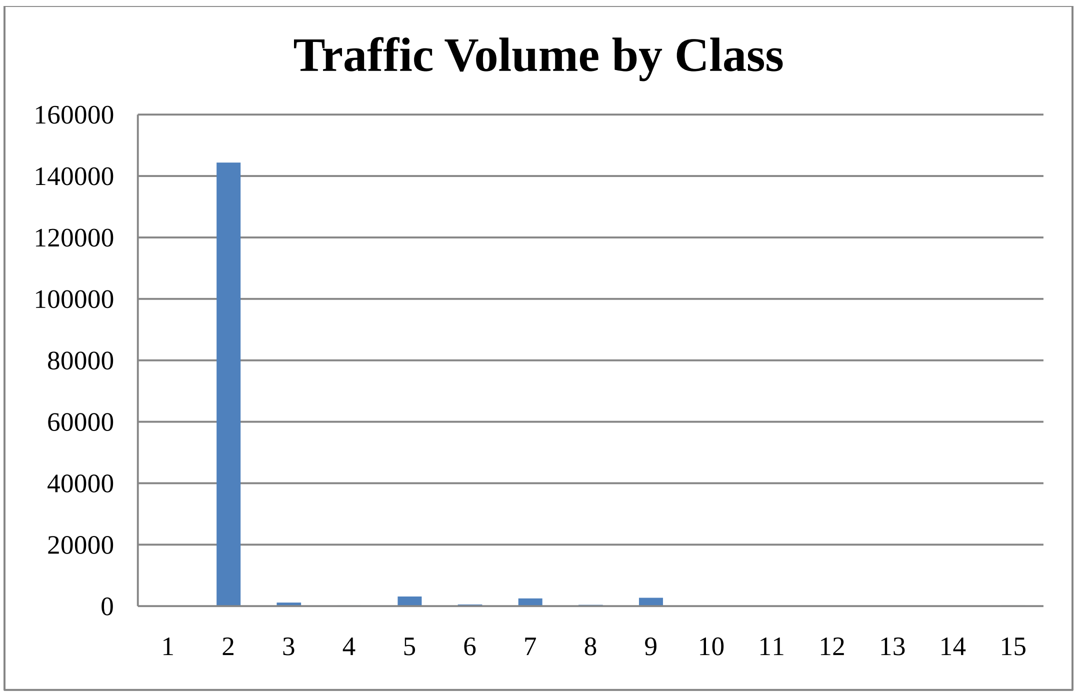



**Figure 53. Traffic Volume by Class**

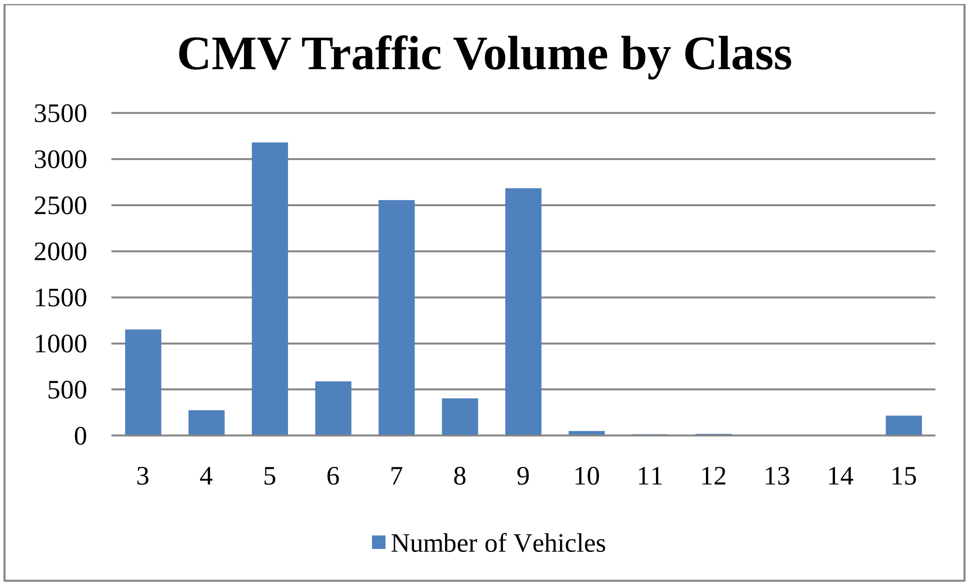
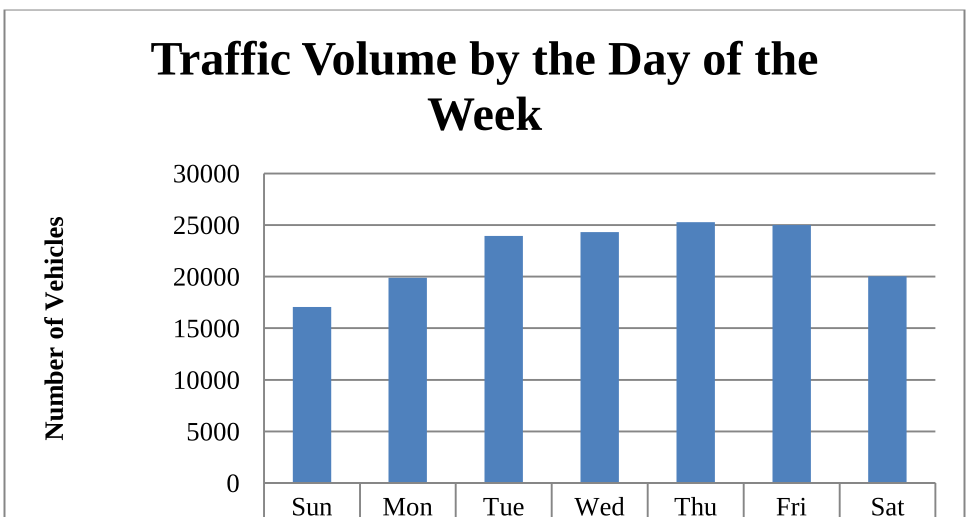



**Figure 54. CMV Traffic Volume by Class[16]**

Traffic volume by day of the week is provided in Figure 55. During weekdays, traffic volume is about the same except on Monday. Contrary to popular belief, the traffic volume on Fridays is at least as heavy as any day between Tuesday and Thursday. The least amount of traffic is on Sunday. This trend is consistent even though only vehicles with Class 3 and above are counted (See Figure 56).




| | Sun | Mon | Tue | Wed | Thu | Fri | Sat |
|---|---|---|---|---|---|---|---|
| Number per Day | 17047 | 19870 | 23938 | 24322 | 25282 | 24990 | 20050 |

**Figure 55. Traffic Volume by the Day of the Week**

[16] Class 3 and above are roughly regarded as CMV in this figure.

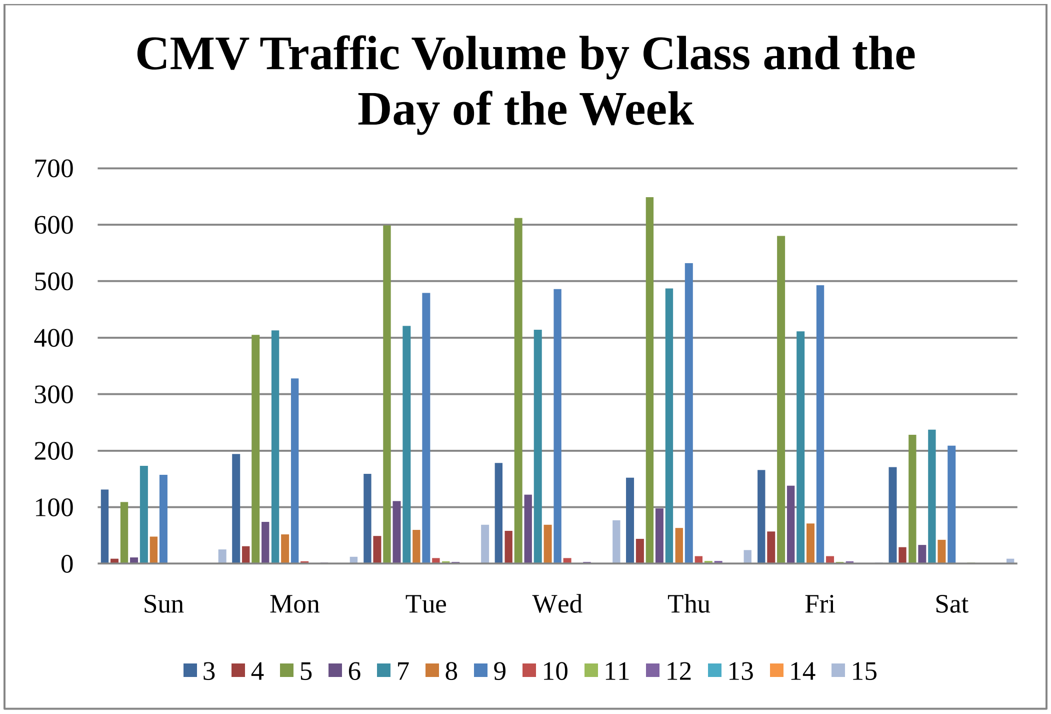
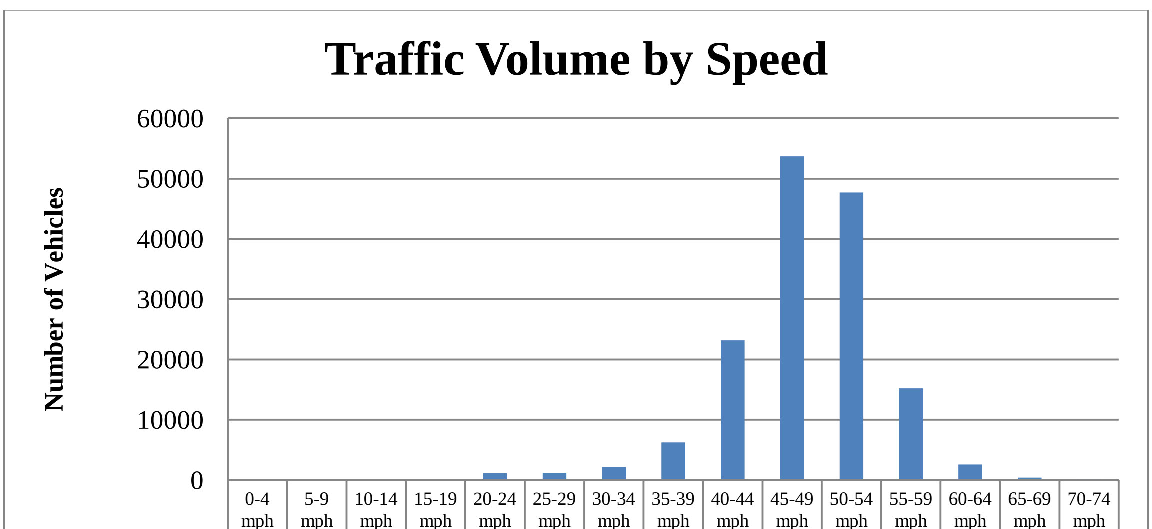



**Figure 56. CMV Traffic Volume by Class and the Day of the Week**

Most vehicles on Route 32 run between 45 mph to 54 mph. This data is provided in Figure 57.




| | 0-4 mph | 5-9 mph | 10-14 mph | 15-19 mph | 20-24 mph | 25-29 mph | 30-34 mph | 35-39 mph | 40-44 mph | 45-49 mph | 50-54 mph | 55-59 mph | 60-64 mph | 65-69 mph | 70-74 mph |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Vehicles | 0 | 0 | 0 | 70 | 1148 | 1213 | 2161 | 6242 | 23152 | 53715 | 47706 | 15214 | 2605 | 423 | 125 |

**Figure 57. Traffic Volume by Speed**

Rush hour on Route 32 is between 6AM to 9AM according to the data in Figure 58. However, it is noted that if Class 2 vehicles are discarded, the CMV traffic volume seems fairly constant between 6AM to 4PM (See Figure 59). The time for target inspection can be selected considering this observation.

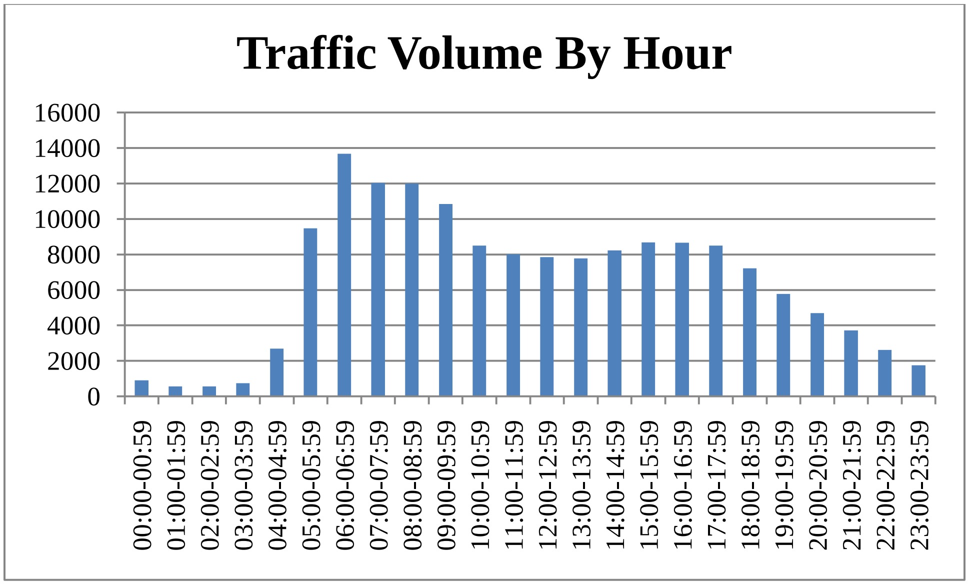



**Figure 58. Traffic Volume by Hour**

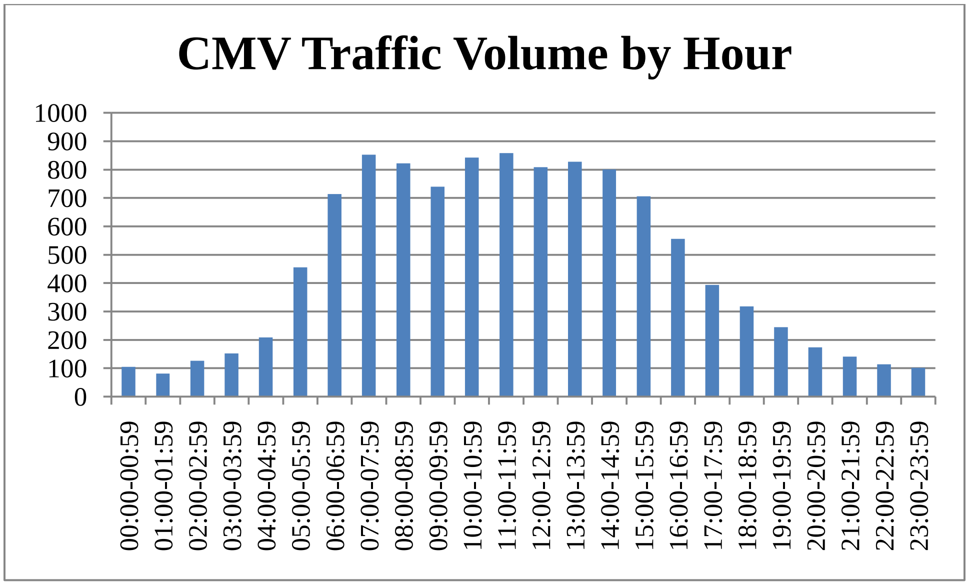



**Figure 59. CMV Traffic Volume by Hour**

# 12. GENERAL GUIDELINES FOR FUTURE DEPLOYMENTS AND INSPECTIONS

## 12.1. Site Selection

The factors discussed in the section 3 should be taken into consideration:

- Appropriate surface topology and elevation

  It is widely known that if the site conditions are not ideal, the system performance degrades by a significant factor. Therefore it is suggested to choose a potential bypass site with proper travel lane surface topology and elevation.

  ASTM E 1318-09 Standard (ASTM International, 2009) provides requirements for the site. According to this standard,

  - the roadway lane for 200 ft (60 m) in advance of and 100 ft (30m) beyond the WIM-system sensors shall have a radius not less than 5700 ft (1.7 km) measured along the centerline

  - longitudinal gradient of the road surface for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM system sensors shall not exceed 2 %

  - The cross-slope (lateral slope) of the road surface for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall not exceed 3 %

- Proximity to available AC power

- Proximity to cell tower

  Verizon Wireless provides a comprehensive radio coverage map (Verizon Wireless). Other telecommunications companies are also providing similar radio maps. It is suggested to check the radio map of the proposed site to decide if cellular technology is appropriate for the proposed location.

  For our purposes, we verified that EVDO provided good bandwidth coverage at the Route 32 location.

- Availability of a safe and effective pull-off site.

## 12.2. WIM Sensor

- It is suggested that we calibrate the WIM sensor every six months.

  Even though we had a limitation in performing the drift analysis (small sample size), the analysis implies that WIM sensors need to be calibrated every six months. The weights generated with the certified portable scales by MSP troopers can be used regularly to gauge the calibration and the drift. Depending on this result, the calibration period can be adjusted appropriately.

- An appropriate test calibration vehicle with all axles touching the ground sufficiently is recommended. This is critical when it is running over the WIM during the calibration process.

  When we performed initial calibration, we had a problem with the test vehicle from Advanced Scale. The main problem was that the lift axle was not completely touching the ground or the lift axle was raised. Thus we had to drop some test results. In order to avoid this kind of problem, the choice of test calibration vehicles is important.

- Care should be taken to ensure that the WIM sensor cables are offset for the inside and outside sensor during the installation. In addition, the WIM sensor cables should not be allowed to ‘float’ during the application of epoxy. This may result in premature cable wear and cause a complete and catastrophic premature loss of the WIM sensor.

## 12.3. Camera

- Since the camera cannot be configured remotely, the angle, frame and images should be confirmed during the initial setup of the camera. Thoughtful consideration of the operational requirements at individual sites may need to be made in order to select the best camera for our needs.

## 12.4. IR

- Beam width and angle of the IR have to be configured carefully at every individual site. During the installation of the IR illuminator at the pilot VWS, it has taken an inordinately long time for the vendor to determine the right illuminator for our application. A sample image (Figure 60) with appropriate set-up and a sample image (Figure 61) with IR issues are provided. With proper IR settings, distinctive features of CMVs are recognizable even during night time.

- In order to recognize CMV distinguishing features during night time, it is suggested we capture a larger side view of the CMV. To accomplish this, a software time delay of approximately 60-70 milliseconds needs to be added to the camera image capture after this function is triggered by the loop detector, so the image is delayed and better use of the full image frame can be accomplished. We have completed evaluating the quality of night time images with a variety of delay settings to determine if this approach is effective.

- If one IR illuminator does not provide enough visibility during night time, another IR illuminator can be installed to enhance the visibility.

**Figure 60. A Sample Image with Appropriate IR Settings**

**Figure 61. A Sample Image with IR Setting Problems**

## 12.5. Loop Detector

- The appropriate sensitivity level of the loop detector has to be determined at the site.

  If the level is too low, it may not detect the presence of some vehicles. If the level is too high, it may be activated by the traffic traveling in the adjacent lane. It is recommended to check if images with no vehicles (or vehicles traveling in the opposite direction) appear frequently. If so, it is recommended to lower the sensitivity level.

  The pilot VWS uses sensitivity level four for the loop detector. Note that this sensitivity level will vary with individual locations.

## 12.6. Cell Router and Cell Antenna

- The cell router should be configured such that the thin client can access the server at the router's external IP address. The administration page of the cell router should be accessible by using a specific port number (e.g. http://166.143.28.250:2080). This allows router pass through with a secure username and password configuration that allows access to the application only.

- The wire connecting the cell antenna should be routed and covered properly, perhaps by a threaded metal conduit that completely covers the wire. The antenna cable installed at the pilot VWS uses a drip loop configuration; however, during periods of heavy wind and inclement weather, it may be subject to wear and tear and may eventually degrade or breakaway from the antenna structure, resulting in cell connectivity loss at the site.

**Figure 62. Antenna Cable Routing at the Pilot VWS**

### 12.7. WIM Thin Client

- During peak hours of voice traffic, we may experience images being dropped from the telecommunication networks even though the images are stored at the WIM Server (this occurs as a result of cell network priority rules – voice, data, images and video, in that order). In this case, it is suggested we use the last 10 vehicles menu from the report pages of the thin client, if activity needs to be observed.

- It is suggested that no more than two or three thin clients are active at the same time. When there are too many clients connecting to the WIM server, images and data may be dropped due to the limitation of cellular bandwidth.

- When multiple clients are connected, running the reporting function on a client may cause the server to stop sending data and images to other clients. Thus it is suggested we use the reporting functions only when there is a single active client, or use the reporting functions outside normal enforcement hours.

- It is suggested we disable the hibernation function of MSP-CVED laptops when the thin client is operating. When the computer goes into hibernation mode, the connection to the server can be lost because the EVDO cell aircard on the laptop goes into dormant mode to conserve power and bandwidth (this is a standard feature of all aircards). In this case, the browser has to be refreshed so that the connection can be established again.

- We need to disable a certain function of the MSP-CVED laptop firewall to use the WIM thin client. Laptops with Sunbelt Kerio personal firewall need the "Enable web filtering" option on the Ad Blocking tab to be disabled.

- It is suggested to add more types of reports such as "count by violations".

### 12.8. Sensor Layout

- The current sensor layout of our pilot VWS is the QWIM following the Loop Detector. (Loop-QWIM). Kistler's publication (Helg & Pfohl), uses two inductive loops, one before each set of sensors. They indicate that the best result was obtained with this layout. At our pilot VWS, we use a single loop before the first set of sensors. Kistler has not suggested using anything different from our current layout. Another layout that can be considered is "QWIM-loop-QWIM" configuration. This configuration is used by some other vendors and in other countries and it may have the potential to decrease the image mismatch rate and classification read problems during stop and go traffic. In this layout, the time that the application has to wait for a current vehicle to clear the configuration is smaller. During the pilot VWS installation, a definitive answer to the appropriate layout was not available. It is suggested that we consider a change to the current layout (Loop-QWIM) as more results from other sources are available.

### 12.9. WIM Server PC

The general guideline for maintaining a PC with Microsoft Windows XP operating system also applies to the WIM Server PC. The general guideline for PC maintenance is, for example, provided in (Langa, 2005).

- It is suggested that we power cycle the WIM server PC once every month during off-hours.

  Some of the software installed on the WIM Server PC could have memory leak problems. When memory leaks exist, memory is unintentionally consumed by computer programs where programs fail to release memory when no longer needed. Thus it is generally suggested to power cycle the PC from time to time.

- It is suggested that we defragment the hard disk once every six months during off- hours.

  Fragmentation of the hard drives may cause system sluggishness and crashes.

- It is suggested we use the Windows' built-in Disk Clean-up tool to recover any wasted space on the hard drive once every six months.

- It is suggested we check if enough (at least 50%) hard drive space is available whenever the PC is power cycled.

- It is suggested we add an extra hard disk for full back up every week. Classification, weight, and image data from the WIM Server PC need to be archived. Due to data restrictions using Verizon's EVDO consumer subscription service, 'over the air' backup and retrieval of the WIM database is not practical. A local hard disk needs to be added in the WIM cabinet (or within the WIM server PC) to enable a complete copy. This copy will also be beneficial if the primary hard disk used in the WIM Server PC were to fail prematurely for any reason.

**12.10. WIM Cabinet**

- It is suggested we use a server rack inside the WIM cabinet in future deployments since a rack is a very practical solution for squeezing a large amount of hardware into a small space. The WIM cabinet currently does not utilize interior installation space efficiently. A rack layout with cables neatly bunched and routed around the rack make a much better and cleaner installation possible, and will also allow more efficient airflow around the components.

- It is recommended we use the I-boot device. This is an IP addressable device that allows quick, remote reboots of devices such as PCs. The solution is inexpensive, and allows remote reboots of devices that could have potentially locked up due to application hangs, operating system issues, etc. It potentially avoids the need to physically go to the site to reboot the PC and/or other devices. http://dataprobe.com/remote-reboot.html

- It is recommended we install a rack mounted keyboard, mouse, and monitor inside the WIM cabinet. If the WIM cabinet is to be made completely self-contained, the WIM Server PC requires a keyboard, mouse and monitor for local diagnostics. The cost of this solution is miniscule compared to the overall benefits. The monitor can be left in a powered-off state, turned on only if local access to the system is required.

### 12.11. Construction

- Proper SHA grounding methodology needs to be followed for future deployments. Grounding at the pilot site is adequate; however it is achieved slightly differently compared to SHA standards for electrical grounding.

- Pull boxes and hand holes should be examined for proper grounding. All sensor and other cable wires need to be neatly looped and stowed.

- Grounding plan should be submitted for review.

- All electrical and cable conduits, especially the WIM cable conduits, need to be examined carefully for water or moisture intrusion. Moisture intrusion in a Kistler WIM sensor is extremely detrimental and will result in premature failure of the sensor.

- WIM sensor cables should not be allowed to ‘float’ during epoxy pour and cure. At the very minimum, they should be at least 1” beneath the traveling road surface to prevent premature damage and sensor failure. WIM sensor and loop epoxy should be examined every six months to ensure there is no premature wear.

- A set of current schematics need to be placed in the WIM cabinet. All cables and patch panels should be properly labeled.

- All conduit entry points into the cabinet should be properly sealed to prevent rodents and other insects/animals from entering the cabinet and damaging sensitive cables and equipment.

- The WIM cabinet air filter should be examined and replaced every six months.

- During Phase II tests, it was noticed that some CMVs tried to intentionally avoid the WIM sensor altogether by running over the shoulder. A curbing system or some other traffic compliance measures may need to be investigated for each VWS location. This investigation is not part of the scope of this study.

### 12.12. Inspection

- As seen from the Phase II test results, inspection effectiveness appears to be best when we use WIM data and visual cues from the images simultaneously. The WIM indications which are not directly relevant to the violations (e.g. unbalanced load) can be excellent clues for over weight, high risk or potentially unsafe vehicles.

- It is suggested that mobile enforcement inspections using the VWS are performed avoiding rush hour since the WIM classifier can be unstable during stop and go traffic.

- It is suggested that between enforcement actions, reports of WIM violations by class, speed, and hour are examined. These reports provide good clues for CMV behavior during certain times of day, or days of the week. Enforcement actions could be tailored for maximum effectiveness during such hours.

- It is speculated that CMV traffic on Route 32 may decrease as operators become aware of the VWS. After the pilot VWS was installed, it has been reported that drivers have figured out there is a new weight pre-screening tool on Route 32. During enforcement actions, it has been observed that certain CMV configurations (such as milk trucks) avoid using Route 32 during the daytime; however violators seem to be prevalent during nights and weekends. It is suggested that the VWS should collect a few months of baseline data before any targeted enforcement actions are put in place to examine CMV behavior during other hours. *Note: Based on two days of SHA gathered traffic count data at station B130102 0.3 miles north of Burntwoods Road (approximately 0.7 miles north of the VWS location), there is no evidence to suggest that traffic counts for commercial vehicles have changed significantly after the VWS was installed; more data is needed.*

- It is suggested to use the VWS to test for appropriate usage of lift axles. There is a potential to use this application for a new NCHRP study. Images and weight information can be clues to determine if the lift axles are being used properly.

### 12.13. Follow up Research Potential

- Follow up studies could include Level 1 inspections by MSP-CVED using a cleaner, well controlled group for random CMV selection. This may help determine a correlation between weight and safety, if it exists. Looking at gross weight violations may be valuable as it is less likely to be indicative of an inadvertent loading condition and more likely to be an intentional violation that could potentially indicate additional violations.

- A larger number of samples need to be considered to determine various correlation results. For the purposes of our study, the number of samples was quite limited.

- The addition of a license plate reader or USDOT reader to augment and enhance the information being provided by the VWS should be considered. This could provide additional benefits to law enforcement to tailor enforcement actions.

## 13. CONCLUSIONS

In this research, a VWS system was constructed at Dayton. This VWS has been in operation since April 2009. It is being utilized by MSP-CVED to assist troopers in effective pre-screening of CMVs on Route 32. During two phases of tests, five sample CMVs provided by SHA and eighty five CMVs on the road were selected for this research. This research, though short-term, has provided the following essential results:

- Improved effectiveness of selection methods over a traditional method relying on random selection.

  - In 2008, 26,112 over weight citations were issued out of 1,646,582 (1.6%) CMVs at thirteen fixed TWIS in Maryland according to (The Motor Carrier Division of the Maryland State Department of Transportation, State Highway Administration, Office of Traffic and Safety, 2009). The WIM based methods are shown to be much more efficient in targeting weight violations. The WIM based method shows inspection effectiveness of 62% in detecting weight violations.

  - The method based upon information from the VWS in determining selections for inspections achieves 5.6 times better inspection effectiveness than random selections in detecting weight violations. WIM based method also provides 1.5 times better inspection effectiveness over random selections in detecting any kinds of violations. It has been observed that the sensor measurements information and the visual information gained from images are useful for target inspection.

  - The WIM based method can target 11% more CMVs with ISS score over 75. Also it is observed that 69% of CMVs with unbalanced violations are high risk CMVs. It is believed that some unbalanced conditions are caused by driver's intentional maneuver to avoid citations.

- Observed correlation between violations and OOS conditions. Weight violations are not observed to be correlated with OOS conditions. However, more research is needed since this result is based upon a very limited number of samples.

- Gathered data on accuracy, reliability and serviceability of Quartz-Sensors as a tool for flexible and quick VWS deployment. It has been shown that the Kistler Quartz Sensors achieve an accuracy level sufficient for effective law enforcement pre-screening of CMVs. During Phase I tests, the pilot VWS meets accuracy levels required by ASTM E 1318-09 standard for gross weights, axle weights and lengths.

- Developed a flexible, cost effective and rapid deployment model for future planned VWS deployments in the state.

- Provided a practical test, calibration and maintenance methodology for the pilot VWS and future planned VWS deployments in the state.

As the first VWS in the state of Maryland, this VWS has been successfully deployed by State Highway Administration in conjunction with the University of Maryland, Cardinal Scale Manufacturing Company and its design is expected to be the predecessor of future VWS deployments in Maryland.

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## APPENDIX A LAYOUT OF MD VWS

See attachments provided separately with this document.

## APPENDIX B CALIBRATION IMAGES

See attachments provided separately with this document.

## APPENDIX C PHASE I TEST IMAGES

See attachments provided separately with this document.

## APPENDIX D CARDINAL WIM READER MANUAL

See attachments provided separately with this document.

## APPENDIX E CARDINAL WIM THIN CLIENT MANUAL

See attachments provided separately with this document.

## APPENDIX F PROXICAST CELL ROUTER MANUAL AND SCREEN SHOTS.

See attachments provided separately with this document.

## APPENDIX G WIM CALIBRATION PROCEDURE

See attachments provided separately with this document.

## APPENDIX H PHASE II TEST IMAGES AND REPORTS

See attachments provided separately with this document.

## APPENDIX I CAPITAL COSTS ASSOCIATED WITH THE PILOT VWS

- VWS equipment and associated installation: $99,041.00
- VWS construction and civil works installation: $153,959.00
- VWS Cellular infrastructure installation: $5,078.00
- VWS Electrical (BGE) circuit installation and provisioning: $7,739.00
- VWS equipment and construction inspection services: $7505.00
- VWS total capital costs: $273,322.00
- VWS Cellular subscription cost (monthly, ongoing): $65.00
- Approximate ongoing maintenance cost (annual budgetary figure): $20,000