Executive Summary

Purpose
This Virtual Weigh Station Demonstration Project was created to advance the concepts developed in the Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan (2005). The fundamental principle behind the Strategic Plan is the belief that better weight compliance will significantly help protect and extend the life of the State’s highway infrastructure. The Strategic Plan laid out a long-range deployment program for promoting commercial vehicle weight compliance across the state. This project developed several key portions of the Strategic Plan and focused heavily on enhancements to existing Weigh-in-Motion (WIM) scales to introduce Virtual Weigh Station functions.

This Project was created with the following goals:

- To complete the network definition of potential future WIM sites
- To demonstrate the features of several brands of WIM controllers and related equipment under field conditions
- To deploy pilot technology at an existing WIM site to resolve the technical and institutional issues of Virtual Weigh Station operations (This goal was expanded)
- To assess the feasibility of a dynamic feedback system

Project Highlights
The project addressed the four goals listed above in several ways as described below.

WIM Site Maps
The network definition task completed the initial layout work that began during the Strategic Plan. Details of the existing sites were collected and mapped to produce handy reference materials for enforcement personnel. This included WIM, inspection site maps and photos.

Equipment Comparisons
The WIM controller features were demonstrated when several brands of WIM controllers were installed and run through their paces. This was done to assess the current state-of-the art features for WIM controllers and to establish a listing of acceptable products that could be used for Virtual Weigh Station (VWS) applications. The list included IRD, ECM, Cardinal and PEEK controllers. All were found acceptable for satisfying basic planning level needs (their original intended purpose) in terms of accuracy and data produced. They were all connected to quartz piezzo weight sensors embedded in the pavement (Mn/DOT’s current standard for all WIM sites.)

During this demonstration process MSP’s roadside weight measurements were successfully used to check and recalibrate the WIM scales. This has significant ramifications in terms of data reliability, detection of WIM problems, and routine calibration costs.

“WIMCAT”
Early in the contract, it became evident the data produced by the WIM controller would need editing to be useful for routine enforcement. To address this issue, the scope was modified to what create became known as the “WIMCAT” (short for Weigh in Motion Compliance Assessment Tool). This new data processing tool creates useful information from raw WIM data about Class 9, 10, and 16 trucks (the most common truck types). The output from this tool includes the following information for any series of daily time periods.

- Hour of the week violation rates
- Hour of the day violation rates
- Excessive Equivalent Single Axle Load (ESAL) results
- An Excessive Load Ratio performance measure
- Odds of capturing a violator
- Several data quality checks

The WIMCAT was deemed to be an important new ingredient in the
Executive Summary

Virtual Weigh Station process because it provides immediate use of existing WIMs for real-time enforcement purposes, and establishes performance measures that can be used to guide the WIM deployment process. It enables many of the functions essential to a weight compliance program and will become the basis for a central operating system for all of the Minnesota WIMs. The “WIMCAT” can be used to recommend optimal hours of the week for enforcement activity and can be used as a basis for estimating the damage caused by overweight vehicles. It also incorporates some very effective data quality filters developed by Purdue University.

VWS Pilot

The WIMCAT was used during the pilot demonstration to show how targeted enforcement and performance monitoring can effectively improve weight compliance on a roadway. During this demonstration officers were scheduled to conduct roadside enforcement during those hours of the week that the WIMCAT showed the highest number of violators. They positioned themselves downstream and monitored in real time the axle and gross weight values as they appeared on the WIM controller. This enabled them to single out those trucks for a detailed roadside inspection without disturbing the majority of compliant vehicles. Initially, the WIM data was only presented to them as a screen on their laptops. Later on, they were also given a digital image of each violating truck along with the WIM data. This improved their ability to single out the suspect vehicles, particularly during high truck volume conditions.

License Plate Recognition Systems

A demonstration of License Plate Recognition Systems was removed from the scope of this contract because a review of available products indicated the current technology has not evolved enough for this application, and invitations to demonstrate their products was declined by the vendors.

Performance Measures Plan

The list of Performance Measures established during the Strategic Plan was refined to produce working level measures. The resulting list of recommended measures includes the following.

- Damage estimates which can also be thought of in terms of potential pavement life extension
- Violation Rates by day of week and hour of the day
- Potential ESAL benefit if all overweight trucks were made legal
- WIMCAT was used to produce several performance measures based on data quality checks developed at Purdue University

Communications Plan

Considerable attention was given to the need for effective communication between the WIM, the Minnesota State Patrol vehicles, and a central processing operation at the Transportation Data Analysis (TDA) section of Mn/DOT. The recommended standard mode of communication is a wireless application based upon a cellular air card or wireless high speed internet service (depending on need and availability of service). In the event that wireless service is not available in remote areas, a decision tree was developed to determine cost effective alternatives for new sites.

Conclusions and Recommendations

This pilot project demonstrated WIM scales can be utilized to provide both planning data and assistance to law enforcement (enabling MSP to optimize their schedules and screen for non-compliant vehicles in real time). Because of these positive results, it is recommended all existing WIM sites be upgraded to Virtual Weigh Stations and additional WIM sites be added to the network as resources become available.
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1.1 Project Scope and Goals

The Minnesota Department of Transportation (Mn/DOT) created a demonstration project to establish a Virtual Weigh Station “starter system” built around the existing Weigh-in-Motion (WIM) site. The project scope required enhancements to the existing WIM to support both the existing (Mn/DOT) planning activities and the Minnesota State Patrol (MSP) weight enforcement functions.

The project scope required the development of performance measures to guide the advancement of the weight compliance program. The project identified key measures to determine cost estimates of the damage from excessively loaded trucks, baseline weight violation rates, and WIM equipment performance. These measures will help Mn/DOT and MSP to focus their resources effectively.

In addition, Mn/DOT commissioned a study to assess the feasibility of a dynamic feedback system that alerts specific truck drivers of their weight status immediately after passing a WIM site. The intent is to promote weight compliance and provide truck drivers with accurate and timely information. (Many truck drivers are often unaware of operating above legal load limits.) If successful, this new equipment could diminish the need for MSP enforcement efforts.

Finally, the original scope of services provided for demonstrations of various Weigh-in-Motion scales, license plate reading and digital imaging equipment for Mn/DOT to understand the potential features of this program.

Early successes and budget increases in the demonstration equipment budget allowed Mn/DOT to meet both the original scope and the accelerated deployment of Virtual Weigh Stations from the **Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan**.

<table>
<thead>
<tr>
<th>Project Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Complete the network definition of potential future WIM sites</td>
</tr>
<tr>
<td>• Demonstrate the features of several brands of WIM controllers and related equipment under field conditions</td>
</tr>
<tr>
<td>• Deploy pilot technology at an existing WIM site to resolve the technical and institutional issues of Virtual Weigh Station operations (This goal was expanded)</td>
</tr>
<tr>
<td>• Assess the feasibility of a dynamic feedback system</td>
</tr>
</tbody>
</table>

1.2 Relationship to Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan

The 2005 **Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan** provided the focus for improving weight compliance in Minnesota. An effective program requires continuous interaction among MSP and Mn/DOT personnel. This project enhanced those relationships and led to a better understanding about how the stakeholders can most effectively interact.

The **Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan** laid out a long-range deployment program for promoting commercial vehicle weight compliance across the state. This demonstration project developed several key portions of the Strategic Plan. It focused on enhancing existing WIM scales to enable another application of these devices to support Virtual Weigh Station functions. The project features are listed as follows.
Introduction

Demonstrations

- Assessment of current state-of-the-art features for WIM controllers
- Digital image capturing systems for covert enforcement
- Live monitoring of several WIM sites by MSP field personnel using laptop computers wirelessly connected to nearby WIM cabinets. (These demonstrations defined the standard components needed to upgrade all future sites.)
- License Plate Recognition Systems were considered, but not demonstrated in this contract. Current technology has not evolved enough for this application.

“WIMCAT”

The digital imaging equipment procurement was canceled due to excessive equipment costs and technical issues. Vendor demonstrations were substituted. The funds for the digital imaging equipment were diverted to create a WIM compliance analysis tool. This new tool, nicknamed “WIMCAT”, was written in Visual Basic. This tool translates the standard output data from the WIM controller into useful reports about Class 9 and 10 truck weight factors for stakeholders’ use of data. The project team found WIMCAT as an important new ingredient in the Virtual Weigh Station process. MSP can use existing WIMs for real-time enforcement purposes. WIMCAT establishes performance measures to guide the WIM deployment process and enables many essential functions to a weight compliance program; thereby, becoming the basis for a central operating system for all of the Minnesota WIMs. MSP can use “WIMCAT” to determine and plan the hours for enforcement activities, as well as estimate the damage caused by overweight vehicles. WIMCAT very effectively incorporates the data quality filters developed by Purdue University.

WIM Site Documentation

The Appendix 6.1 contains maps of the WIM locations and their associated inspection sites for use by MSP personnel working in unfamiliar districts.

Communications System

The project focused attention on developing an effective communication system among the WIMs, the Minnesota State Patrol vehicles, and the central processing operation at Mn/DOT’s Transportation Data Analysis (TDA) section. The recommended communication is a wireless application based on a cellular air card or wireless high speed Internet service (depending on need and availability of service). This approach helps officers to position themselves covertly downstream from the WIM sites. Multiple users can access the system concurrently, thus, eliminating the need for landline dial-up service. If wireless service is not available in remote areas, a decision tree was developed to determine cost effective alternatives for new sites.
2.1. Pilot Network Definition

The Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan mapped the existing and proposed WIM sites. Figure 1 represents the current state of deployment. This project expanded the list by including details of the inspection sites associated with each WIM site (Appendix 6.1).

2.1.1. WIM Site Map

Figure 1. Current Deployed WIMS
2.1.2. WIM Inspection Site Map Matrix

Identify and document suitable inspection sites to fully utilize the enforcement potential of each WIM location. Table 2-1 lists the details for each WIM site. Appendix 6.1 contains the map, individual site descriptions, photos and notes for each location. The individual site maps are intended as a tool to provide enforcement personnel WIM site locations coupled with the suggested inspection areas.

<table>
<thead>
<tr>
<th>WIM Location</th>
<th>Site</th>
<th>Mile Post</th>
<th>Enforcement Direction</th>
<th>Mn/DOT District</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 53</td>
<td>WIM Scale</td>
<td>42.1</td>
<td>NB and SB</td>
<td>1 – Duluth</td>
</tr>
<tr>
<td></td>
<td>NB Inspection</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 61</td>
<td>WIM Scale</td>
<td>16</td>
<td>EB and WB</td>
<td>1 – Duluth</td>
</tr>
<tr>
<td></td>
<td>NB Inspection</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection</td>
<td>CR 50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 2</td>
<td>WIM Scale</td>
<td>8</td>
<td>EB and WB</td>
<td>2 – Bemidji</td>
</tr>
<tr>
<td></td>
<td>EB Inspection</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB Inspection</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 2</td>
<td>WIM Scale</td>
<td>92</td>
<td>EB and WB</td>
<td>2 – Bemidji</td>
</tr>
<tr>
<td></td>
<td>EB Inspection</td>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB Inspection</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 94</td>
<td>WIM Scale</td>
<td>198</td>
<td>WB</td>
<td>3 – Brainerd</td>
</tr>
<tr>
<td></td>
<td>EB Inspection</td>
<td>195</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EB Inspection Alt.</td>
<td>195</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 35</td>
<td>WIM Scale</td>
<td>30</td>
<td>NB and SB</td>
<td>6 – Rochester</td>
</tr>
<tr>
<td></td>
<td>NB Inspection</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection</td>
<td>179 (TH 30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection Alt.</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 60</td>
<td>WIM Scale</td>
<td>65</td>
<td>EB</td>
<td>7 – Mankato</td>
</tr>
<tr>
<td></td>
<td>EB Inspection</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection</td>
<td>30.5 (TH 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 212</td>
<td>WIM Scale</td>
<td>78</td>
<td>EB and WB</td>
<td>8 – Willmar</td>
</tr>
<tr>
<td></td>
<td>EB Inspection</td>
<td>82</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WB Inspection</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH 23</td>
<td>WIM Scale</td>
<td>122</td>
<td>NB and SB</td>
<td>8 – Willmar</td>
</tr>
<tr>
<td></td>
<td>NB Inspection</td>
<td>128</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SB Inspection</td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1.3. Communications Plan

The Communications Plan is built around the basic concepts developed in the Minnesota Statewide Weight Compliance Strategic Plan (2005). A number of the objectives developed in the Strategic Plan are highly dependent upon the stakeholders’ ability to routinely make numerous communication transactions, along the paths shown in Table 3.

As simple as these paths appear, several complex issues must be resolved when considering how to produce a practical, robust and affordable system on a statewide basis. These include such factors as availability of service, bandwidth, monthly service charges, communications standards, end users’ skill sets, simultaneous access to the controller data, and several others. In addition, there are several forms of communication available, each with their own advantages and disadvantages.

A comprehensive analysis of these options began with an understanding of how dual use WIM communications had previously been accomplished during previous experiments in Minnesota by State personnel. This review, coupled with input from several communications engineers, led to a recommended standard configuration suitable for most future WIM sites. A decision tree was then created to identify an appropriate configuration for non-standard sites. See Appendix 6.8.

This report addresses optional communication architectures supporting either local VWS (the current arrangement) or centralized operations (as described in the Mn/DOT Statewide Commercial Vehicle Weight Compliance Strategic Plan, 2005). “Communications architecture” is a term that describes a framework of system components in terms of their functionality and relationships to each other. This includes details about the various information flows that must occur between the elements in the system. Architecture does not specify technologies; only the functions the equipment must satisfy. This architecture serves to define the equipment specifications and dimensions while maintaining a competitive procurement process or flexibility to adapt to newer technologies. The material covering the architecture options are also presented as reference material in Appendix 6.8.

The bulleted list below presents key Strategic Plan objectives dependent upon electronic communications and defines the origin and destination of each type of transaction.

### VWS Objectives

- Maintaining current planning data functions of the WIM sites
- Enabling Minnesota State Patrol (MSP) to use data in real-time to covertly establish probable cause for a suspect vehicle
- Enabling MSP to identify problem areas so they can optimize their enforcement scheduling
- Enabling Mn/DOT to produce realistic estimates of pavement damage caused by illegally loaded trucks

### Communications Paths

- Cabinet to Mn/DOT Central
- Cabinet to MSP vehicle
- Cabinet to MSP Districts
- Mn/DOT to MSP
- Cabinet to Mn/DOT Central

In 2005, the Strategic Plan brought several state agencies and Mn/DOT functional areas together to focus on the need for enhanced weight compliance in Minnesota. To be effective, a comprehensive project like this requires continuous interaction between MSP and Mn/DOT.
Communications Plan

personnel. This project enhanced those relationships by building a better understanding about how stakeholders can most effectively interact.

**Current Practice**

The current practice utilized by MSP for Virtual Weigh Station enforcement is to use an air card in their enforcement vehicle. This connects to the controller in the WIM cabinet via cellular connection (on the vehicle side) and land line (on the cabinet side). The MSP officer’s laptop utilizes standard HyperTerminal software available on most laptops. Mn/DOT’s Transportation Data Analysis (TDA) section shares the dial up line and only one user can be connected at a time. Slow communication speed through the air card is the most significant limitation of this approach. This type of system does not support digital or video images, so the officer must be within sight distance of the WIM to distinguish the non-compliant trucks from the others in the stream of traffic. The benefits of this approach are low initial costs with modest monthly service fees and easier maintenance.

**Recommended Standard Configuration**

The recommended standard configuration satisfies the immediate needs of localized operation at each WIM site yet, can be easily modified to handle centralized operation in the future. This report recommends the standard configuration to be cellular broadband service for both the vehicle and cabinet. This would then become the standard for every new site, unless circumstances dictate a more unusual configuration. Basic operation would not include digital imaging. However, cellular broadband would support the higher throughput demand required if the site is upgraded. This configuration would simply utilize a wireless Internet modem replacing the air card in the vehicle and a second wireless Internet modem to replace the land line telephone connection in the cabinet. A separate server or website is not required for this configuration. This arrangement will be slightly more expensive than the air card/landline configuration in current use. These fees will be offset significantly by the savings from reduced landline monthly service charges. TDA and MSP would share the connection. Also, the arrangement makes site selection more flexible because landline service is sometimes difficult to arrange in rural areas. The primary benefit for this configuration is the potential for support of future digital imaging or slow scan video described below. Details are presented in Table #1.

**Digital Image Enhancement**

A digital imaging option is recommended for those locations experiencing considerable enforcement activity or in locations where the officer cannot position the enforcement vehicle within sight distance of the cabinet, for safety reasons. Everything else is similar to the recommended standard configuration above. The optional digital camera would be connected to a field grade computer in the cabinet. This computer then merges the digital image with the vehicle parameters generated by the WIM to produce a report available to the officer downstream on his laptop. The camera image can be triggered by optional strategies such as the WIM itself, a laser rangefinder or other form of detection. The arrangement also
supports slow scan video, providing the MSP officer with several images of each suspect truck.

**Custom Configuration**

For those areas unable to receive cellular broadband, a custom configuration will be required. Local conditions would dictate specific requirements, and choices can be made according to the two decision trees documented in Appendix 6.8.

**Centralized Configuration**

When Minnesota’s Commercial Vehicle Weight Compliance Program advances to include a Central Operating System, then each WIM site configuration will need to be modified to communicate with a central server/website. A Central Server continuously collects, processes and stores data from all the WIM sites using mostly automated processes. This enables a large system to be practical and affordable. It also enables useful new features such as routine performance measure reports to be created. With a centralized system, all authorized users (TDA, MSP and anyone else Mn/DOT authorizes) could access data from the website independently and simultaneously for a wide variety of purposes and applications.

---

**Table #1, Communication System Options**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Current Practice</th>
<th>Recommended Configuration</th>
<th>Custom Configuration</th>
<th>Centralized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Without Imaging</td>
<td>With Imaging</td>
<td></td>
</tr>
<tr>
<td>Cabinet to Mn/DOT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dial Up</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Location Specific</td>
</tr>
<tr>
<td>Cellular Service (Air Card)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Location Specific</td>
</tr>
<tr>
<td>Cellular Broadband</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Location Specific</td>
</tr>
<tr>
<td>Cabinet to Vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellular (Air Card)</td>
<td>Yes, at some locations</td>
<td>No</td>
<td>No</td>
<td>Location Specific</td>
</tr>
<tr>
<td>Cellular Broadband</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Location Specific</td>
</tr>
<tr>
<td>Digital Imaging</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Optional</td>
</tr>
<tr>
<td>Slow Scan Video</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Optional</td>
</tr>
<tr>
<td>Dual Access</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Simultaneous Access</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Communications Plan

Table #1, Communication System Options

<table>
<thead>
<tr>
<th>Feature</th>
<th>Current Practice</th>
<th>Recommended Configuration</th>
<th>Custom Configuration</th>
<th>Centralized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Without Imaging</td>
<td>With Imaging</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Low cost</td>
<td>Supports imaging and video</td>
<td>Enables covert enforcement</td>
<td>Enables simultaneous viewing</td>
</tr>
<tr>
<td></td>
<td>Simple maintenance</td>
<td>Simple maintenance</td>
<td>Allows safer vehicle staging</td>
<td>No downloading of data required by end user</td>
</tr>
<tr>
<td></td>
<td>Modest cost</td>
<td>Website not required</td>
<td></td>
<td>Enables automated report generation</td>
</tr>
<tr>
<td></td>
<td>Eliminates need for land line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Does not support imaging</td>
<td>May not be available everywhere</td>
<td>Higher initial costs</td>
<td>Higher development costs</td>
</tr>
<tr>
<td></td>
<td>Officer must have line of sight to cabinet</td>
<td></td>
<td>Higher maintenance costs</td>
<td></td>
</tr>
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<td></td>
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</tbody>
</table>

WIM Vendor Options

Another consideration for the digital imaging portion of this project involves a review of off-the-shelf solutions available from qualified vendors. At the time this report is being written, only two vendors, IRD and Mettler-Toledo have available WIM imaging products. The following is a brief discussion of each of these vendor supplied systems:

**Mettler-Toledo**: The Mettler-Toledo system uses a standard WIM Controller to collect the scale data. The WIM Controller data is then passed on to a hardened PC running Windows XP. This PC processes the data, controls the camera actuation, and provides the appropriate communications interface. The Mettler-Toledo system supports both serial and Ethernet interfaces, which allows it to support any type of communications equipment. Furthermore, this system is capable of displaying the data and vehicle image as a web page either at the WIM site or at the Central location. One benefit of having a separate hardened PC for post processing and image capture is it allows easy upgrades to existing WIM stations, regardless of WIM controller manufacturer. Another benefit of this approach is it enables additional devices to be added to the system, such as: speed monitoring, infrared tire/wheel temperature monitoring, and acoustic devices that expand the usefulness of the VWS site.

**International Road Dynamics (IRD)**: The IRD system is built into their WIM controller which processes the data, controls the cameras, and provides web pages from a single device. This produces a simpler cabinet installation, except limits flexibility For
Communications Plan

As time goes on, it is expected other vendors will develop similar solutions. Therefore emphasis should be placed on specifying interoperable and interchangeable systems. While this approach may increase the short-term cost of implementing WIM sites, in the long run it will provide lower overall cost both in terms of capital and maintenance expenditures. To accomplish interoperability and interchangeability, national standards such as NTCIP protocols, Internet protocols, and Mn/DOT (state) developed standards should be implemented.

**Communications Service Provider Options**

<table>
<thead>
<tr>
<th>Landline Low Speed (LS) / Dial-Up</th>
<th>Slow speed landline, dial up, communication links rely on standard phone lines to provide a connection. Dial-Up service is problematic due to inconsistent levels of communication speed and quality. The communication speed can vary from as low as 15Kbps to a theoretical maximum of 32Kbps. The driving factors behind the various communication speeds and reliability are quality of the phone line available at any given WIM site and its proximity to the telephone switch station. The farther the WIM site is from the switch station, the lower speed and quality of the connection. Dial-Up coverage is usually very good, making it the most available form of landline communications. Furthermore, Dial-Up cost for both capital and reoccurring are lower than any of the other communication options.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landline High Speed (HS) / DSL</td>
<td>High speed landline communication links are capable of providing faster communication with upload speeds of 128Kbps and download speeds of 1.5Mbps. DSL can provide up to 1.5 Mbs upload speeds; however, there is an excessive cost associated with commercial service. DSL uses the same communications cable as Dial-Up (twisted pair copper cable), and suffers from the same issues as Dial-Up links. Additionally, DSL is more sensitive to how far the WIM site can be from the phone central switch station. Typically, this ranges between two to three miles. Therefore, the availability of DSL in rural areas is very limited. DSL links are designed to provide connection to the Internet, and DSL modems are typically designed with an Ethernet port for local interface.</td>
</tr>
<tr>
<td>Landline High Speed (HS) / Cable Modem</td>
<td>High speed cable communications technology can provide faster communications with download speeds of 6Mbps and upload speeds of 384Kbps. Cable Modems, as the name implies, use Cable TV infrastructure. As a result, service is only available in urban areas at this time. Similar to DSL, Cable Modems are designed to provide connection to the Internet only, and their main local interface is an Ethernet port.</td>
</tr>
<tr>
<td>Wireless LAN (802.11a, b, and g)</td>
<td>Wireless LAN communication uses radio frequencies ranging from 2.4GHz and 5GHz, which is available to the public without licensing. This type of wireless technology was originally developed to support short distance (&lt;400') wireless connections between several computers. Under ideal conditions and short distances, Wireless LAN can achieve speeds up to 50Mbps. Using high gain external directional antennas can increase the range and speed of the connection although this may also increase the cost.</td>
</tr>
</tbody>
</table>

Mn/DOT Virtual Weigh Station Demo  Page 9
antennas Wireless LAN can support point-to-point communications over distances ranging from one to 20 miles. The distance Wireless LAN can communicate is heavily dependent on line of sight between stations as well as topological features. As a result, each installation requires a propagation study to determine how far the stations can be from each other. In addition, Wireless LAN bandwidth decreases significantly as the distance between stations increases to about 1Mbps at 3 miles. Wireless LAN can provide reliable communication when properly implemented. Wireless LAN installations require an upfront capital expenditure, with minimum recurring cost. Wireless LAN radios use Ethernet as the local communication interface.

**Satellite**

Satellite communications technology is capable of providing communication at any location where the southern skies are visible. Satellite communications can support upload speeds between 128Kbps to 512Kbps and download speeds between 1.0Mbps to 1.5Mbps. Satellite communications require a dish antenna, which limits mobility and portability of the system. All communications through a satellite network are routed through a ground base station. Connection to the ground base station can either be through dedicated links such as T1 or through the Internet using VPN technology. Satellite equipment can support multiple interfaces such as T1, serial, and Ethernet.

**Cellular Broadband**

Cellular Broadband communications links can provide bandwidth in the range of 70Kbps to 2.4Mbps, and is available through most cellular network vendors. The bandwidth available for a given network is dependent on technology deployed by the cellular vendor. Cellular Broadband networks are primarily designed to connect the user to the Internet however; some vendors are capable of providing private connections. Table #2 shows the different available cellular data networks in the project area and their corresponding technology and bandwidth by provider.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Technology</th>
<th>Average</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cingular</td>
<td>EDGE</td>
<td>70-135</td>
<td>320Kbps</td>
</tr>
<tr>
<td>Sprint</td>
<td>1xEV-DO</td>
<td>400-700</td>
<td>2.4Mbps</td>
</tr>
<tr>
<td>Verizon Wireless</td>
<td>1xEV-DO</td>
<td>400-700</td>
<td>2.4Mbps</td>
</tr>
</tbody>
</table>

**Communications Architecture**

To help identify the edge device needs, Mn/DOT WIM systems can be broken down into three primary communication links as shown in the following Diagrams #1 and #2. The main difference is how the officer obtains information when positioned in the enforcement vehicle. In Architecture "A", the vehicle communicates directly with the WIM cabinet. In
Communications Plan

Architecture “B”, the vehicle gets WIM information relayed via the Central Server. Architecture “A” is recommended as the preferred architecture, at least for the near term, because it enables immediate use of existing WIMs without the need for a Central Server. However, in the future it may be more effective to switch to Architecture “B” to increase functionality and save on costs when a central server is operational.

Architecture “A”

Diagram #1

Architecture “B”

Diagram #2
Cost Factors

Cost is a critical element when considering communication infrastructure. Cost for communication systems has two components: capital and recurring. Table #3 shows the costs of the different communication options previously discussed:

<table>
<thead>
<tr>
<th>Communication Type</th>
<th>Speed</th>
<th>Typical Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Download</td>
<td>Upload</td>
</tr>
<tr>
<td>Dial-Up</td>
<td>15-32 Kbps</td>
<td>15-32 Kbps</td>
</tr>
<tr>
<td></td>
<td>$30.00</td>
<td><strong>&lt; $500.00</strong></td>
</tr>
<tr>
<td>DSL</td>
<td>1.5 Mbps</td>
<td>128 Kbps</td>
</tr>
<tr>
<td></td>
<td><strong>&lt; $500.00</strong></td>
<td><strong>$60.00</strong></td>
</tr>
<tr>
<td>Cable Modem</td>
<td>6 Mbps</td>
<td>384 Kbps</td>
</tr>
<tr>
<td></td>
<td><strong>&lt; $500.00</strong></td>
<td><strong>$60.00</strong></td>
</tr>
<tr>
<td>Cellular Data</td>
<td>50 - 128 Kbps</td>
<td>70-700 Kbps</td>
</tr>
<tr>
<td></td>
<td><strong>&lt; $300.00</strong></td>
<td><strong>$80.00</strong></td>
</tr>
<tr>
<td>Satellite</td>
<td>1 - 1.5 Mbps</td>
<td>128-512 Kbps</td>
</tr>
<tr>
<td></td>
<td><strong>$1,200.00</strong></td>
<td><strong>$140.00 - 700.00</strong></td>
</tr>
<tr>
<td>Wireless LAN</td>
<td>1-50 Mbps</td>
<td>1-50 Mbps</td>
</tr>
<tr>
<td></td>
<td><strong>$5,000.00</strong></td>
<td><strong>$50.00</strong>*</td>
</tr>
</tbody>
</table>

* Maintenance Cost

Edge Device Communication Needs

Each of the edge devices (e.g. MSP Laptop, WIM Site, and Central Communication) has different communication needs. The following discussion identifies needs and summarizes the appropriate communications technology for implementation.

Central: Central Communication bandwidth requirements will depend heavily on the selected architecture. Architecture A will require considerably less bandwidth than Architecture B because the Central Communication would be collecting data from the WIM sites sequentially. Furthermore, the collection could occur at night over long periods of time, making speed less of an issue. For Architecture B, all of the WIM data would be collected in real time and re-transmitted to multiple MSP laptops requesting the information/data. While communications for Architecture A could operate using multiple low speed connections, Architecture B would require Central Communication to use a high speed connection. (A Central site is a fixed location in an urban setting where landline connections would be inexpensive and easy to implement). Depending on which architecture is selected and the total number of virtual WIM sites ultimately deployed, either a High Speed or Low Speed landline could be implemented for providing the Central communications link.

MSP Laptop: Because the MSP laptops are mobile, only
wireless technology can be implemented such as; Satellite, Wireless LAN, and Cellular Data. Satellite, unlike Wireless LAN, and Cellular Data, requires a dish antenna, which makes it impractical for installation on an MSP cruiser. As a result, only Cellular Data and Wireless LAN should be considered as viable options. Of the different Cellular Data services available in the project area, those providing high speed services such as Sprint and Verizon Wireless would be preferable assuming a 60Kbyte file is generated for each vehicle violation. Due to Wireless LAN high capital cost, it should only be considered for sites where no Cellular Data services are available. Wireless LAN is a point to point link between the MSP laptop and the WIM site. As a result, Wireless LAN can only be implemented using Architecture A.

**WIM Site:** The communication requirements of WIM sites will vary depending on which architecture is selected. For Architecture A, communications requirements to the Central server can be low since the file transfer is not time dependent. Therefore, connections such as Dial-Up would suffice. On the other hand, the communications link to the MSP laptop needs to be high speed to support real time data transfer such as Wireless LAN, Cellular Data, Satellite, or High Speed Landline. For Architecture B, all of the data is sent to the Central server in real time requiring the communications link to be high speed as well.
2.1.4. Performance Measures Plan

The Mn/DOT Statewide Weight Compliance Strategic Plan recommended a preliminary list of performance measures. This section identifies specific performance measures for the Virtual Weigh Station Demonstration Project.

Why Use Performance Measures?

Performance measures can be used to guide mid-course corrections as the weight compliance program evolves in Minnesota. They can effectively serve as an interface between planners and operations personnel because the measures quantify specific needs. Performance measures are utilized for the following reasons.

- Support existing and proposed infrastructure investments
- Prioritize projects
- Refine operational procedures
- Provide responses to legislative inquiries
- Provide input during organizational changes

Types of Measures

This project uses three types of performance measures.

- **System Outcomes** - To rate the effectiveness of the overall program
- **Condition Measures** - To track the deployment progress of the system components and identify the magnitude of the problem
- **Operational Measures** - To gauge the effectiveness of specific countermeasures

Recommended Measures

Table 2-2 is an overview of the performance measures recommended for this project. The most important performance measures are damage estimates in the System Outcomes category since they represent the fundamental purpose for the Mn/DOT Weight Compliance effort.

A performance measure is only effective when it can improve decision making. A list of potential uses is included in the right hand column.

The most left-hand column contains a value, indicating data availability according to the following factors:

- *1 = Readily available now from various Mn/DOT sources
- *2 = Now available using “Weight Watcher” developed for this project
- *3 = Can be calculated from the processed WIM data
- *4 = Must be collected manually from MSP and Mn/DOT sources
## Performance Measures

### Table 2-2

<table>
<thead>
<tr>
<th>Performance Measures Table</th>
<th>Some Potential Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Outcomes</strong> (To measure the effectiveness of improvements)</td>
<td></td>
</tr>
</tbody>
</table>
| *3 | Annual damage estimates (preventable) | ✓ Qualifying violation rate and permit rate  
✓ Legislative inquiries  
✓ Prioritizing enforcement officer deployment  
✓ Estimating needed enforcement hours/year  
✓ Providing background info for permit regulations  
✓ Adjusting capital improvement budgets  
✓ Creating Federal reports |
| *3 | Overall weight compliance rating (% vehicles operating legal) | ✓ Responding to Legislative inquiries  
✓ Justifying enforcement budgets  
✓ Assessing effectiveness of WIM, Civil Weight, and Fixed Scale enforcement efforts  
✓ Developing Federal reports |
| **Condition Measures** (To track the deployment progress of system components and to identify the magnitude of the problem) | Some Potential Uses |
| **System Dimensions** |  |
| *1 | Scale Facility Deployment: Number of scale facilities | ✓ Creating Maintenance budgets  
✓ Qualifying extrapolated data accuracy  
✓ Preparing various official reports |
| *1 | Roadway Surface Areas: Total pavement and bridge deck surface areas for each pavement classification | ✓ Calculating annual pavement damage estimates  
✓ Programming new WIM sites  
✓ Responding to Legislative inquiries  
✓ Scheduling resurface/rehabilitation projects |
| *1 | Pavement replacement cost per square foot for each classification | ✓ Calculating annual pavement damage estimates |
| **System Loading** |  |
| *1 | Average daily truck traffic | ✓ Revising design life cycle parameters  
✓ Qualifying violation rate and permit rate  
✓ Responding to Legislative inquiries  
✓ Prioritizing enforcement officer deployment  
✓ Estimating needed enforcement hours/year |
| *4 | Vehicles with weight permits | ✓ Calculating annual pavement damage estimates  
✓ Correcting violation rates derived from WIM data  
✓ Responding to Legislative inquiries  
✓ Identifying seasonal trends |
| *4 | Violation rates | ✓ Revising design life cycle parameters  
✓ Identifying seasonal trends |
| **Operations Measures** (To gauge the effectiveness of specific countermeasures) | Some Potential Uses |
| *4 | Enforcement “hit” rate for weight violations (for MSP use only) | ✓ Comparing effectiveness of various types of enforcement  
✓ Assessing performance of new work procedures |
Performance Measures

| Performance Measure Sub-Categories | The measures listed above are general. The final reports will include several measures reported by various time frames and territories. For example, the measure for the percent of overweight vehicles is presented for each WIM site over different time frames and grouped by “bins” (e.g. 0% - 5%, 5% - 10%, etc.). Typical timeframes are weekly, monthly, and annually. These measures are defined in the Performance Measure Details in Appendix 6.3. |
| Automation | To make the program affordable, automate the collection of data and generation of reports for each measure by utilizing the WIMCAT produced under this contract. This tool processes the daily WIM data files to produce various reports and charts. The future central operating system will incorporate these same functions as well as create global reports, real-time monitoring for extreme loads, automated polling, and custom report options. |
| Data Archiving | Establish a formal archiving system for the data. Archived data is useful for other research, legislative inquiries, design life cycle studies, historical paving material studies, and many more forms of data mining. |
| Website Reporting | Post the data on a secure Website instead of distributing paper copies of a general report to appeal to a broader audience. Configuration of the Website can allow users to “drill down” from general categories to specific measures of interest. Users can then send pages to the “Shopping Cart” to assemble custom reports that fit their needs and “Checkout” to print them. They can also create templates or save electronic versions. The template option enables users to call up next month’s report with a simple keystroke. A routine back-up of this Website allows data to be archived and accessible for queries. |
| Data Volatility | The shelf life of the data collected for these measures can vary substantially from measure to measure. For example, the number of fixed scales is a quantity unlikely to change more than once every five years, while hour of the week violation rates change weekly. The various methods required to produce the data may affect the electronic processes, work procedures and sampling frequencies. (These issues are discussed in the Performance Measure Details Section, Appendix 6.3). The detail sheets were created to collect performance measurement data. The detail sheets will eventually change as the end users’ needs change; frontline employees develop creative improvements to the work procedures, technology changes, and outside entities (such as, |
legislative or FHWA mandates) impact the program.

**“Excessive Load Ratio”**

Defining the measure for violation rates involved addressing both the quantity and magnitude of the violation rate. This measure is called the Excessive Load Ratio (ELR). This is different from simply counting the number of violations. Both measures are somewhat similar since they provide gauges for the extent of the violations. The distinction is the percent of overweight trucks relates to only the number of violations, while the excessive load ratio takes into account both the quantity and the magnitude of the violations. The ELR is defined below with further examples in Appendix 6.3.

This excessive load ratio (ELR) can be calculated for any sampling period using the following formula.

\[
\text{Excessive Load Ratio} = \left( \frac{\text{Total Excessive Load}}{\text{Total Number of Trucks}} \right) \times K
\]

Where:
- Total excessive load = Total tons of cargo in excess of legal loading for all trucks in the sample.
- Total number of trucks = Total number of trucks in the sample (includes both legal and overloaded trucks)
- \(K\) = an adjustment multiplier that changes the decimal to whole numbers (100)

**Proposed Near Term Applications**

The project moves Mn/DOT closer to its goal of a comprehensive commercial vehicle weight compliance program. It establishes the tools needed to enable dual use of WIM scales. A few examples of how performance measures can be used are shown below.

**Repeat Offenders**

Create a tally of repeat offenders as a near term application for Mn/DOT’s Weight Compliance Program. High probability, repeat offenders account for an over represented percentage of the violations, resulting in a focus for reducing violation occurrences.

**Bridge Assessment**

Establish a concentration of WIMs and enforcement to help mitigate overstressing specific bridges. This may occur on structures that are already weight restricted for legal or permit loads, if truck drivers do not obey posted legal limits or they do not obtain special permit routes that are determined to be safe for over legal loads. It may be prudent to monitor the truck traffic with WIMs and target enhanced weight enforcement for bridge preservation purposes. Hence, this should significantly protect the highway infrastructure and improve safety.

**Rolling Out the Performance Measure Program**

The previously-described performance measures represent the current vision for a mature Weight Compliance Program. The implementation of performance measures will occur over a period of time. Furthermore, other performance measures will become available as Mn/DOT navigates through the development of the weight compliance process. The following application criteria are recommended to manage the selection of performance measures.

**Recommended Performance Measure Selection Criteria**

- Develop measures that directly influence specific decision making processes (e.g., enforcement schedules, planning
Performance Measures

Create and establish affordable measures to perpetuate.
Allocate the appropriate staff resources to support the creation and ultimate application of the measure.
Where possible, establish automated processes to collect and manipulate the data and generate reports.
Early in the process, create mockup reports, with the approval of all stakeholders, to ensure the performance measure is appropriate and functional.

Currently Available Performance Data Sources

Use existing data sources to minimize cost. Minnesota has a number of potential data input sources. The key to success is to identify practical data extraction procedures from these current data sources:

- Weigh in Motion scales (WIMs)
- Automated Traffic Recorders (ATRs)
- Vehicle classification sites
- Relevant evidence data
- Bridge sufficiency ratings
- Safety data
- Annual infrastructure reports

Recommended Actions

The following actions are recommended to ensure the process is suitable over the long term.

1. Identify how the measure will be used first and, then, create the report content and format.
2. Establish a baseline for each measure, if possible. If not available, establish the baseline by using data from the early months of implementation.
3. Automate these reports.
4. Identify a practical quality assurance process for each measure to ensure long-term quality.
5. Schedule an annual Oversight Committee review date for each measure to determine if the measure is still appropriate or if modifications are needed.

Strategies for Establishing Baselines

Establish baseline rates by analyzing data collected from the WIM stations for a period of four summer months (provided the data is available). This suggested baseline period sidesteps the influence of seasonal impacts on commodity movements. Appendix 6.4 compares a 4-month baseline vs. a 12-month baseline. There are several ways to generate performance measure baselines.

Sampling: Establish baselines using sampled truck weights from fixed scales, available WIMs, and short bursts of statistically-random roadside enforcement. Short bursts are necessary to prevent bias in the data because
Performance Measures

of the influence of trucker CB transmissions. However, twenty-four hour WIM counts should be unaffected as long as targeted enforcement is not applied.

Comparisons: For routes where instrumentation is unavailable, baseline values can be estimated by comparing similar routes. This is particularly true of interstate and large trunk highways.

Moving Averages: Establish a baseline by simply taking measurements and continuously calculating four-week moving averages. Then, the moving averages become the current baselines. While current baselines lack historical values, they establish the baseline for future comparisons. Although this approach does not quantify the benefits of the initial countermeasures, it is useful for assessing future practices. The initial rollout of this program is likely to be modest and increase over time. This strategy is a valid method to establish baselines to eventually monitor trends. The previous year’s data then serve as the most significant baseline.
2.2.1. Calibration Validation

The quality and reliability of WIM data are important issues for all the stakeholders involved with Weigh-in-Motion scales. It is imperative the WIM calibration be validated regularly (i.e. more frequently than current practice). This higher level of performance is essential for the weight compliance program for the following reasons:

**Enforcement Officer Confidence**
Nothing can discourage the enforcement officers from using the system faster than stopping a truck based on a WIM report only to find the truck was not overweight. Conversely, accurate WIM reports can effectively single out the few gross violators inspiring a great deal of confidence in the system. This confidence can be bolstered by understanding well calibrated WIMs improve their ability to protect the roadways from damage due to excessive truck loads.

**Damage Estimate Accuracy**
Mn/DOT’s annual damage estimate is based on WIM scale results. Poorly calibrated WIM readings can result in inaccurate pavement and bridge damage estimates.

**Timely WIM Maintenance**
The WIM error reports generated by the WIMCAT can be utilized to trigger maintenance and recalibration actions often before the data becomes unacceptable. This can result in lower system down-time.

**Feedback System Reliability**
If Mn/DOT should decide to implement the dynamic feedback system, truckers would receive instant notification of their weight as they drive down the road. Consequently, the WIM scales will need to be operating at a very high level of accuracy. This implies continuous calibration efforts.

**Accuracy of Various Federally Mandated Reports**
For years, the FHWA has required states to report transportation statistics based on WIM scale data. The inaccuracy of data could have budget ramifications if the scale data is underreporting.

There are a number of reasons why a WIM scale may produce data errors. They are included in the following list. Some of these factors cause temporary or non-fatal errors to occur. Others require physical maintenance on the WIM scale or the pavement associated with the WIM. It is interesting to note, how frequent re-calibration can adequately detect problems while data still has value and the WIM can be scheduled for repair without a gap in operation.

**Sources of Errors**
There are a number of sources for WIM equipment errors. The most prevalent are:

- Rough pavement
- Temperature variability
- WIM equipment malfunctions
- Hardware drift
- Electronic drift
Types of Errors

Basically, there are two types of errors produced by a WIM scale:

- **Random** errors are the most difficult to deal with because they usually require maintenance/repair of the field equipment or the pavement itself. WIMs producing random errors may still produce data with value, if the errors are within reasonable tolerances. However, these types of errors do require urgent attention if the WIM is to be of any long term value to the stakeholders.

- **Consistent** errors deviate from true values by constant amounts and can be addressed by simply recalibrating the scale. Roadside inspections provide a steady stream of true weight readings useful for calibration purposes. Although, when a trend is established (i.e. the error is steadily increasing over a few days or weeks), resulting in closer inspection of the equipment.

The WIMCAT developed as part of this project encompasses several WIM data checks. WIM data falling outside certain parameters triggers errors in the output report. The data quality functions help Mn/DOT move toward automated performance measures. The proof checks are based on known data ranges. The following list describes these WIMCAT proof checks.

**Fatal Errors**

Fatal errors cause the current set of data to stop the WIMCAT from running. Fatal errors are produced as WIMCAT counts the number and types of vehicles in the data file. If the numbers are below expectation, then the macro will not run.

**Left vs. Right Scale Comparison**

Based on some recent research conducted at Purdue University, the left and right scale readings are compared after correcting for the crown of the road. Ideally, both scales should give very similar results because most trucks are loaded along their center of gravity. Odds are both scales will not fail at the same time. This provides Mn/DOT initial notice when one of the scales may be malfunctioning or getting out of range.

**Front Axle Upper/Lower Limits**

The front axles on most standard trucks fall within a fairly narrow weight range for both loaded and unloaded vehicles, providing Mn/DOT with an approximate known value for the first axle to cross the scale. If a significant number of trucks have weights falling outside of this range, then the scale may be malfunctioning. WIMCAT will indicate if the scale is weighing light, heavy, or erratic, suggesting maintenance and/or recalibration are required.

**Speed Check Using 2nd – 3rd Axle Spacing**

Purdue University also developed an innovative strategy for checking the WIM reported truck speeds. Nearly all trucks manufactured in the U.S have a standard range of spacing between the second and third axles (the tandems on a tractor). This known distance can be utilized to back-calculate a speed value for the truck, and compared with the speed reported by the WIM. The speed value is important because the WIM uses it for calculating axle spacings. Axle spacings determine both vehicle classification and allowable winter load increases. Both affect the violation rates. Purdue’s strategy was incorporated...
Calibration Validation

into the WIMCAT, enabling Mn/DOT to routinely check for WIM speed errors every time they run a WIMCAT report.

**Error Reports**

The WIMCAT generates two reports for Mn/DOT to assess the health of the scale.

- A WIM data report that identifies anomalies within the data
- An error report reflecting the output from the proof checks described above.

The current Minnesota weight compliance efforts offer cost saving opportunities for attaining a high level of WIM performance without the need for using calibration trucks. This benefit can be achieved by very simple inter-agency work procedures and automated processes.

**Manual Calibration**

Standard practice for WIM calibration is done by passing a truck of known weight over the WIM repeatedly and then averaging the results to produce a correction factor. Manual calibration is accurate, yet costly, time consuming, and does not lend itself to frequent fine tuning of the WIMs. The manual calibration conducted during the project is summarized in Table 2.2.1. The details are presented in Appendix 6.9.

Alternative practice utilizes roadside inspections to establish known truck weight values, comparing the results with the WIM output. After a few repetitions, a revised calibration factor can be computed, and the WIM adjusted by Mn/DOT or enforcement personnel.

MSP recently developed a quick technique for confirming WIM accuracy. Prior to conducting the day’s inspections, the officers can witness their own vehicle weight reported by the WIM on their laptop. This provides the officer a higher level of confidence in the WIM information.

**Automated Calibration**

It is possible to have portable or fixed scale measurements automatically fed back to the WIM for self calibration. This is commonly done on ramp sorter WIMs where a fixed scale weighs each truck immediately after it has been weighed by the WIM. Similarly, auto-calibration can be produced using roadside enforcement. When the officer has completed each roadside weight inspection, the results are automatically transmitted back to the WIM controller. Then the values are averaged with previous readings to produce a correction factor for the WIM controller.
### Table 2.2.1 - Calibration analysis

**Mn/DOT TH2, RP8.0**

<table>
<thead>
<tr>
<th>Date</th>
<th>Lane</th>
<th>Initial Calibration Factor</th>
<th>Adjusted Calibration Factor</th>
<th>Controller</th>
<th>Deviation range prior to adjustment (%)</th>
<th>Standard deviation prior to adjustment</th>
<th>Deviation range after adjustment (%)</th>
<th>Standard deviation after adjustment</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/12/2006</td>
<td>1</td>
<td>1.645</td>
<td>1.645</td>
<td>IRD</td>
<td>-3% to -1%</td>
<td>0.011</td>
<td>-3% to -1%</td>
<td>0.011</td>
<td>No adjustment made</td>
</tr>
<tr>
<td>1/12/2006</td>
<td>2</td>
<td>1.66</td>
<td>1.856</td>
<td>IRD</td>
<td>-13% to -7%</td>
<td>0.029</td>
<td>na</td>
<td>na</td>
<td>Schedule did not allow confirmation runs</td>
</tr>
<tr>
<td>1/17/2006</td>
<td>1</td>
<td>1.7</td>
<td>1.8</td>
<td>IRD</td>
<td>-4%</td>
<td>na–one run</td>
<td>-1% to 0%</td>
<td>0.005</td>
<td>Very close standard deviation. Based on three runs.</td>
</tr>
<tr>
<td>1/17/2006</td>
<td>2</td>
<td>1.856</td>
<td>1.8</td>
<td>IRD</td>
<td>0% to +3%</td>
<td>0.017</td>
<td>-2% to +3%</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>7/22/2006</td>
<td>1</td>
<td>1.58</td>
<td>1.62</td>
<td>IRD</td>
<td>-6% to -3%</td>
<td>0.016</td>
<td>-1% to +2%</td>
<td>0.013</td>
<td>Minimal adjustment</td>
</tr>
<tr>
<td>7/22/2006</td>
<td>2</td>
<td>1.8</td>
<td>1.58</td>
<td>IRD</td>
<td>+11%</td>
<td>na–one run</td>
<td>0% to +4%</td>
<td>0.006</td>
<td>Close standard deviation based on 6 runs.</td>
</tr>
<tr>
<td>9/6/2006</td>
<td>1</td>
<td>1.62</td>
<td>1.71</td>
<td>IRD</td>
<td>-6% to -3%</td>
<td>0.017</td>
<td>-3% to +3%</td>
<td>0.045</td>
<td>Minor adjustment made to 1.68</td>
</tr>
<tr>
<td>9/6/2006</td>
<td>2</td>
<td>1.58</td>
<td>1.66</td>
<td>IRD</td>
<td>-4%</td>
<td>na–one run</td>
<td>-3% to +1%</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>9/6/2006</td>
<td>3</td>
<td>p1-633 p2-641</td>
<td>p1-607 p2-638</td>
<td>ECM</td>
<td>+3% to +4%</td>
<td>??????? ???</td>
<td>-1% to -1%</td>
<td>na–one run</td>
<td>Initial setup and calibration of ECM Unit</td>
</tr>
<tr>
<td>10/10/2006</td>
<td>1</td>
<td>1.68</td>
<td>1.68</td>
<td>IRD</td>
<td>-5% to -2%</td>
<td>0.019</td>
<td>-5% to -2%</td>
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<td>No adjustment made</td>
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<tr>
<td>10/10/2006</td>
<td>2</td>
<td>1.66</td>
<td>1.66</td>
<td>IRD</td>
<td>-5% to -2%</td>
<td>0.011</td>
<td>-5% to -2%</td>
<td>0.011</td>
<td>No adjustment made</td>
</tr>
<tr>
<td>10/10/2006</td>
<td>3</td>
<td>p1-607 p2-638</td>
<td>p1-607 p2-638</td>
<td>ECM</td>
<td>-1% to +3%</td>
<td>0.019</td>
<td>-1% to +3%</td>
<td>0.019</td>
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<td>11/2/2006</td>
<td>1</td>
<td>1.68</td>
<td>1.71</td>
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<td>-2% to +1%</td>
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<td>2</td>
<td>1.66</td>
<td>1.68</td>
<td>IRD</td>
<td>-4% to +1%</td>
<td>0.024</td>
<td>-4% to +1%</td>
<td>0.024</td>
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<tr>
<td>11/2/2006</td>
<td>3</td>
<td>p1-607 p2-638</td>
<td>p1-607 p2-638</td>
<td>ECM</td>
<td>+3% to +5%</td>
<td>0.007</td>
<td>+3% to +5%</td>
<td>0.007</td>
<td>ECM made a -4% adjustment on Nov. 22nd, 2006</td>
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## Calibration Validation

<table>
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<tr>
<th>Date</th>
<th>Lane</th>
<th>p1</th>
<th>p2</th>
<th>Sensor</th>
<th>IRD</th>
<th>Adjustment %</th>
<th>Error</th>
<th>Adjustment Factor</th>
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<tr>
<td>1/10/2007</td>
<td>1</td>
<td>1.71</td>
<td>1.82</td>
<td>IRD</td>
<td>-10% to -9%</td>
<td>0.007</td>
<td>-3% to -3%</td>
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<td>1.90</td>
<td>IRD</td>
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<td>p1-598 p2-619</td>
<td>p1-598 p2-619</td>
<td>ECM</td>
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<td>-4% to +2%</td>
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<tr>
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<td>1</td>
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<td>1.82</td>
<td>IRD</td>
<td>-10% to +6%</td>
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<td>-3% to +6%</td>
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<tr>
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<td>2</td>
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<td>1.70</td>
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<td>Cardinal</td>
<td>initial calibration</td>
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</tr>
<tr>
<td>1/24/2007</td>
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<td>1.82</td>
<td>IRD</td>
<td>-2% TO +1%</td>
<td>0.022</td>
<td>-2% to +1%</td>
<td>0.022</td>
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<tr>
<td></td>
<td>2</td>
<td>1.7</td>
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<td>IRD</td>
<td>-8%</td>
<td>NA</td>
<td>-5% to +3%</td>
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</tr>
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<td>+8%</td>
<td>NA</td>
<td>0% to +3%</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>2/16/2007</td>
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<td>1.82</td>
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<tr>
<td></td>
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<td>1.825</td>
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<td>-7% to +1%</td>
<td>0.032</td>
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<td>0.024</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- First major adjustment on this sensor. Ground is frozen.
- Adjustment in the same direction and magnitude as lane 1.
- Consistent, based on 7 runs.
- No adjustment made.
- Adjustment factor not known. Adjustment made in %.
- No adjustment made based on six runs.
2.2.2. Baseline Calculations

The methodology for calculating the baseline damage estimates was outlined in the *Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan* (2005). In this project, the WIMCAT was developed to assist the methodology and calculation of baseline violation rates.

**Damage Estimate Overview**

Chapter 3 of the *Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan*, provides details for a damage estimate methodology based on Equivalent Single Axle Loads (ESALs). The outputs from the calculations are shown in the Results section of this report. In general, this process involves the following steps.

1) **Classify the road types:** Divide the roadway network into groups with similar characteristics including a separate group for all bridge decks. (In the Strategic Plan a total of six groups were identified.)

2) **Estimate ESALs per group:** An annual excessive ESAL estimate is then established for each group. This is done by assigning all WIM sites to their appropriate groups and averaging the excessive ESAL rates among each group.

3) **Calculate pavement life:** An expected remaining pavement life is calculated for each group assuming the current excessive ESAL rates will continue for the life of the pavement.

4) **Calculate pavement costs:** Annualized pavement costs are calculated for both the original life and remaining life (which will be shortened due to excessive ESAL consumption).

5) **Calculate damage estimate:** The difference between the two annualized costs is the damage estimate. For this project, 2006 data was utilized to establish a baseline.

6) **Measure life cycle impacts:** Any reduction in ESAL rates from one year to the next, then translates into an extended pavement life. This ESAL reduction becomes a fundamental performance measure for the program.

**Assumptions**

A number of assumptions were made to produce practical and informative performance measures. The assumptions are as follows.

- Rail crossing damage was considered to be negligible. This assumption was made due to the difficulty in calculating the amount of damage caused by overweight vehicles.
- For bridges, only the deck damage was considered.
Baseline Calculation

Excessive vehicle loads do contribute to faster deterioration of the bridge superstructure. However, the calculations for this damage would be very complex and unique to each structure making it unrealistic to calculate.

- Concrete pavement life is estimated at 30 years.
- Asphalt pavement life is estimated at 25 years.
- An annualized interest rate of 5% was assumed.
- Salvage value was considered to be zero at the end of the design life.
- Only class 9, 10 and 16 trucks were considered as predominant types of commercial vehicles in Minnesota.

Violation Rates

A twelve month violation rate baseline was calculated from 2006 WIM data. After careful consideration, a four month summer baseline was suggested as the most representative measure of the existing conditions. Theoretically, excessive loads should be minimized during the summer months outside of harvest seasons and cold weather impacts. However, this did not prove to be the case, as shown in Appendix 6.4. Increased summer truck activity appears to complicate this assumption. Consequently, monthly comparisons need to be made on a “same month last year” basis, not an average monthly value. In a similar manner, annual damage estimates would be based on twelve month totals compared with the previous year’s totals.

The Strategic Plan suggests violation rate baselines can be utilized by enforcement to focus resources and measure performance. During the project, three week moving average baselines were used to monitor weight compliance progress. The WIMCAT enables such a calculation to be made easily per WIM site, for any time period measured in daily units. The values enable the Technical Committee to measure compliance, to justify resource allocations, and to set priorities for deployment across the state.

Excessive Load Ratio

During the course of this project, a refinement was made to the original violation rate strategy. Simple violation rates did not take into account the magnitude of each violation. For example, one site with fewer and heavier excessive loads may rank lower than a second site with more violations of lighter excessive loads. To address this problem, an Excessive Load Rating (ELR) was included in the WIMCAT. The ELR adjusts the raw violation rate up or down depending on the size of the excessive loads, yielding a more realistic assessment of the violation problem. Calculation methodology for the ELR is described in more detail in Appendix 6.3.

ESAL Calculations

Damage and violation rate calculations are based on excessive ESAL values determined by the WIM readings and the class of truck. The WIMCAT takes the WIM values for each truck, and if a violation is identified, theoretically offloads the excess weight onto an empty truck. Then the ESAL value for both
vehicles are summed and compared to the original overloaded truck. The difference results in the maximum amount an effective weight compliance program can achieve.

**Winter Loads**

Minnesota law allows heavier loads during the winter months because frozen subgrade can support more weight. To account for these differences in allowable maximum weights, WIMCAT references a “Winter Load Increase Table” and automatically adjusts the maximum load allowed according to the date of each WIM transaction. This allows some unauthorized excess loads to be considered legal, and modestly understates the total damage estimate.

**Permitted Vehicles**

Without some sort of identifier, such as a transponder, it is impossible for a WIM to detect a vehicle carrying a permit. These vehicles are subject to higher legal limits. To offset this error, a correction factor can be applied to the annual violation estimate based on the number of permits issued each year.
2.2.3. Site Equipment – Enforcement Training

The original project scope was slightly modified to allow for changes in the Minnesota State Patrol (MSP) hardware and software for equipment and training purposes. The intent was always to use the MSP laptops as the officers’ interface. However, the information sources changed. Wireless communication was established using Mn/DOT air cards and violation detection training evolved through the interaction of agencies, the equipment vendors and URS.

MSP Calibration

Significant efforts were made on the part of MSP and Mn/DOT personnel to identify methods for calibrating the WIM sites based on roadside inspection results. The level of effort for this work was unexpected. However, the proven result created a method for ensuring WIM reliability while lowering calibration costs. The WIMCAT supports the calibration and scale maintenance effort by routinely reporting WIM errors as an addendum to the WIM reports. These reports alert the agencies to WIMs showing early signs of failure.

MSP also created an innovative strategy for a quick WIM calibration check. This simple, but effective strategy, involves using the officer’s vehicle as a known weight and driving over the WIM several times at different speeds while observing the results from the WIM. This quick calibration check is routinely done, just prior to conducting enforcement operations.

Weekly Enforcement Schedule Training

Three week moving average ELR and Violation Rates were developed over a period of six weeks using the WIMCAT, and then presented to MSP personnel for scheduling enforcement efforts. This interaction between the WIMCAT developers and end users served three purposes. It provided training to key MSP personnel, helped to refine the tool, and defined the routine process of using data to produce targeted enforcement. It also addressed the institutional issues associated with transmitting WIM data to and from partnering agencies.
2.2.4. Enforcement Scheduling

A critical aspect of the Virtual Weigh Station program is the integration of MSP's enforcement scheduling process with the Mn/DOT WIM data. This inter-agency exchange of information is facilitated by the WIMCAT reports. An annotated sample report is included in Appendix 6.2. A brief overview of the recommended scheduling process is as follows.

**Step 1, Check Error Reports**
The first step is to establish the confidence level for each site. This is done by simply checking the WIMCAT error report for fatal errors. If the value in the second row of the table, "Fatal Errors" is above 20%, then the site should receive maintenance attention. Next, this site should be reported to TDA, and temporarily rejected for use as a VWS site.

**Step 2, Rank WIM sites**
With a recent 3 week WIMCAT report in hand for each available WIM site passing the error check, the scheduler can rank the sites based on the monthly total Excessive Loading Ratio (ELR). Sites with the highest values are the most critical, and will have the highest probability of capturing a violator.

**Step 3, Identify Vehicle Class**
Taking each site selected for enforcement in Step 2, the scheduler can compare the ELR values for Class 9's and Class 10's. It is not unusual for one to be greater than the other. Also note, WIMCAT automatically adds class 16 trucks as if they were class 10. The class with the highest ELR values would then be targeted for enforcement, and the scheduling process continues using the WIMCAT Hour and Day of the Week reports as a guide.

**Step 4, Hours of the Week**
The WIMCAT reports produce graphs for both the Days of the Week and Hours of the Day. They are averaged for the entire three week period. The highest bars on the graphs represent days and hours of the week with the greatest number of violations. As a result, this indicates the most productive hours for conducting enforcement. The scheduler can use this information to prepare a work schedule for each enforcement crew.

WIMCAT's "Capture Odds" can be provided to the enforcement officers to determine how frequently they can expect a violator. For example, Capture Odds of 1:8 would suggest on average one out of every eight trucks would be a violator. A high ratio allows the officer to be selective when setting the WIM controller filter to capture only the worst offenders. A low ratio would suggest fairly tight compliance, and the officer may want to set the filter closer to legal limits in order to balance the inspection workload to the current conditions.

The goal is to establish conspicuous inspections at sites with the highest violation rates. This can be done by staging the officer as covertly as possible, and then inspecting the vehicles as conspicuously as possible. Using Capture Odds enables WIM filter settings appropriate to the circumstances, producing...
a sufficient number of violation alerts to keep them fully engaged while screening for only the worst offenders.

**Performance Measurement**  
Evaluation of the impact of the selective enforcement process can be accomplished by charting out the total weekly ESAL values for each site and then annotating the charts with the level of enforcement conducted for the week. Over a period of a few months, it should become apparent if the compliance rate is improving. Also, it should how long it is sustained after enforcement is halted at sites with acceptable compliance levels.

**Recalibration**  
If the WIMCAT reports suggest a WIM is beginning to drift, the scheduler may also want to use the inspection reports to produce an adjustment factor for the WIM. Then an officer can schedule recalibration of the WIM controller. Recalibration may not be appropriate when large variations in temperature occur at WIM sites embedded in thin asphalt pavements (~8” or less). Sites are expected to drift at predictable levels and will return to normal at moderate temperatures.
2.2.5. **WIMCAT** *(Weigh-in-Motion Compliance Analysis Tool)*

Ultimately, the purpose for the Virtual Weigh Station program is to reduce pavement and bridge deck damage caused by overweight vehicles, and this can be accomplished by improving truck weight compliance. One of the major objectives in achieving this goal is to establish dual use mainline WIM stations to routinely produce timely information and target enforcement resources accordingly. To facilitate this WIM dual use, an Excel macro was developed to produce enhanced WIM reports from the raw data in a timely manner. The Excel macro was named “WIMCAT” (short for Weigh-in-Motion Compliance Analysis Tool). The WIMCAT output can be utilized in a variety of ways to improve decision making.

A detailed flowchart depicting how WIMCAT works is presented in Appendix 6.2.

### WIMCAT Functions

<table>
<thead>
<tr>
<th><strong>Objectives</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• To chart violation rates</td>
<td></td>
</tr>
<tr>
<td>• To provide information, helping MSP optimize enforcement scheduling</td>
<td></td>
</tr>
<tr>
<td>• To automate the production of performance measures</td>
<td></td>
</tr>
<tr>
<td>• To facilitate the production of pavement damage estimates</td>
<td></td>
</tr>
<tr>
<td>• To flag potential WIM equipment and raw data problems</td>
<td></td>
</tr>
<tr>
<td>• To serve as a preliminary step in creating a vision for a Central Operating System</td>
<td></td>
</tr>
</tbody>
</table>

**Vehicle Classes**

To simplify the process only class 9, 10 and 16 trucks were considered by the current version of WIMCAT. These two vehicle classes represent the majority of trucks currently in use by the motor carrier industry. (The damage from smaller vehicles is substantially less significant.) When a Central Operating System is created the methodology would be expanded to include all other vehicle types.

**Methodology**

WIMCAT calculates the Equivalent Single Axle Loads (ESALs) for each truck, determines if the truck was in violation of weight laws, and then produces a variety of reports. A significant piece of the process involves calculating the excess ESALs above legal limits. Briefly stated, this can be described as a process that theoretically offloads the excess weight from violating trucks on to empty legal trucks, and then recalculates the damage for the pair of trucks. The difference between the ESALs for the pair of theoretically legal trucks vs. the existing single overloaded trucks provides a measure of the excess. This methodology produces a convenient performance measure related directly to the annual damage calculation, as Mn/DOT pavement designs are based on design life ESAL predictions. A flowchart describing the details of this process is included in the Appendix 6.2.

**Data Quality**

In addition to the methodology described above, the system also flags data anomalies. This includes unreasonable axle weights, and it also incorporates some proof checks developed by Purdue University indicating if the WIM data is trending...
WIMCAT

away from acceptable levels. (One of these checks involves a comparison of left and right wheel weights. Under most conditions these two values should be approximately the same.) Another process checks the WIM reported speed by back calculating the speed from the reported second and third axles (known to be from 51” to 54” for most trucks). Other checks test for missing data, an expected common front axle weight, and unreasonably high or low values. WIMCAT then produces an error report listing all the errors found. This can be useful for TDA as a quick data screening tool, to identify when calibration may be needed, and establish a level of confidence in the output.

Reports

Performance Measures
Performance Measures are utilized as a guide for the decision making process. Mn/DOT has selected several performance measures clearly supporting the weight compliance program decisions, and several of these measures come directly or indirectly from WIMCAT, including:

- Percent of overweight vehicles by class and violation type
- An Excessive Load Ratio (ELR) taking both magnitude and volume into consideration
- Percent of overweight trucks by levels of magnitude (ex. 0-10k, 10k-20k, etc.)
- Pavement damage due to overweight vehicles (in dollars)
- Violations listed by hour of the week
- Violations listed by day of the week

Scheduling Tool Aid
The performance measures described above are useful for prioritizing the deployment of limited enforcement resources. For example, knowing what days of the week and hours of the day the greatest number of violations are occurring can be useful for planning weekly MSP enforcement schedules. Knowing which WIMs are experiencing the most severe damage can be helpful in planning "blitz" enforcement where groups of officers can team up and work an area extensively. This can also identify seasonal and commodity-specific weight violation trends.

Special Event Reporting
Because Minnesota allows different load maximums during various weeks of the year, this WIM data can be used to monitor compliance before and after the load limits change. Again, this can benefit the scheduling of enforcement details, and informing legislators about the impacts of the regulations in place or under consideration. WIMCAT automatically adjusts for the winter load increases by referencing a table of start and end dates for these increases.

Special Use Reports
There are also some special applications supported by WIM data. For example, truck weight compliance can be studied
around areas having high concentrations of specific commodities (such as, locations adjacent to ethanol plants or lumber harvesting) for assessing the impacts those movements have on the highway infrastructure.

Processed WIM data makes the potential use of pavement warranties practical. For example, the use of WIM data can reasonably determine if vehicle loading was within expected ranges.

The information generated from WIM data supports the annual production of FHWA reports about truck movements and weight compliance. The content and format of these annual reports should be built into the requirements for a Central Operating System.

A significant calibration benefit can be derived by comparing the MSP’s actual roadside weight measurements with the observed WIM data. The calibration of WIM sites is a costly, time-consuming process, resulting in a tendency to calibrate infrequently. The axle weights produced during the roadside inspections can routinely be averaged and then utilized to adjust the calibration of the WIM to compensate for drift.

Special WIMs located in advance of load limit posted bridges, can monitor for excessive truck weights to protect the structures from damage and help set repair/replacement schedules for these structures.

Undoubtedly, there would also be benefits for a variety of research projects. These might fall into categories such as: pavement design studies, commodity studies, or pavement and bridge material wear studies.

### Institutional Issues

**Operational Issues**
The development of the WIMCAT created new opportunities for improving the way business is conducted. This also suggests changes may be needed to work procedures, funding allocations, and agency responsibilities. The list below addresses a few of the significant issues.

**Communication Options**
Historically, all WIM data has been acquired through landline modems. The Communications Plan describes options for supporting wireless connectivity to the enforcement vehicles as well as Internet access to the WIM data. Multiple uses for the communications systems are encouraged to take advantage of cost savings for the departments sharing these facilities.

**Work Procedures**
The most likely institutional impacts will occur in the form of changes to work assignments and work procedures.

- Historically, the Transportation Data Analysis section has been responsible for collecting and distributing the data. With dual use WIMs, this process could be changed. For example, it is now possible for these new applications to be established with the data being stored on secured websites, giving the various end users access rights.
according to their needs. As in the past, this provides TDA full control of the data and also enables other access without additional responsibilities for TDA.

- The turn around time for translating raw WIM data to functional information will need to be faster than previously required. Planning level information typically is developed on an annual basis. Enforcement level information will need to be at the very least monthly, and preferably weekly or daily to be useful.

- WIM calibration can be effectively focused on those times when the WIM health is questionable based on the WIMCAT error reports. This enables Mn/DOT to maintain reliable WIM performance with limited manpower.

- A quick WIM verification can be conveniently accomplished by police officers passing their own vehicles over the WIM prior to using the WIM for weight enforcement monitoring.

- WIM controllers can be auto calibrated, if the roadside reports can be automatically fed back to an interfacing computer (either local or centralized). This can be done manually or automated in a manner similar to a process used for fixed scale ramp sorters.

- Planning level reports can be generated from the WIM output data in monthly, quarterly and annual reports. This enables trend analysis, ESAL consumption rates (life cycle cost analysis) and FHWA annual report generation.

Central Operating System

WIMCAT can be thought of as an early version of a central operating system for a statewide network of WIMs. This global operating system would contain the same functions described above with some additional features. These may include the following.

- All vehicle classes reported
- Automated polling of the data each day
- A website to provide convenient access for multiple users
- Automated weekly, monthly, quarterly and annual reports.
- Alerts for data anomalies and very large loads
- Auto calibration of the WIMs
- Speed detection and other forms of monitoring
3.1.1. Imaging Systems

The demonstration of an imaging system at one of the WIM sites was accomplished through a cooperative effort between Mn/DOT and Mettler-Toledo. Mn/DOT prepared the site by including the conduit, foundation and pedestal. Mettler-Toledo loaned their demonstration equipment and provided on-site assistance to set up the system. For Mn/DOT, imaging of the vehicles is an important aspect of the VWS concept. The officers’ ability to accurately identify suspect vehicles from a downstream location proved to be a very successful demonstration.

**Configuration**

Mettler-Toledo furnished a field computer placed inside the cabinet serving as a hub, joining the WIM output data with the image of the truck. It also handled the file transfer from the cabinet to the officer’s vehicle. The intent of this configuration is to enable the officers to be covertly positioned downstream and to confidently identify specific vehicles. A limited range Local Area Network (LAN) was installed along with the camera equipment. Mettler-Toledo’s equipment provided excellent access up to 2000 feet away from the cabinet. Enforcement personnel appreciated the ease of access; however, they require a longer range for effectiveness. MSP dispatch personnel also indicated a desire to have access to the images from their work stations. (See section below on post-processing images.)

**Deployment Criteria**

To be consistent, all WIM cabinets should be equipped to support imaging systems; however, there are circumstances when the equipment may not be required. These include the following.

- **Conspicuous MSP enforcement**
  
  The Weight Compliance Program is to promote compliance not punishment. If a low volume site occasionally shows signs of increased violation activity, short bursts of conspicuous enforcement can effectively “get the message out” to the local carriers, particularly if the violators are frequently trucks hauling a region-specific commodity.

- **WIMs located on low volume roads**
  
  Enhancement costs may not be justified for low volume roads. MSP can effectively identify specific vehicles downstream without imaging when trucks are spaced far apart.

- **Budget constraints**
  
  WIMs can be setup without imaging and have the camera equipment added later to phase the construction and maximize VWS coverage.

- **WIMs located on roads with minimal violation activity**
  
  There are many reasons for installing a WIM, such as: vehicle classification/counting; pavement warrantee analysis; violation monitoring and damage estimation.
If violation behavior only occurs occasionally, then imaging may not be justified.

**Types of Images**

The demonstration for this project used still digital images triggered by the WIM controller. An alternative strategy is to capture short segments of MPEG4 video by using a digital video recording scheme. In this configuration, the camera is recording in a non-stop loop of only a few minutes to save media storage. Upon the arrival of an overweight vehicle, the computer saves the previous and subsequent three seconds of video to a file on the computer hard drive. This video is either stored for post processing or transmitted immediately to a downstream officer, where enforcement is active. This alternative gives the officer an enhanced view of the tractor and trailer prior to the vehicle’s arrival at the officer’s post. The downside to this alternative, is video images require more bandwidth to transmit. Also note, the camera triggering scheme used for this demonstration was nearly 100% effective at capturing the image of the vehicle corresponding to the WIM information.

**Post Processing Images**

Another approach for promoting weight compliance is to inform specific carriers when their vehicles are consistently operating overweight. Roadside enforcement may not be necessary, if the carrier chooses to obey the regulations once they have been put on notice without punitive action. Two approaches are possible.

1) A permanent camera at the WIM captures and uploads the images for post processing.

2) A manual approach, whereby an agency person sitting in an unmarked vehicle (such as a maintenance pickup) monitors the truck activity with their laptop and then manually captures images or short video clips of the non-compliant vehicles for further processing. This individual would be on site at times suggested by the WIMCAT for greater efficiency. The analyst who processes the video or images would capture the USDOT numbers and carrier information from the side of the truck.

In both approaches the habitual offenders are contacted by MSP to encourage non-punitive compliance.
3.1.2. License Plate Reading Systems

The scope of this project also called for an investigation into the potential use of license plate reading technology (LPR) as an enhancement to the VWS process. An attempt was made to attract an LPR vendor to put on a demonstration, and unfortunately none responded. A brief review of available LPR products indicated a successful recognition rate of approximately 60%. Vendors claim their system performance can be improved by “training” the computer to recognize the most frequently observed plate formats (color, font size, graphics, etc.). However, Mn/DOT and MSP agreed this was not reliable enough for their current project purpose and decided not to pursue LPR. Mn/DOT and MSP agreed to monitor the LPR industry’s progress pending more mature products yield the benefits listed below.

**Benefits**

License Plate Readers have a significant potential for enhancing VWS performance.

- A license plate provides a distinguishable “pattern” delineating one vehicle from another. If a license plate can be accurately read at the WIM, then it can be used to identify the same vehicle downstream without the need to transmit an image of the vehicle. This offers efficiencies in terms of bandwidth and speed of data transfer.

- A database of license plates associated with weight violations could be easily sorted to identify habitual offenders. Subsequent improvements in their compliance rates would prove to be very cost effective.

- A license plate reading function at a WIM could also provide a way of screening for stolen vehicles, amber alerts and vehicles with tax and registration issues.

**License Plate vs. DOT Number**

Although this section is entitled “License Plate Reading Systems”, there are actually two identifiable features on trucks usable as “patterns”. One is a license plate and the other is a USDOT number. Either one could be used in the short term to recognize a truck downstream from the WIM, but each has benefits and challenges.

**License Plates:** Of the two, license plates are unique to every truck. Minnesota requires front plates, but not all states require front plates on the tractor, making out of state trucks more difficult to identify. Also, each trailer has a unique license plate and can often vary from one trip to the next, complicating any database of habitual offenders.

**USDOT Numbers:** USDOT numbers are issued for each carrier, consequently every vehicle in the carrier’s fleet will have the same number. In Minnesota, intrastate carriers are not required to have USDOT numbers.

**Challenges**

The technology has many obstacles to overcome.

- Reading a front license plate requires the image to be taken either head-on or from a shallow angle. This is difficult to achieve because mounting the camera can be expensive. Reading a back license plate is extremely
difficult to do if a semi is hauling a trailer. Camera placement for reading USDOT numbers is slightly easier because it is located on the side of the vehicle.

- To read a number on a truck, the computer must first locate it. License plates are easier to read than USDOT numbers, due to the rectangular frame and positioning at bumper height. On the other hand, USDOT numbers can be placed just about anywhere on the side of the tractor and are not required to be in a frame. This makes it difficult for the computer to distinguish between the USDOT number and other graphics on the cab. Font sizes are not standardized, resulting in an increase in image variability.

- Reflectivity and embossed letters can present challenges to image recognition.

- Day/Night issues also exist and are similar to any imaging system in terms of color and contrast.

**Manual Enhancement**

It is possible to develop a semi-automated LPR system; however, no agency has done this to date. Because the number of violations logged in a typical day at a WIM is not extremely large, a daily file of images could be produced by a standard LPR system for either the license plates or the USDOT numbers. These images could be processed by a human operator, presented with the image of the truck, and a small window showing the LPR system’s interpretation of the number. The operator would verify the accuracy of the number by comparing the two and then approving the value, correcting it manually, or removing it from the file (if it is illegible). We estimate a trained operator could comfortably process about 200 images per hour. This is a post processing action; it would be ineffective for real time roadside enforcement. There is value for identifying repeat offenders and utilizing the information for other enforcement purposes. Also, this would provide an accurate performance measure for evaluating the latest versions of LPR technology. When the number of successful “reads” moves to the 95% (or more) range on a consistent basis, then the semi-automated process could be replaced with a fully automated system.
3.1.3. Dynamic Feedback System

Four potential concepts for providing immediate weight status feedback to commercial vehicle operators are presented below. Information is provided at a high level on the potential benefits and challenges of implementing each alternative.

**Concept 1: Permanent Display at Existing Mainline WIM Sites**

This concept would involve using permanent Variable Message Signs to provide commercial vehicle drivers with information about their weight status as they pass over existing mainline Weigh-in-Motion scales.

**Potential Benefits:**
- Increases driver awareness
  - Commercial vehicle operators could verify their weight without stopping at a fixed scale facility.
  - Drivers would be made aware their weight is being measured, potentially recorded and communicated to law enforcement.
  - Regularly informing drivers of their weight status makes a clear statement to truckers that weight compliance is a priority for Minnesota authorities.
- Increases peer pressure
  - Exposes a violator to other drivers (especially other commercial vehicle operators) applying pressure to “police” themselves.
- Increases efficiency
  - Utilizes existing WIM equipment, reducing overall costs and deployment time.
  - With the addition of digital imaging, the system could collect data for enforcement activities and/or warnings to violators.

**Potential Issues/Challenges:**
- Complicates enforcement process
  - Drivers may somehow use the feedback information to circumvent enforcement.
  - Drivers may experiment with the WIM equipment to determine how to generate a false reading.
  - Commercial vehicle operators may challenge a citation if the feedback system mistakenly showed they were in compliance.
  - Increasing the visibility of WIM sites may decrease their effectiveness by encouraging WIM evasion.
  - The weight measurement for this system would not be as accurate as a static scale. (If adequate resources are not provided for the calibration necessary to maintain system accuracy, false information will be presented to drivers.)
- Roadside to vehicle communication is difficult
  - Displaying weight status for commercial vehicles in different lanes of a multilane facility may be challenging. (Possible ways to address this issue: require trucks to move to the far right lane, as they approach the WIM scale and/or mount Variable
Message Signs on a mast arm over each lane.
- Timing the information display to reach the intended driver could be challenging on high-speed facilities.
- Weight information is easily visible to all drivers, creating a distraction to drivers of passenger vehicles. This could unnecessarily raise public concerns.

Possible System Components:
- Variable Message Sign
  - Mounted on mast arm over lanes
  - Permanent VMS on right shoulder
- WIM Station (Existing)
- Communications
  - Dial up or DSL
  - Wireless communications
  - Ethernet communications using fiber connection
- Additional Elements
  - Digital Imaging Unit

Figure 3-1 shows the layout for a similar system in Georgia providing feedback to commercial vehicle drivers on their speed, using data from upstream WIM scales.

**Figure 3-1 Georgia’s System**

Estimated Cost:
Figures 3-2 and 3-3 show estimated equipment costs for one direction. Installation, maintenance and operations costs are not included.
Figure 3-2 Estimated Equipment Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Message Sign</td>
<td>$25,000 - 118,000 *</td>
</tr>
<tr>
<td>Variable Message Sign Structure</td>
<td>$25,000 - 120,000 *</td>
</tr>
<tr>
<td>Communications</td>
<td>$8,000 - 15,000 *</td>
</tr>
<tr>
<td><strong>Total Cost (one direction)</strong></td>
<td>$93,000 - 253,000 *</td>
</tr>
</tbody>
</table>

*Low unit cost is for roadside message signs installed on right shoulder. Higher capital cost is for full matrix, LED VMS installed over multiple lanes.

Figure 3-3 Optional Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Imaging Unit</td>
<td>$28,000</td>
</tr>
<tr>
<td>Flash Unit</td>
<td>$2,200</td>
</tr>
<tr>
<td><strong>Total Cost (one direction)</strong></td>
<td>$30,200</td>
</tr>
</tbody>
</table>

Concept 2: Permanent Display at Existing Sorter WIM Sites

This concept provides gross weight information at mainline and ramp sorter WIM sites typically found at fixed weigh stations instead of, or in addition to the existing arrow indications. The existing Variable Message Signs could display weight status information if they can display enough characters.

Potential Benefits:
- Increases driver awareness
  - Commercial vehicle operators could verify their weight even if they are given the by-pass indication.
  - Regularly informing drivers of their weight status makes a clear statement to truckers that weight compliance is a priority for Minnesota authorities.
- Increases peer pressure
  - Exposes a violator to other drivers (especially other commercial vehicle operators) applying pressure to “police” themselves.
- Increases efficiency
  - The accuracy of the displayed weight values could be improved by establishing auto calibration.
  - Due to slower vehicle speeds, this system would have greater accuracy than mainline WIMs yet not as high as static scales.
  - Utilizes existing WIM equipment, reducing overall costs and deployment time.
  - With the addition of digital imaging, the system could collect data for enforcement activities and/or warnings to violators.

Potential Issues/Challenges:
- Complicates enforcement process
  - The arrow indication, or text stating the action a driver needs to make, is still necessary in addition to the weight status information (the weighmaster may choose to pull the truck in for reasons other than weight).
  - Drivers may experiment with the WIM equipment to determine how to generate a false reading.
Drivers could somehow use the weight information provided to circumvent enforcement.

Commercial vehicle operators may challenge a citation if the feedback system mistakenly showed they were in compliance.

Roadside to vehicle communication is difficult:

- At mainline sorting WIMs, timing the information display to reach the intended driver could be challenging due to the traveling speed of vehicles.
- If only gross weight is displayed, it may not be clear to drivers whether they should bypass the scale or report to the inspection station.
- At mainline sorter WIM sites, the weight information would be easily visible to all drivers, distracting passenger vehicle drivers.
- Timing the information display to reach the intended driver at mainline sorting sites could be challenging on high-speed facilities.
- If adequate resources are not provided for the calibration necessary to maintain system accuracy, false information will be provided.

Possible System Components:

- Variable Message Sign
  - Existing VMS (if they have the capability to display enough characters)
  - Additional VMS
  - Remote Weight Display Unit

- Additional Elements
  - Digital Imaging Unit

Estimated Cost:

Figures 3-4 and 3-5 show estimated equipment costs for one direction. Installation, maintenance and operations costs are not included.

**Figure 3-4 Estimated Equipment Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Message Sign *</td>
<td>$1,700 - $60,000 **</td>
</tr>
<tr>
<td>Variable Message Sign Structure</td>
<td>$15,000 - $25,000 **</td>
</tr>
<tr>
<td>Communications</td>
<td>$0 - $8,000 **</td>
</tr>
<tr>
<td><strong>Total Cost (one direction)</strong></td>
<td>$16,700 - $93,000 **</td>
</tr>
</tbody>
</table>

* Cost if existing VMS cannot be utilized.

** Low unit cost is for remote display sign. High unit cost is for roadside message sign.

**Figure 3-5 Optional Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Snapshot Unit</td>
<td>$28,000</td>
</tr>
<tr>
<td>Flash Unit</td>
<td>$2,200</td>
</tr>
<tr>
<td><strong>Total Cost per Lane (one direction)</strong></td>
<td>$30,200</td>
</tr>
</tbody>
</table>
Concept 3: Portable System for Use on Mainline Freeway and Expressway Locations

This system would combine a Portable WIM with a Portable Variable Message Sign to produce a temporary weight feedback system.

Potential Benefits:

- Increases driver awareness
  - Display of the weight information, in unexpected locations might give the impression law enforcement is everywhere.
  - Commercial vehicle operators could verify their weight without stopping at a fixed scale facility.
  - Drivers would be made aware their weight is being measured, potentially recorded and communicated to law enforcement.
  - Regularly informing drivers of their weight status makes a clear statement to truckers that weight compliance is a priority for Minnesota authorities.

- Increases peer pressure
  - Exposes a violator to other drivers (especially other commercial vehicle operators) applying pressure to “police” themselves.

- Increases efficiency
  - Moving the feedback system frequently would increase monitoring randomness.
  - Drivers would have more difficulty experimenting with a mobile system to defeat its purpose.
  - With the addition of digital imaging, the system could collect data for enforcement activities and/or warnings to violators.
  - The system could be set up on primary and secondary fixed scale evasion routes.
  - Mn/DOT’s existing fleet of Portable Variable Message Signs could be utilized, if available.
  - The system could be used as an additional component of the Virtual Weigh Station initiative.
  - The system could be set up temporarily in locations where seasonal increases in overweight truck traffic (i.e. logging, agricultural) are expected.
  - The system could be set up to temporarily monitor material hauling vehicles on local roads surrounding highway projects.
  - With the addition of digital imaging, the system could collect data for enforcement activities and/or warnings to violators.

Potential Issues/Challenges:

- Complicates enforcement process
  - To be effective, the system must be moved frequently to increase the element of surprise. This takes enforcement time and effort.
  - Portable systems are typically used with active enforcement. Remote monitoring during off hours is not practical.
  - Drivers may experiment with the WIM equipment to
determine how to generate a false reading.
  o Commercial vehicle operators may challenge a citation if the feedback system mistakenly showed they were in compliance.
  o Drivers may communicate the location of the system to each other resulting in increased traffic on alternate routes with weaker pavement.
  o The weight measurement for this system would not be as accurate as a static scale. (If adequate resources are not provided for the calibration necessary to maintain system accuracy, false information will be presented to drivers.)
• Roadside to vehicle communication is difficult
  o Timing the information display to reach the intended driver could be challenging on high-speed facilities.
  o Weight information is easily visible to all drivers creating a distraction to drivers of passenger vehicles. This could unnecessarily raise public concerns.

Possible System Components:
• Portable Variable Message Sign
• Portable WIM system
  o Two portable WIM sensor systems were recommended by a 2006 Mn/DOT sponsored feasibility study: Capacitance Mats (by Truvelo), and Piezoelectric Sensors (by ECM)
• Communications
  o Wireless communications
• Additional Elements
  o Digital Imaging Unit
  o Flash unit

Estimated Cost:
Figures 3-6 and 3-7 show estimated equipment costs for one direction. Installation, maintenance and operations costs are not included.

**Figure 3-6 Estimated Equipment Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable WIM System Electronics</td>
<td>$10,000</td>
</tr>
<tr>
<td>Portable Variable Message Sign</td>
<td>$16,000</td>
</tr>
<tr>
<td>Portable Sensors (per lane)</td>
<td>$ 7,000</td>
</tr>
<tr>
<td>Supervision, Training &amp; Calibration</td>
<td>$ 8,000</td>
</tr>
<tr>
<td><strong>Total Cost (one lane, one direction)</strong></td>
<td><strong>$ 41,000</strong></td>
</tr>
</tbody>
</table>

**Additional Optional Components:**

**Figure 3-7 Optional Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Snapshot Unit</td>
<td>$28,000</td>
</tr>
<tr>
<td>Flash Unit</td>
<td>$ 2,200</td>
</tr>
<tr>
<td><strong>Total Cost per Lane (one direction)</strong></td>
<td><strong>$30,200</strong></td>
</tr>
</tbody>
</table>
Concept 4: Portable/Semi-Permanent System for Use for Special Applications

This concept utilizes a portable or permanently installed WIM system along with a Portable Variable Message Sign to provide commercial vehicle operators with information about their weight status as they approach a bridge, or segment of road, that has a posted weight limit. The system is deployed at the point where overweight vehicles could make the choice to divert to an alternate route. A system similar to this was deployed by the Maine Department of Transportation at the Waldo Hancock Bridge to prevent overweight vehicles from crossing a weight restricted bridge. The Maine DOT WIM screening equipment included a digital snapshot unit to take pictures of overweight vehicles and VMS trailers displaying the total weight of each vehicle. More detailed information about this project is provided in the Literature Search section of this report.

Potential Benefits:

- Increases driver awareness
  - Deployment of the Waldo Hancock Bridge project by the Maine DOT significantly decreased the incidence of bridge crossings by overweight vehicles.
  - The system enables enforcement to monitor for trucks operating above their legal or permitted limits.
  - Displaying truck weight status along with the weight limit would make it very clear to drivers whether their vehicle can legally cross a posted bridge.
  - Commercial vehicle operators could verify their weight is within limits required for the bridge crossing.
  - Drivers would be made aware their weight is being measured, potentially recorded and communicated to law enforcement.
  - Regularly informing drivers of their weight status makes a clear statement to truckers that weight compliance is a priority for Minnesota authorities.
- Increases peer pressure
  - Exposes a violator to other drivers (especially other commercial vehicle operators).
- Increases efficiency
  - With the addition of digital imaging, the system could collect data for enforcement activities and/or warnings to violators.
  - Mn/DOT’s existing fleet of Portable Variable Message Signs could be utilized if available.
  - The system could be used as a component of the Virtual Weigh Station initiative.
  - The system could be set up temporarily where there is a seasonal increase in overweight truck traffic (i.e. logging, agricultural).
Potential Issues/Challenges:

- Complicates enforcement process
  - Commercial vehicle operators may challenge a citation if the feedback system mistakenly showed they were in compliance.
  - Drivers may choose to avoid the system resulting in an increase of overweight vehicles on alternate routes
  - It might be necessary to deploy the system on alternate routes.
  - It is important that the system be remotely operated.

- Roadside to vehicle communication is difficult
  - Timing the information display to reach the intended driver could be challenging on high-speed facilities.
  - Weight information is easily visible to all drivers creating a distraction to drivers of passenger vehicles. This could unnecessarily raise public concerns.
  - If adequate resources are not provided for the calibration necessary to keep the system accuracy, false information will be presented.

Possible System Components:

- WIM Station (one per direction)
- Variable Message Sign
- Communication between the WIM station and the VMS
- Additional Elements
  - Digital Snapshot Unit
  - Flash unit

Figure 3-8 shows the layout used for the Waldo Hancock Bridge project:

Figure 3-8 Waldo Hancock Bridge System Layout
Estimated Cost:
Figures 3-9 and 3-10 show estimated equipment costs for one direction. Installation, maintenance and operations costs are not included.

**Figure 3-9 Estimated Equipment Costs**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIM System Electronics</td>
<td>$17,000</td>
</tr>
<tr>
<td>Sensors (per lane)</td>
<td>$12,000</td>
</tr>
<tr>
<td>Portable Variable Message Sign</td>
<td>$16,000</td>
</tr>
<tr>
<td>Supervision, Training &amp; Calibration</td>
<td>$ 8,000</td>
</tr>
<tr>
<td><strong>Total Cost per Lane (one direction)</strong></td>
<td><strong>$53,000</strong></td>
</tr>
</tbody>
</table>

**Figure 3-10 Optional Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Snapshot Unit</td>
<td>$28,000</td>
</tr>
<tr>
<td>Flash Unit</td>
<td>$ 2,200</td>
</tr>
<tr>
<td><strong>Total Cost per Lane (one direction)</strong></td>
<td><strong>$30,200</strong></td>
</tr>
</tbody>
</table>
Conclusions

4.1. Results of the Virtual Weigh Station Pilot

The project scope called for a pilot demonstration at one site. This goal of utilizing the WIM at the Fisher for both enforcement and planning was successful in several ways as described below.

**Digital Imaging**

The TH 2, Fisher Site, was equipped with a Mettler-Toledo camera and hardware enabling the downstream officer to view both the digital image and data reported by the WIM. This was considered to be an important feature because it enables an officer to operate covertly downstream from the WIM without having the enforcement activity associated with the WIM site. This makes the enforcement appear to be more random, overcomes some of the CB radio broadcast issues, and lends itself to a process of identifying habitual offenders. Digital images can also be utilized to diagnose WIM data anomalies.

**Basic VWS Operation**

Combining efforts previously done by Mn/DOT and MSP with the project initiatives enabled Mn/DOT to equip all existing sites with basic VWS functionality. This includes weight violation reports presented wirelessly, in real time via air card technology to a downstream vehicle located within sight distance of the WIM. Basic VWS functionality was established at all of Minnesota’s available WIMs, not just the pilot site. Although the enforcement officer must be within sight distance to identify the violating truck, he or she can now select specific vehicles from the stream of traffic with greater confidence.

**WIMCAT**

The WIMCAT reports make the VWS process considerably more effective by optimizing the enforcement scheduling and tracking results. For further details, Appendix 6.2 demonstrates the WIMCAT reports and Appendix 6.5 summarizes the enforcement effort results.

**WIM Calibration**

Calibration of the WIM scales is an important issue for both Mn/DOT and MSP. Roadside inspections offer a unique synergy between MSP and Mn/DOT to improve the calibration process. Roadside inspections are conducted with certified portable scales, and a short series of inspections can produce calibration adjustments. These field measurements may also help Mn/DOT determine if the WIM is giving erratic results and requires scale maintenance. Effectively, this shortens the time typically required to identify and verify WIM health problems.

**Relationship Building**

One intangible, yet very important result of the pilot study was the strengthening of relationships among the various partners in Mn/DOT and MSP. Working together on this project, both stakeholders found several opportunities for integrating their operations. These included improved enforcement scheduling, lower cost WIM calibration, and the development of performance measures from common data sources.
4.2. Results of the Equipment Comparisons

The comparison of available Weigh-in-Motion equipment features included WIM controllers, digital imaging equipment and license plate readers. In general, all WIM controllers offered acceptable functionality; however, some different features were identified. The results are outlined below, and a detailed comparison is provided in Table 4.1.

**WIM Controllers**

The existing inventory of WIM controllers deployed in Minnesota was purchased from International Road Dynamics (IRD). All of these controllers are connected to Kistler quartz scales embedded in the pavement.

ECM, Cardinal, and PEEK Controllers were demonstrated in the project by their vendors. This was accomplished by temporarily replacing one of the existing controllers at the Fisher site.

**Digital Imaging**

The original project scope included purchase of one digital imaging camera along with the associated hardware and software required for integration with the WIM controller. The associated costs exceeded original project estimates. Instead, Mettler – Toledo demonstrated their product at the Fisher site with a camera mounted on a Mn/DOT installed pedestal. This provided Mn/DOT and MSP with hands-on experience. In addition, Mettler – Toledo and IRD provided live website demonstrations of their existing sites in Florida and Canada.

**License Plate Readers**

After preliminary review of available license plate reading technologies, only 60% reliability has been achieved under harsh roadside conditions. This is unsatisfactory for routine VWS applications. Vendors expressed little interest in demonstrating their products. However, near the end of this contract one vendor claimed 95% reliability. Time constraints did not allow for a demonstration during this project.
5.1. Recommendations

The Strategic Plan recommended deployment goals based on available resources. The recommendations from this project include (1) combining the WIM enforcement and planning functions and (2) expanding WIM network coverage. Activities to support the VWS deployment schedule follow.

Equipment Deployment

**Digital Image Deployment Criteria**

Budget limitations and projected low traffic demand prevent the installation of digital imaging technology at all WIM sites. The recommended application criteria are listed below, to determine which sites should be deployed.

- **High truck volumes** make it difficult to identify non-compliant trucks.
- **Remote site locations** enable monitoring from a distance.
- **Heavy commodity traffic locations** increase the potential for overweight vehicles.
- **By-pass route WIMs** monitor fixed scale evasion on obviously fixed scale by-pass routes.
- **Multiple site monitoring** supports simultaneous enforcement for multiple sites within a region of the state.

**Digital Imaging Specification**

Create a new specification to procure WIM digital imaging equipment to allow the following general strategies.

- Purchase commercially available systems from a WIM vendor.
- Create a generic equipment configuration compatible with any WIM controller. (See Fisher site for configuration details.)

**Digital Imaging Without WIM**

Digital imaging can also be utilized with a vehicle classifier. Typically, this is applied on routes where vehicles by-pass a fixed scale or an actively patrolled mainline WIM site. The intent is to identify specific trucks that evade the scale. The equipment is similar to the WIM imaging equipment, except the camera is triggered by a classifier instead of a WIM controller. MSP or local enforcement officers would monitor these images while the mainline enforcement is underway to single out evaders. One strategy to distinguish evading from non-evading vehicles is to position the officer at the point where the evading vehicle is likely to return to the mainline roadway. Any vehicles corresponding with these images are potential evasion candidates.

**Complete Fisher Site Equipment**

The Fisher site is now ready to install permanent digital imaging equipment. Consider one of these choices.

- Use vendor supplied equipment (IRD products, estimated range from $40,000 to $80,000 depending on features).
- Develop a generic digital imaging system triggered upon a violation.

A simple system consists of a low cost camera, a PC in the cabinet,
**Recommendations**

and Internet access. This equipment configuration allows a digital image or short video stream to be triggered upon a relay closure from the WIM. The image is then automatically attached to a blank e-mail and sent to an enforcement officer downstream. Although the officer lacks access to the WIM data, this limitation can be overcome by using a high WIM filter threshold.

Also, a modest upgrade to this simple system could be configured to attach the WIM data along with the image file before it is sent electronically to the officer. Both cost effective options enable the officer to distinguish non-compliant trucks at any distance downstream from the WIM.

Replacement of this simple system would occur when the central operating system is built.

The central operating system takes this concept one step further by continually posting both WIM data and images on a website for all authorized users to view over the Internet. For comparison, the optional configurations are outlined in Table 5-1.

<table>
<thead>
<tr>
<th>Level</th>
<th>Features</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No connection between the officer and the WIM cabinet</td>
<td>Officer selects vehicles based on observations</td>
</tr>
<tr>
<td>1</td>
<td>Air card connectivity between WIM and Cabinet</td>
<td>Officer must be within sight distance of the cabinet, however can view live data for each vehicle’s weight</td>
</tr>
<tr>
<td>2</td>
<td>Image sent as an email</td>
<td>Officer merely waits for the emails to arrive. Then the officer stops the vehicle and conducts a roadside inspection.</td>
</tr>
<tr>
<td>3</td>
<td>PC merges WIM data and image and then sends email</td>
<td>Similar to #2, except the officer has more information to make a decision to stop a vehicle.</td>
</tr>
<tr>
<td>4</td>
<td>System posts images and WIM data on a website map</td>
<td>Officer selects the WIM site and monitors images and weight data using a browser interface. The officer can choose to see any or all vehicles by filtering parameters.</td>
</tr>
</tbody>
</table>

**Calibration**

**WIM Speed Errors**

During the WIMCAT processing, the error reports showed a number of WIM sites with fast speed errors. (The WIM speed values are reporting values registered faster than the true speed of the vehicles). The WIMCAT error reports validated the need for calibrations. The calibration process is important for corrections to be made to the speed values, since the WIM reports the speed values are required to calculate the axle spacing. The axle spacing can affect how the WIM assigns vehicles to each classification bin.

**Manual MSP Calibration**

For sites equipped with basic VWS features, develop work procedures and training to certify MSP officers for standard routine manual calibration of WIM sites. An alternate version of this is to submit scale reports from the roadside inspections to TDA to calculate calibration adjustment factors. TDA then recalibrates the scale.

**Auto Calibration**

Some VWS vendors offer an auto-calibration feature with their
equipment, typically used for fixed scale by-pass ramp sorters. These systems average the fixed scale values and, then, automatically adjust the ramp sorter WIM values. This system can be adapted to repeat roadside portable scale readings as a WIM calibration factor semi-automatically. The factor is recalculated every time the officer wirelessly submits the completed roadside inspection report. If the auto-calibration factor exceeds the user-specified threshold, then the system automatically applies the correction factor.

Institutional Recommendations

**Update Documentation**
To maintain the VWS program, routinely update the following documents.

- WIM Site & Inspection site maps with corresponding tables (as changes occur)
- The damage report spreadsheet (annually)
  - ESAL values
  - Pavement replacement costs
  - Pavement & bridge deck square footage values
- WIMCAT (as changes occur)
  - Winter Load Increase Table
  - Annual permit adjustment factors

**Coordinate Activities with Local Agencies**
Encourage MSP to assist local agencies with weight compliance issues.

- Trucks by-passing the fixed scales
- Trucks by-passing WIM scales when enforcement activity is underway.
- Movement of heavy commodities prone to operating overweight.

A comprehensive monitoring of state and local roadway networks has the greatest potential for encouraging compliance.

**Enforcement Scheduling**
The WIMCAT reporting process can help develop weekly statewide and district level schedules. This process can track performance and compare any changes in compliance with the level of enforcement. The prototype phase of this contract confirmed that active enforcement reduces the violation rate for short periods of time. National targeted enforcement experiences have demonstrated periodic “maintenance” enforcement can extend the benefits of compliance indefinitely. WIMCAT can help determine when and where periodic enforcement is considered necessary.

**Develop VWS Training Modules**
Develop VWS training modules to provide a smooth transition when personnel changes occur.

- **Introduction to Virtual Weigh Stations**
  - Definition of the compliance program
Recommendations

- Roadway damage caused by overweight trucks
- Limitations of fixed scales
- Advantages of WIM screening strategies
- VWS components
- How VWS performance measures enhance the decision making process
- Focus - compliance vs. enforcement
- Inter-agency integration

WIM Calibration
- WIM calibration techniques
- Daily enforcement vehicle WIM check

Scheduling Strategies Using WIMCAT
- Critical site selection from basic ELR values
- Critical hours of the week selection from charts
- Measurement of progress from 3-week moving averages
- Make use of WIMCAT “Capture Odds” to set expectations
- Determine violation threshold values
- Establish data confidence from the error reports

Conspicuous Enforcement
A recent Minnesota study, Collision Prevention Strategies II, found conspicuous enforcement had a significantly stronger impact on compliance than covert enforcement. Similarly, conspicuous inspections sent clear messages to carriers who violated weight regulations. The CB radio system facilitates message distribution.

Randomized enforcement is achieved by covert positioning of the inspectors. The combination of covert screening and conspicuous inspection strategies provide the impression MSP has broader coverage. MSP can further leverage this impression by randomly shifting the location of officers based on the WIMCAT reports.

Pilot Project

Pursue Pilot for Dynamic Feedback System
The TranSmart study suggests the dynamic feedback system is feasible under certain circumstances. To develop a pilot project, the recommended steps are as follows.
- Choose criteria and select a prototype site
- Develop pilot project scope/schedule/budget
- Create an evaluation plan

Develop Additional Tools
Create a plan to introduce these tools to supplement the VWS initiatives in Minnesota.
- A Central Operating System with the following features
  - Website access for all stakeholders
Recommendations

- Daily automated data polling
- Auto calibration
- Alerts for extreme violations
- Scheduling tools
- WIM health tracking reports
- Performance measure reports

- Low cost weight compliance supplementary tools
  - Local road by-pass monitoring (non-WIM tools)
  - Statewide inspection sampling strategy for trunk highways not having WIMs
  - A map of heavy commodity trips to help establish priorities for new WIM sites.
  - A pavement assessment map indicating pavement strengths to recommend priorities for enforcement.

Research Recommendations

During the course of this project several future research concepts were identified.

- A study to compare truck crash data with overweight vehicle statistics
  To determine if overweight trucks have a higher propensity for crashes; hence, providing a safety justification for funding.

- Advance license plate reading technology
  The state of the art for LPR is improving. New technologies are required to raise the accuracy rates.

- Identification of heavy commodity movement trends
  These may leverage the work of others to identify common overweight truck paths for locating new WIM sites.

- Seasonal commodity trends
  Again, this may benefit WIM site selection and influence seasonal enforcement schedules.
TH 53 WIM - Cotton
District 1 (Duluth) – St. Louis County

WIM Scale Cabinet is located on the east side of the TH 53 NB lanes. Access to the cabinet is shared with a private driveway. All of the four NB and SB lanes have scales. The suggested inspection site for NB traffic is at the Rest Area located at MP 49. The suggest inspection site for SB traffic is at the frontage road in Cotton at MP 39.
TH 53 WIM Location – NB Inspection Site

The NB inspection site is located at MP 49 along TH 53. There is a rest area at this location that can provide a safer inspection site. This location is approximately 7 miles north of the WIM Scale. This location is at the Anchor Lake Rest Area. TH 53 in this area has a paved shoulder on the right side approximately 10’ in width and an additional 3’ gravel shoulder.
TH 53 WIM Location – SB Inspection Site

The SB inspection site is located at MP 39 along TH 53. This site is on the west side of TH 53 on the frontage road. This section of the frontage road dead-ends north of the nearest access intersection to the frontage road. The frontage road services a few small business and homes with very light traffic and a pavement width in excess of 24’. TH 53 in this area has a paved shoulder on the right side approximately 10’ in width and an additional 3’ gravel shoulder.
TH 61 WIM – Two Harbors
District 1 (Duluth) – Lake County

WIM Scale Cabinet is located on the west side of the TH 61 SB lanes near MP 16. Access to the cabinet is provided via a township road approach. Both NB and SB lanes have scales. There are two suggested inspection sites for NB traffic, one is at MP 18 at the Knife River Rest Area and the other is at MP 21 just before Larsmont Rd. The suggested inspection site for SB traffic is at the CR 50 (Ryan Rd.) intersection.
TH 61 WIM Location – NB Inspection Site

The NB inspection site is located at MP 21 along TH 61. This site is on the east side of TH 61 just before the Larsmont Road. TH 61 in this area has a paved shoulder on the right side approximately 10’ in width and an additional 3’ gravel shoulder. An alternate location is at MP 18 at the Knife River Rest Area.
TH 61 WIM Location – SB Inspection Site

The SB inspection site is located at left-turn lane just before County Rd. 50 (Ryan Rd.) along TH 61. TH 61 in this area has a paved left-turn lane on the left side of the SB lanes approximately 12’ in width and an additional 3’ gravel shoulder.
TH 2 WIM - Fisher  
District 2 (Bemidji) – Polk County

WIM Scale Cabinet is located on the north side of the TH 2 WB lanes. Access to the cabinet is provided via a field driveway. Both EB and WB lanes have scales. The suggested inspection site for EB traffic is at the Fisher's Landing Rest Area located at MP 12. The suggestion inspection site for WB on a frontage road located near MP 2.
TH 2 WIM Location – EB Inspection Site

The EB inspection site is located at MP 12 along TH 2. This site is on the north side of TH 2 at the Fisher's Landing Rest Area. This location will require crossing the WB lanes to enter the Rest Area, however this site is designed for both directions of traffic to enter the rest area.
TH 2 WIM Location – WB Inspection Site

The WB inspection site is located at MP 2 along TH 2 in East Grand Forks. This site is on the north side of TH 2 on the Service Road and can be entered at 7th Ave. or 5th Ave.
WIM Scale Cabinet is located on the north side of the TH 94 WB lanes. Access to the cabinet is provided via the MnROAD test track, it is not accessible from TH 94. Only the WB lanes on the test road have scales. The suggested inspection site for WB traffic is CR 75 (Exit 195). Several locations on or just after this exit would be suitable for inspection.
TH 94 WIM Location – WB Inspection Site

One WB inspection site is the auxiliary lane located on CR 75/Broadway St. at the WB off-ramp (Exit 195) from TH 94. This site is on the east side of CR 75 adjacent to the off-ramp acceleration taper onto CR 75. Return access to WB TH 94 is via WB Broadway St. to SB TH 25 to the TH 94 interchange (Exit 193). Total distance is approximately 2.5 miles.
TH 94 WIM Location – WB Inspection Site Alts.

Two alternate WB inspection sites are located near the CR 75/Broadway St. interchange with TH 94 (Exit 195). These sites are the paved shoulder (12' wide) before the right-turn lane from Broadway St. to Hart Blvd. south of Riverview Dr. or on Hart Blvd. between Broadway St. and Riverview Dr. Currently this section of Hart Blvd. services a residential development and mostly undeveloped parcels of land. Return access to WB TH 94 is via WB Broadway St. to SB TH 25 to the TH 94 interchange (Exit 193). Total distance is approximately 2.5 miles.
TH 35 WIM - Owatonna
District 6 (Rochester) – Steele County

WIM Scale Cabinet is located on the west side of the TH 35 SB lanes. Access to the cabinet is provided via a gravel field driveway. Both NB and SB lanes have scales. The suggested inspection site for NB traffic is at the Rest Area located at MP 35. The SB traffic has two suggested locations. One is on TH 30 (Exit 26), 0.5 mi west of TH 35 at the right turn lane for SW 42 Ave. The other location is at an old fixed scale station on TH 35 at MP 17.
TH 35 WIM Location – NB Inspection Site

The NB inspection site is located at MP 35 along TH 35. This site is on the east side of TH 35 at the Straight River Rest Area. The Rest Area location has a large area for truck parking and should provide a several safe and suitable locations for inspection.
TH 35 WIM Location – SB Inspection Sites

Two locations exist for a SB inspection site. The closest location is on TH 30 near the TH 35 interchange (Exit 26). The inspection site is approximately 0.5 miles west of TH 35 at the right-turn lane from TH 30 to SW 42nd Ave. This location provides an easy turn around site to return to TH 35 for the inspected vehicle. The shoulder and pavement for the right turn lane is approximately 13’ in width.
TH 35 WIM Location – SB Inspection Sites

The second location for a SB inspection site is on TH 35 near MP 17. This location is at a closed Weigh Station on SB TH 35. Although this site is located several miles from the WIM site it provides a safe location along TH 35 and allows for covert stationing at Exits 22 and 26.
The WIM Scale Cabinet is located on the south side of TH 60 EB lanes. Access to the cabinet is provided via a field drive. Only the EB lanes have scales. Two inspection sites have been identified, one for trucks that continue EB and another for trucks that exit TH 60 and travel south on TH 4.
TH 60 WIM Location – EB Inspection Site

The EB inspection site is located at MP 73 along TH 60. This site is on the north side of TH 60 at the Watonwan River bi-directional Rest Area. This rest area provides ample parking space to provide a safe inspection location away from highway speed traffic.
TH 60 WIM Location – SB Inspection Site (EB TH 60 to SB TH 4)

The SB inspection site is located at MP 30.5 along TH 4. This site is on the west side of TH 4 on the paved shoulder just before the right turn lane to CR 10 near Long Lake Road. This site can be used for any EB TH 60 vehicles that exit onto SB TH 4 approximately 0.75 miles east of the TH 60 WIM site. This location is about 5 miles south of the interchange. The paved shoulder at this inspection site is approximately 13’ in width.
WIM Scale Cabinet is located on the south side of the TH 2 EB lanes. Access to the cabinet is provided via a private driveway. Both EB and WB lanes have scales. The suggested inspection site for EB traffic is at located at MP 96 near Shevlin. The suggest inspection site for WB on the frontage road located at MP 87 on the west side of Bagley.
TH 2 WIM Location – EB Inspection Site

The EB inspection site is located at MP 96 along TH 2. This site is on the south side of TH 2 at the turn lane for CR 2. TH 2 in this area has a paved shoulder on the right side approximately 12’ in width.
TH 2 WIM Location – WB Inspection Site

The WB inspection site is located at MP 87 along TH 2. This site is on the north side of TH 2 on the frontage road approaching CR 25. The frontage road provides a location away from the more heavily traveled TH 2.
WIM Scale Cabinet is located on the south side of the TH 212 EB lanes at MP 78. Access to the cabinet is provided via a private driveway. Both EB and WB lanes have scales. The suggested inspection site for EB traffic is in Bird Island located at MP 82. The suggest inspection site for WB traffic in Olivia is located at MP 76 or alternatively on the frontage road (Walnut Ave.).
TH 212 WIM Location – NB Inspection Site

The EB inspection site is located at MP 82.0 on TH 212. This location is just past 5th St. in Bird Island. There is a paved shoulder at this location, which is approximately 12’ wide.
TH 212 WIM Location – WB Inspection Site

The WB inspection site is located at MP 76 between 12th St. and the TH 71 East Junction in Olivia. As an alternate, a frontage road (Walnut Ave.) exists along the north side TH 212 on the west side of Olivia before the airport and the TH 71 West Junction.
TH 23 WIM – Clara City  
District 8 (Willmar) – Renville County

WIM Scale Cabinet is located on the west side of the TH 23 SB lanes at MP 122. Access to the cabinet is provided via a private driveway. Both NB and SB lanes have scales. The suggested inspection site for NB traffic is in Raymond located at MP 128. The suggest inspection site for SB traffic is in Clara City located at MP 120.
TH 23 WIM Location – NB Inspection Site

The NB inspection site is located at MP 128 on TH 23. This location is just past 3rd St. in Raymond. There is a paved shoulder at this location, which is approximately 12’ wide.
TH 23 WIM Location – SB Inspection Site

The SB inspection site is located at MP 120 on TH 23. This location is just past Main St in Clara City on a frontage road. The frontage road is located on the west side of TH 23.
6.2 MnDOT WIM Data Processing Report Outline

1 Purpose
Ultimately, the purpose for the Virtual Weigh Station program is to reduce pavement and bridge deck damage caused by overweight vehicles, and this can be accomplished by improving truck weight compliance. One of the major objectives in achieving that goal is to establish the dual use of mainline WIM stations that routinely produce timely information that can be used to focus limited enforcement resources wisely. To achieve this WIM dual use, an Excel macro was developed to produce enhanced WIM reports from the raw data in a timely manner. These new functions include the following.

- To identify, quantify and categorize the different violation rates
- To produce pavement damage estimates
- To provide information that will help MSP optimize enforcement scheduling
- To serve as a preliminary step in creating a vision for a Central Operating System

2 Process Overview
The Excel macro was built with several characteristics as described below.

2.1 Vehicle Classes
To simplify the process only Class 9 & 10 trucks are considered by the macro. These two vehicle classes represent the majority of trucks currently in use by the motor carrier industry. (The damage from smaller vehicles is substantially less significant.) It is expected that the methodology developed for these two classes would be expanded to include all other vehicle types when a Central Operating System is created.

2.2 Methodology
From a high level perspective, this can be described as a process that theoretically offloads the excess weight from violating trucks on to empty legal trucks and then recalculates the damage for the pair of trucks. The difference between the damage caused if both trucks were legal vs. the existing condition (i.e. one overweight truck) provides a performance scale for the weight compliance program. A flowchart describing this process is included in the Appendix.

2.3 Data Quality
In addition to the methodology described above, the system also flags data anomalies. This includes unreasonable axle weights, and it also incorporates some proof checks developed by Purdue University that indicate if the WIM data is trending away from acceptable levels.

3 Reports
The WIM macro output can be used in a variety of ways to improve decision making.

3.1 Performance Measures
Performance measures are used to guide a decision making process. Mn/DOT has selected several performance measures that clearly support weight compliance program decisions. Several of these measures come directly from the WIM data and are derived from the new Excel macro. They include.

- Percent of overweight vehicles by class and violation type
• Percent of overweight trucks by levels of magnitude (ex. 0-10k, 10k-20k, etc.)
• Pavement damage due to overweight vehicles (in dollars)
• Violations listed by hour of the week
• Violations listed by day of the week

3.2 Possible Use as a Scheduling Tool
The performance measures described above are useful for prioritizing the deployment of limited enforcement resources. For example, knowing what days of the week, and what hours of the day the greatest number of violations are occurring can be useful for planning weekly MSP enforcement schedules. Knowing which WIMs are experiencing the most severe damage can be helpful in planning "blitz" enforcement where groups of officers can team up and work an area extensively. This can also be used to identify seasonal and commodity-specific weight violation trends. When excessive loading is observed in the WIM data for areas with large sources of specific commodities, this information can also be used to focus civil weight enforcement on the sources that produce those commodities. Digital images of the violating trucks can sometimes reveal certain carriers' company names. Or, if a few roadside inspections pick up a trend for a few specific DOT numbers, then civil weight enforcement can be applied to those carriers.

3.3 Special Event reporting
Because Minnesota allows different load maximums during different weeks of the year, this WIM data can be used to monitor compliance before and after the load limits change. Again, this can be useful for scheduling enforcement details, and it can also be used to inform legislators about the impacts of the regulations they have in place or are considering.

3.4 Specific Use Reports
There are also some special applications that are supported by WIM data. For example, truck weight compliance can be studied around areas that have high concentrations of specific commodities such as locations adjacent to ethanol plants or lumber harvesting for assessing the impacts that those movements have on the highway infrastructure.

Although pavement warranties have not been implemented to date in Minnesota, there has been significant interest shown, and the processed WIM data makes the potential use of warranties much more practical. For example, the use of WIM data can be a fair way to determine if vehicle loading was within expected ranges.

The information generated from the WIM data can be helpful in producing annual FHWA reports about truck movements and weight compliance. It is recommended that the content and format of these annual reports be built into the requirements for a Central Operating System.

A significant calibration benefit can be derived by comparing the MSP's actual roadside weight measurements with the observed WIM data. The calibration of WIM sites is a costly, time-consuming process, so there is a tendency to calibrate infrequently. The axle weights produced during the roadside inspections can routinely be averaged and then used to adjust the calibration of the WIM to compensate for temperature changes and equipment trends.

Special WIMs located along roadways that contain vulnerable bridges (such as older welded steel girder structures) can monitor truck weights, and that information can be used to target enforcement when needed to protect the structures from damage.

Undoubtedly, there would also be many research projects that could use this information as well. These might fall into categories such as pavement design studies, commodity movement studies, or pavement and bridge material wear studies.
4 Operational Issues
The development of the Excel macro created new opportunities for the way business is conducted. This also suggests that changes may be needed to work procedures, funding allocations, and agency responsibilities. The list below addresses a few of the significant issues.

4.1 Communication Options
Historically all WIM data has been acquired through landline modems. The Communications Plan found in other sections of this report describes communications options that can be used to support wireless connectivity to the enforcement vehicles as well as Internet access to the WIM data. Multiple uses for the communications systems are encouraged to take advantage of cost savings for the departments sharing the facilities.

4.2 Procedures
Probably the biggest institutional changes will occur in form of work assignments and work procedures. These will come in many forms such as those listed below.

- Historically, the Traffic Data Analysis section has been responsible for collecting and distributing the data. With dual use WIMs, this process could be changed. For example, it is now possible for these new applications to be established with the data being stored on secured websites, giving the various end users access rights according to their needs. This gives TDA full control of the data as in the past, and also enables other access without adding more burdens to TDA.

- The turn around time for translating raw WIM data to useable information will need to be faster than previously required. Planning level information typically is developed on an annual basis. Enforcement level information will need to be at the very least monthly, and preferably weekly or daily to be useful.

- WIM calibration can be effectively focused on those times when the WIM health is questionable based on the Excel macro error reports. This enables Mn/DOT to maintain reliable WIM performance with limited manpower.

- A quick WIM verification can be conveniently accomplished by police officers passing their own vehicles over the WIM prior to their using the WIM for weight enforcement monitoring.

- WIM controllers can be auto calibrated if the roadside reports can be automatically fed back to an interfacing computer (either local or centralized) that performs the averaging and then suggests calibration adjustments. This can be done manually or automated in a manner similar to fixed scale ramp sorters.

- Planning level reports can be generated from the WIM output data in monthly, quarterly and annual reports. This enables trend analysis, ESAL consumption rates (life cycle cost analysis) and FHWA annual report generation.

4.3 Equipment and Services Required
Dual use of the WIM sites implies that additional technologies be added to the cabinets and to the enforcement vehicles. This implies up-front capital investments and monthly operating costs from service providers as well as maintenance costs through the life of the equipment. As with any technology, on-going operating expenses can be expected. These will come in the form of calibration efforts, replacement of modules due to damage (ex. lightning) or electronic equipment failure and replacement at the end of the useful life cycle. Routine and non-routine maintenance will also be needed, and this can become more demanding as more end users begin using the data.
Blank ESALCalc Check  (BLANK/NOT BLANK)

**NOT BLANK**
Spreadsheet opens but not the GUI

**BLANK**
GUI opens and waits for user input  [PROCESS/HELP/EXIT]

User clicks the **Process Button**
Checks for .xls files in the DATA folder (YES/NO)

**YES**
- Message Box tells the user to remove the XLS files and try again.

**NO**
Checks for .ASC files (YES/NO)

**YES**
- Function Auto_Week is called
- Function cleanUp is called
- Function fileSize is called

**NO**
- Returns to cleanUp
- Function monthAndYear is called

**YES**
- Returns to cleanUp
If the vehicle class is 10
- Function class10 is called
- Function superWim is called
- Function currentRow is called
- Function hourlyCounter is called

If the vehicle class is 9
- Function class9 is called
- Function superWim is called
- Function currentRow is called
- Function hourlyCounter is called

If the vehicle isn't a class 9 or a class 10 it loops back to check the next vehicle.
If the end of the file is detected

Returns to Auto_Week
- Function nameThings is called
Once the last .ASC file has been processed the macro opens the **finalForm GUI**

**Report Printing Button**
- Print Class 9 Report
- Print Class 10 Report
- Print Combined Class Report
- Print All Reports

**Error Printing Button**
- Select the **Summary** checkbox
- Select the **Summary + Log** checkbox
- No check boxes selected
- Help Button
- Exit Button

**YES**
- Exits the macro and the XLS spreadsheet

**NO**
- Message Box warns the user that there aren't any .ASC files to process.

User clicks the **Help Button**
User clicks the **Exit Button**

**YES**
- Exits the macro and the XLS spreadsheet

**NO**
- Returns to the GUI
6.3 Excessive Load Ratio – Example

The Excessive Load Ratio = \( \frac{\text{Total Excessive Load}}{\text{Total Number of Trucks}} \times K \)

Where:
- Total excessive load = Total tons of cargo in excess of legal loading for all trucks in the sample.
- Total number of trucks = Total number of trucks in the sample (includes both legal and overloaded trucks)
- \( K \) = an adjustment multiplier that changes the decimal to whole numbers (100)

The tables below demonstrate how using the ELR as a performance measure is more sensitive and demonstrates how improvement can be expressed regardless of whether the compliance improvement is realized in terms of the volume or the magnitude of violations or both, giving a truer presentation.

<table>
<thead>
<tr>
<th>Case #</th>
<th>Total # Trucks in Sample</th>
<th>Total # Overweight Trucks</th>
<th>Total Tons of Excess Cargo</th>
<th>% Overweight</th>
<th>ELR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month #1</td>
<td>200</td>
<td>20</td>
<td>20</td>
<td>20/200 = 10%</td>
<td>(20/200) x 100 = 10</td>
</tr>
<tr>
<td>Month #2</td>
<td>200</td>
<td>20</td>
<td>10</td>
<td>20/200 = 10%</td>
<td>(10/200) x 100 = 5</td>
</tr>
<tr>
<td>Month #3</td>
<td>200</td>
<td>10</td>
<td>5</td>
<td>10/200 = 5%</td>
<td>(5/200) x 100 = 2.5</td>
</tr>
</tbody>
</table>

Table #2 presents a comparison of the two performance measures and the advantages of the ELR.

<table>
<thead>
<tr>
<th>Case Comparisons</th>
<th>What is different</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month #1</td>
<td></td>
<td>For comparison purposes in Month #2 and #3, this will serve as last month’s data (i.e. a baseline).</td>
</tr>
<tr>
<td>Month #2</td>
<td>The quantity of violations did not change from Month #1. In Month #2, however, the total excess load for all violating trucks was lower.</td>
<td>The % overweight showed no improvement, but the ELR picks up the fact that the excessive loading was smaller, showing the improvement in compliance.</td>
</tr>
<tr>
<td>Month #3</td>
<td>In Month #3 both the quantity and the magnitude of the damage decreased from month #1.</td>
<td>The % overweight value showed improvement, but it does not reflect the true compliance improvement that occurred due to smaller violations. ELR reflects both aspects.</td>
</tr>
</tbody>
</table>
6.3 Detailed Performance Measures

Each measure found in the summary table presented earlier is described below in greater detail. The Steering Committee will coordinate the necessary actions to get these measures adopted into the appropriate agencies’ day-to-day operations, preferably in an automated fashion to minimize cost and effort.

The following details are provided to explain each measure:

- **Name** (Brief name to distinguish measure from all the rest)
- **Measure Category** (Organizing tool that assigns related measures into convenient groups)
- **Definition** (Specific information that clearly identifies what is being measured)
- **Criteria for Use** (A brief explanation of why the measure is being used)
- **Reporting Frequency** (A schedule that identifies how often the measure is produced)
- **Delivery Process** (Details about how the measure is calculated)
- **End Users** (A listing of who will use the report)
- **Producing Agency** (A listing of the agencies that are involved in generating the report)
- **Reporting Format** (A description of what the report will look like and how it will be delivered)
- **Work Procedure** (Once the Technical Committee decides to use a particular measure, detailed work procedures are developed to document exactly how the measure is produced. This includes details about who will do the work, when it is done, how it is done, what tools are needed, distribution lists, and quality assurance procedures)
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Scale Facility Deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>Condition Measures – System Size &amp; Value</td>
</tr>
<tr>
<td><strong>Definition</strong></td>
<td>This measure is a simple inventory of the various truck weight compliance facilities compared to an ultimate inventory vision. This inventory can include fixed scale houses, Weigh-in-Motion (WIM) stations, vehicle classification sites, inspection sites and trailer mounted mobile scales. It would then be presented as a percentage of the ultimate number of planned facilities. This measure is used to provide a quick snapshot of the deployment level within Minnesota for each type.</td>
</tr>
</tbody>
</table>
| **Criteria for Use** | ✓ Determining maintenance budgets  
✓ Qualifying the accuracy of extrapolated data  
✓ Producing various official reports and public info releases  
✓ Justifying staffing budgets/schedules |
<p>| <strong>Reporting Frequency</strong> | Updated annually |
| <strong>Delivery Process</strong> | Reporting on this measure requires that the Size and Weight Committee identify someone who can produce an updated report that shows the total number of each type of facility currently in operation or under construction and calculate a simple percentage of the total vision. The level of effort to do this is very small – probably less than four hours per year to collect the data, update last year’s report and distribute the information. |
| <strong>End Users</strong> | The Size and Weight Committee represents the spectrum of stakeholders. |
| <strong>Producing Agency</strong> | Mn/DOT |
| <strong>Reporting format</strong> | This measure will be reported as part of an annual “Weight Compliance Performance Measures Report.” It could also be included in a web based reporting system. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Roadway Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measure Category</strong></td>
<td><strong>Condition Measures – System Size &amp; Value</strong></td>
</tr>
<tr>
<td><strong>Definition</strong></td>
<td>This measure is a simple inventory of the pavement and bridge deck surface areas for each category of roadway type. This measure is used in the calculation of the annual damage due to excessive truck loading.</td>
</tr>
</tbody>
</table>
| **Criteria for Use** | ✓ Determining the effectiveness of the Weight Compliance Program  
✓ Establishing a “miles per WIM site” factor used in programming for new WIM sites.  
✓ Justifying staffing budgets/schedules |
<p>| <strong>Reporting Frequency</strong> | Updated annually |
| <strong>Delivery Process</strong> | Reporting on this measure requires that the total lane mileage and bridge deck surface area data be obtained for each roadway type. These are then multiplied by the appropriate costs per square foot to derive a replacement cost for the entire roadway network. These values are then used in the annual damage estimate calculation. |
| <strong>End Users</strong> | The various members of the Size and Weight Committee represent a spectrum of primary users for this data. |
| <strong>Producing Agency</strong> | Mn/DOT |
| <strong>Reporting Format</strong> | This measure will be reported as part of an annual “Weight Compliance Performance Measures Report.” It could also be included in a web based reporting system. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Average Daily Truck Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>System Loading</td>
</tr>
<tr>
<td>Definition</td>
<td>This measure represents the total truck traffic that occurs each year. It becomes the denominator in violation rate ratios.</td>
</tr>
</tbody>
</table>
| Criteria for Use       | ✓ Revising design life cycle parameters  
                          ✓ Qualifying violation and permit rates  
                          ✓ Legislative inquiries  
                          ✓ Prioritizing enforcement officer deployment  
                          ✓ Estimating needed enforcement hours/year |
<p>| Reporting Frequency    | Updated annually                                                |
| Delivery Process       | Reporting on this measure requires that the Size and Weight Committee identify the resources needed to produce the data from within the planning level data sources. This data is most likely collected already for a variety of other annual reports and traffic maps. |
| End Users              | This measure is useful to State Patrol because it can be used to rough in priorities based solely on truck volumes. Mn/DOT has interest in this measure because it can be used to establish life cycle estimates, and the potential scope of pavement damage. |
| Producing Agency       | Mn/DOT - Transportation Data Analysis                           |
| Reporting Format       | This measure will be reported in hard copy format as part of the annual “Weight Compliance Performance Measures Report.” It will also be incorporated in the derivation of many of the other performance measures. It could also be included in a web based reporting system. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Vehicles with Weight Permits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>System Loading</td>
</tr>
<tr>
<td>Definition</td>
<td>This measure establishes the ratio of the vehicles with weight permits compared with the total number of commercial vehicles in Minnesota. This measure is used to adjust the calculated annual compliance rate to reflect the legal loads that would be overweight under normal conditions but are made legal by the permit process. While permits do not lessen the damage to the infrastructure, they do impact the level of effort on the part of the State Patrol. They also have bearing on changes to legislation.</td>
</tr>
</tbody>
</table>
| Criteria for Use | ✓ Establishing design life cycle parameters  
✓ Qualifying true violation rates  
✓ Permit compliance assessment  
✓ Responding to legislative inquiries  
✓ Prioritizing enforcement officer deployment  
✓ Estimating enforcement staff sizes. |
<p>| Reporting Frequency | Updated annually |
| Delivery Process | Reporting on this measure requires that the Size and Weight Committee identify the resources needed to produce the data from within the permitting process. If transponders are ever required as on-board evidence of permits, the data would be derived from the WIM reports directly. |
| End Users | This measure is useful to State Patrol because it adjusts the WIM data to give a more accurate picture of the compliance rate. This can have an impact on staff and resource sizes, particularly as compliance rates improve over the years ahead. Members of General Assembly and MnDOT personnel will also be interested because this measure provides a better understanding of the infrastructure costs associated with increasing weight limits. |
| Producing Agency | Mn/DOT - Office of Freight and Commercial Vehicle Operations |
| Reporting Format | This measure will be reported in hard copy format as part of the annual “Weight Compliance Performance Measures Report.” It could also be included in a web based reporting system. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Violation Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>System Loading</td>
</tr>
</tbody>
</table>

**Definitions**

This family of performance measures quantifies the extent of truck weight non-compliance. They include several different measures, and they are produced directly by the Excel macro. Details on their derivation can be found in the Appendix. These measures can be described briefly in the following list.

1. **Percent Overweight Trucks** (a general gauge that sums all violations into one number regardless of the type)
2. **Hour of the Week Violations** (a temporal measure that lists the quantities of any type of violation per hour of the week to help focus enforcement efforts)
3. **Excessive Load Ratio (ELR)** (similar to the Percent Overweight Trucks, but takes the magnitude of the load into account along with frequency in order to give a more relevant measure of the damage being done to the infrastructure)
4. **Percent of Excessive ESALs** (all vehicles contribute ESALs to the loads applied to a pavement. This measure represents only the excessive [i.e. non-legal] portion)

**Criteria for Use**

- Revising design life cycle parameters
- Legislative inquiries
- Scheduling enforcement activity
- Scheduling fixed scale operating hours
- Justifying enforcement resource requests
- Updating design life calculation factors

**Reporting Frequency**

Weekly, monthly and annually

**Delivery Process**

These measures are produced directly from the Excel macro for each WIM site. The same macro is used for all reporting frequencies, and the results are presented in both tabular and chart form.

**End Users**

The primary end users will be MSP, with Mn/DOT also being a strong user of this information. The FHWA will also use this data in their nationwide summary reports.

**Producing Agency**

The Size and Weight Committee will need to identify someone who can supply the data to the macro and distribute the results to the end users.

**Reporting Format**

These measures are formatted within several tables and graphs produced by the macro. These can be printed, or electronically transmitted to those who need the information.
## Name of Measure

**Weight Inspection “Hit” Rates**

## Measure Category

**Enforcement Operations**

## Definition

These measures report the effectiveness of inspector activity. Prior efforts required inspectors to guess which vehicles were overweight because overweight vehicles are typically indiscernible from legal vehicles. Dual use of the WIM data greatly increases an officer’s ability to single out those vehicles with weight violations. Armed with real time axle weight data, an officer can get a “hit” nearly every time they stop a vehicle, dramatically improving their effectiveness. There are three categories for this measure based on the type of enforcement. They are all calculated in the same manner, but reported separately to compare results.

1. Fixed scale “hit” rate
2. Roadside inspection “hit” rate
3. Civil weight enforcement “hit” rate

## Criteria for Use

- Assessing performance of new work procedures
- Comparing the efficiencies of the different enforcement modes.
- Justifying enforcement resource requests

## Reporting Frequency

Weekly, monthly and annually

## Delivery Process

These measures are all calculated by dividing the total number of citations issued by the total number of vehicles inspected for weight compliance.

## End Users

This measure is useful to State Patrol because it directly measures the efficiency of the inspection process, and is useful in determining staff size and distribution across the state.

## Producing Agency

Minnesota State Patrol

## Reporting Format

This can be reported in an Excel table in hardcopy or electronically on a Web site.
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Percent of Weight Violations also having Safety/Regulatory Violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>Enforcement Operations</td>
</tr>
<tr>
<td>Definition</td>
<td>This measure tracks the relationship between weight compliance and safety compliance. The two are believed to have some level of correlation, although the extent is not fully understood at this time. The underlying assumption for this belief is that a trucker who is willing to violate weight limits may just as easily be willing to cheat on safety and regulatory issues as well. If this assumption is true, then stopping vehicles for suspected weight infractions would have the added bonus of being an efficient way of screening for safety and regulatory violations as well. This would be even more effective if specific commodities showed higher levels of correlation, which is reasonable to expect.</td>
</tr>
</tbody>
</table>
| Criteria for Use | ✓ Research on carrier behavior trends  
✓ Research on commodity movement trends |
| Reporting Frequency | Monthly, quarterly and annually |
| Delivery Process | These measures are all calculated by dividing the total number of citations issued for safety/regulatory reasons by the total number of vehicles inspected initially for weight inspections. For fixed scales, this would be calculated by dividing the number of safety/regulatory violations by the total number of vehicles that were diverted from the by-pass lane via the ramp WIM only (randomly sampled pull-ins would be excluded.) |
| End Users        | This measure is useful to State Patrol because it directly measures the efficiency of the inspection process and is useful in determining staff size and distribution across the state. The Department of Revenue would be interested because it could improve their compliance rates with minimal investment, suggesting some potential cost sharing opportunities. |
| Producing Agency | Minnesota State Patrol |
| Reporting Format | This can be reported in a hardcopy or electronically on a Web site. |
| Name of Measure | Man Hours of Enforcement per Month  
(Internal to MSP only) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>Enforcement Operations</td>
</tr>
<tr>
<td>Definition</td>
<td>This measure establishes a reference value upon which other measures can be compared in order to gauge effectiveness. In other words it becomes the denominator in a comparison ratio. For example, the dollars saved due to improved weight compliance can be divided by the annual man hours expended to establish an hourly value of the enforcement – a benefit/cost ratio. This can be repeated using other measures as well, such as: reduced violation rates, reduced ESALs, and even avg. daily truck traffic to get a clear picture of how the enforcement is performing. In addition, using technology and innovative information strategies can lead to improved compliance with the same or less effort. This measure provides a scale for normalizing the level of effort when comparing values.</td>
</tr>
</tbody>
</table>
| Criteria for Use | ✓ Justifying enforcement resource requests  
✓ Redistributing of enforcement resources  
✓ Calculating hourly return on labor/equipment investments |
<p>| Reporting Frequency | Monthly, quarterly and annually |
| Delivery Process | These measures would be derived from timesheets submitted by enforcement personnel and those working in the background to support frontline personnel. This information would be kept internal to the Minnesota State Patrol only due to the sensitive nature of enforcement schedules, manpower levels and deployment areas. Divulging this information to the carrier industry would be counterproductive to the entire weight compliance program and also has negative homeland security implications. |
| End Users | This measure is useful to State Patrol because it directly measures the efficiency of the inspection processes and is useful in determining staff size and distribution across the state. |
| Producing Agency | Minnesota State Patrol |
| Reporting Format | This would be reported on secured internal MSP documents only. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Annual Damage Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>System Outcomes</td>
</tr>
<tr>
<td><strong>Definition</strong></td>
<td>These measures take the excessive ESAL information and translate that data into an annualized damage cost estimate for both pavement and bridge decks. These measures reflect what the taxpayers are losing each year due to non-compliance.</td>
</tr>
<tr>
<td></td>
<td>1. <strong>Annual Pavement Damage</strong> (an estimate of the pavement damage resulting from excess loading)</td>
</tr>
<tr>
<td></td>
<td>2. <strong>Annual Bridge Deck Damage</strong> (an estimate of the bridge deck damage resulting from excess loading)</td>
</tr>
</tbody>
</table>
| **Criteria for Use** | ✓ Qualifying violation rate and permit rate  
|                 | ✓ Legislative inquiries  
|                 | ✓ Prioritizing enforcement officer deployment  
|                 | ✓ Estimating needed enforcement hours/year  
|                 | ✓ Providing background info for permit regulations  
|                 | ✓ Adjusting capital improvement budgets  
<p>|                 | ✓ Federal reports |
| <strong>Reporting Frequency</strong> | Updated annually |
| <strong>Delivery Process</strong> | This report is derived from a calculation outlined in the Minnesota Statewide Weight Compliance Strategic Plan. The data used to calculate these annual damage estimates comes from the other performance measures listed above. |
| <strong>End Users</strong> | This measure is useful to all stakeholders because it is a fundamental measure of weight compliance, the underlying goal of this program. |
| <strong>Producing Agency</strong> | Mn/DOT - Transportation Data Analysis |
| <strong>Reporting Format</strong> | This can be reported in very simple terms in hardcopy or electronically on a Web site. |</p>
<table>
<thead>
<tr>
<th>Name of Measure</th>
<th>Overall Weight Compliance Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure Category</td>
<td>System Outcomes</td>
</tr>
<tr>
<td><strong>Definition</strong></td>
<td>This measure quantifies the percentage of vehicles that are operating within legal limits (% compliant). Specifically, this is the percentage of all trucks that do not present an axle, gross or bridge formula violation.</td>
</tr>
</tbody>
</table>
| **Criteria for Use** | ✓ Legislative inquiries  
✓ Justifying enforcement budgets  
✓ Assessing effectiveness of WIM, civil weight, and fixed scale enforcement efforts  
✓ Federal reports |
| **Reporting Frequency** | Updated annually |
| **Delivery Process** | This data is produced by the Excel macro. |
| **End Users** | This measure is useful to all stakeholders because it is a fundamental measure of compliance, the underlying goal of this program. |
| **Producing Agency** | Mn/DOT - Transportation Data Analysis |
| **Reporting Format** | This can be reported in very simple terms in hardcopy or electronically on a Web site. |
6.4 Baseline: Four month vs. twelve month

The State of Minnesota allows different maximum gross weights during various months of the year due to winter load increases and harvest seasons. WIMCAT adjusts for the winter load increases; however, it does not compensate for the harvest season variances due to the inability of the WIM equipment to register the presence of a permit. It was suggested the annual baseline be established on the basis of the four summer months to produce unbiased values. However, after analyzing 2006 data this did not prove to be the case. As shown below, the Fisher Site (Site 31) chart of Percent Violations indicates significant differences in monthly totals. As a result, performance should be compared on month to month and year to year basis.
VWS Targeted Enforcement Results

The results of the VWS targeted enforcement are summarized in the three following graphs. This experiment was conducted with the cooperation of the Minnesota State Patrol (MSP) over a six week period. Enforcement was conducted as resources were available and an attempt was made to focus enforcement on hours of the week showing the highest violation rates. However, when enforcement was active the violation rate dropped. The opposite was also true.

The day of the week and weekly summaries are presented in Table A6.5-1. The violation rates are presented as 3-week moving averages to reduce variability in the data. Overall it is interesting to note the weekday violation rates dropped consistently and the weekend violation rates increased during the short enforcement period. (See the Chart A6.5-2 for details). This strongly suggests a modest amount of targeted enforcement can have a significant influence on driver behavior.

It is reasonable to assume, continuing the enforcement process and coverage for all seven days of the week would have a positive impact on the overall violation rate. The enforcement also demonstrated how VWS tools can be utilized to focus MSP resources effectively and efficiently.
### Table A6.5 - 1

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours Enforced</td>
<td>% Overweight</td>
<td>Hours Enforced</td>
<td>% Overweight</td>
<td>Hours Enforced</td>
</tr>
<tr>
<td>Sunday</td>
<td>0</td>
<td>8.5%</td>
<td>0</td>
<td>11.9%</td>
<td>0</td>
</tr>
<tr>
<td>Monday</td>
<td>3</td>
<td>20.2%</td>
<td>0</td>
<td>15.9%</td>
<td>0</td>
</tr>
<tr>
<td>Tuesday</td>
<td>4</td>
<td>27.3%</td>
<td>9</td>
<td>25.2%</td>
<td>5</td>
</tr>
<tr>
<td>Wednesday</td>
<td>3</td>
<td>24.8%</td>
<td>7</td>
<td>29.5%</td>
<td>4</td>
</tr>
<tr>
<td>Thursday</td>
<td>0</td>
<td>33.4%</td>
<td>2</td>
<td>30.1%</td>
<td>2</td>
</tr>
<tr>
<td>Friday</td>
<td>0</td>
<td>23.3%</td>
<td>2</td>
<td>18.9%</td>
<td>2</td>
</tr>
<tr>
<td>Saturday</td>
<td>0</td>
<td>6.7%</td>
<td>0</td>
<td>4.2%</td>
<td>0</td>
</tr>
<tr>
<td>Overall</td>
<td>10</td>
<td>24.6%</td>
<td>20</td>
<td>23.8%</td>
<td>13</td>
</tr>
</tbody>
</table>
A scan of national literature was conducted to identify any previous work that has been done towards the development of a system to provide commercial vehicle drivers with notification of their weight status after they pass over Weight-in-Motion scales. This section provides the research abstracts of relevant reports as well as summaries of information gathered about existing projects.

**Relevant Research**

*Feasibility Study of Portable Weigh-in-Motion Systems for Highway Speed*
Kenneth W. Miller, Department of Mechanical and Manufacturing Engineering, St. Cloud State University; Minnesota Department of Transportation Report MN/RC-2006-30; August 2006

Abstract:

Minnesota Department of Transportation (Mn/DOT) needs improved traffic monitoring tools to optimally allocate road maintenance and improvement resources. In particular, the department needs a method of including vehicle and axle weights with portable traffic logging equipment. The cost of existing Weigh-in-Motion (WIM) equipment prevents widespread use in locations where only temporary monitoring is needed. This project was a survey of the suppliers of portable WIM systems, allowing a few systems to be moved between locations of interest. There were four candidate systems found and studied, of which two are recommended for further evaluation. Both systems appear to meet the needs Mn/DOT established and local testing will allow a final decision on their suitability.

Key Points:

- A survey conducted of Mn/DOT engineers found that their requirement was for a WIM system that could be quickly set up to monitor normal traffic traveling at highway speeds and provide the same vehicle data as the existing permanent systems. Preferences for the system included:
  - Portable system that can be installed with one or two work people with lane closures of 30 minutes or less
  - Capable of autonomous operation for up to two weeks
- Four candidate systems were considered
• Study recommended that Mn/DOT consider the ECM and Truvelo systems

Commercial Motor Vehicle Size And Weight (VSW) Enforcement Scan Tour Overview June 16 - July 2, 2006 (Presentation)

This presentation summarizes the findings of a scan of Commercial Vehicle Enforcement practices in seven European countries. One recommendation of interest is the implementation of “Behavior-based” Enforcement Activities:

• WIM/photo data reviewed to determine commonly non-compliant carriers
• On-site visits occur with agreement to cooperatively prevent future overload
  – Transport company begins monitoring period
  – If no positive change is observed, additional enforcement actions may be taken

Virtual Commercial Vehicle Control Stations for California: A Review of Legal and Institutional Issues
Caroline J. Rodier, Susan A. Shaheen, Ellen Cavanagh
California PATH Research Report, UCB-ITS-PRR-2005-33; November 2005

Abstract:

In the past five years, commercial vehicle travel has increased 60 percent on California’s highways, without a corresponding increase in compliance inspection station capacity or enforcement officers. Commercial vehicles that do not comply with regulations impose significant public costs including, for example, pavement and structure damage to roads and catastrophic crashes. In response to these problems, the California Department of Transportation is investigating the potential application of detection and communication technology in virtual compliance stations (VCS) to cost-effectively improve enforcement of commercial vehicle regulations. This study begins with a description of the fledgling VCS research programs in the U.S. as well more advanced international VCS programs. Next, the results of expert interview with key officials involved in the early deployment stages of VCS programs in Kentucky, Florida, Indiana, and Saskatchewan are reported. This is followed by an analysis of institutional barriers to VCS screening and automated enforcement based on the relatively extensive body of literature on the commercial vehicle electronic pre-screening programs and red-light and speeding automated enforcement programs. The paper concludes with some key recommendations to address legal and institutional barriers to VCS deployment in the U.S.

Findings of interest include:

• Automated enforcement programs have raised concerns about the violation of an individual’s right to privacy, as inscribed in the First and Fourth Amendments of the Constitution, but no court case has established an individual vehicle driver’s right to privacy.
• One of the concerns that CVOs have with the implementation of a VCS program is business confidentiality. CVOs, as corporations, do not have the same privacy rights as individuals.
However, they do have an interest in the privacy of the information that is collected about them by pre-clearance, screening, or enforcement systems.

- The evaluative literature on electronic pre-screening programs commonly documents CVOs’ concern that information collected through pre-screening not be disclosed to competitors. The voluntary electronic screening programs address this concern through third-party data management contracts.
- Non-voluntary screen programs would need to work out how to handle confidentiality assurances.

- A US DOT survey indicated that CVOs are more likely to accept technology applications that improve their bottom line rather than increase regulation enforcement.

**Existing WIM Weight Feedback Projects**

**Ports of Louisiana Napolean Avenue Container Terminal – New Orleans**

_WIM (Weigh in Motion) at P&O Ports of Louisiana Napolean Avenue Container Terminal – New Orleans_

Mettler-Toledo; April 2004

This report provides a case study of a WIM application deployed by Mettler-Toledo at the P&O Ports Napolean Avenue Terminal that provides feedback to the driver via both a dedicated AM radio band and a variable message sign. Drivers are informed of what location in the port facility to place their container and are also instructed which container to pick up for outbound shipment from the port.

**Waldo Hancock Bridge Weigh-in-Motion, Maine Department of Transportation**

Faced with overweight trucks crossing a bridge that had been damaged by overloading and age, the Maine DOT implemented a WIM screening station that included cameras to take pictures of overweight vehicles and two VMS trailers to display the total weight of each vehicle. The following resources provide information about the Waldo Hancock Bridge WIM project:

_Maine Tackles Big Trucks_
US DOT FHWA Research & Technology Transporter, September 2006,
[http://www.tfhc.gov/trnsptr/sep06/index.htm#infra](http://www.tfhc.gov/trnsptr/sep06/index.htm#infra)

- Existing Weigh-in-Motion equipment near the bridge was modified so that overweight trucks intending to cross the bridge could be monitored. Previously, the WIM unit could detect only that an overweight vehicle was passing by, but could not discern which vehicle was overweight.
- Upgraded WIM units weighed the vehicles and then used a 900-megahertz (mhz), spread-spectrum radio to send the data to two message boards that display the weight of any trucks that pass over the weight sensors.
- To enforce the weight restrictions, cameras were used to photograph any vehicle that violated the 45,359-kilogram (100,000-pound) limit. Using license plate numbers, Maine DOT tracked down the owners of offending trucks and reached agreements on future compliance.
• WIM units were calibrated from the 45,359-kilogram (100,000-pound) point rather than from zero. This is critical because inaccuracies are more likely to occur the further the actual weight is from the calibration point.

• A quartz sensor array was used to weigh the vehicles. Unlike conventional WIM instrumentation, quartz sensors are impervious to temperature changes, which is important because daily temperatures can fluctuate greatly in Maine, depending on the season. The use of quartz sensors also eliminated the need for frequent recalibrations to maintain a high level of accuracy.

• The WIM units were within two percent of exact accuracy.

• The modified WIM system greatly reduced the frequency of overweight trucks from more than 30 overweight trucks a day before the system to less than ten a day after as shown in the chart below:

![Waldo - Hancock Bridge Overweight Trucks](chart)

Waldo Hancock Bridge Weigh-in-Motion Summary
Maine Department of Transportation

This summary of the Waldo Hancock Bridge WIM project was provided by the Maine DOT. Some key information provided in this summary:

• 900 MHz spread spectrum radio is used for communication from the Vesta (Weigh-in-Motion) unit to each message board
Each lane operates on a separate channel, and anti-coincidence is built into the Vesta so that if a vehicle passes in each lane at the exact same time, one message will be displayed a fraction of a second before the next one.

- A diagram showing the layout of the system
- A graph showing the impact of the WIM/VMS system on overweight violations. The spreadsheet containing this chart and the data behind were provided by Maine DOT and are attached.
- Charts providing information about the calibration of the system

**Phone Interview with Ron Cote, Maine Department of Transportation**

(207) 624-3602

A brief phone interview was conducted on August 27, 2007 with Ron Cote, the project manager of the Waldo Hancock Bridge WIM project. The following is a summary of the interview:

- The project was “extremely worthwhile”. The flash units were turned on at night and the number of overweight vehicles dropped the next day.
- Initially the system showed the weight of every vehicle that passed over the bridge but they received complaints from drivers who noticed that the weight of their vehicles fluctuated significantly. As a result, they changed the system to trigger the display the weight of only Class Five vehicles or above.
- The fact that the weight displayed on the VMS was visible to not only to the truck drivers but also to the vehicles behind them put pressure on drivers to “police” themselves.
- A picture is taken of vehicles that are overweight and the legal department calls the trucking company to let them know that there will be consequences if the problem continues.
- There have been no complaints regarding privacy issues with the display of the weight information. However, Maine DOT is restricted from taking pictures of drivers’ faces.
- It was necessary to put a delay in the software for the signs so that the message would show up as the right vehicle approached. The weight for each vehicle is displayed on the sign for five seconds. If vehicles are closely spaced the weights stack up on the signs.
- Cost for the entire application was approximately $150,000.
- People liked the project. It provided assurance to the public that the DOT was doing everything possible to make sure the bridge was safe.
- After the new bridge was constructed Maine DOT kept the WIM system operational but turned the flashers off. They are currently tracking the impact of this on the number of overweight vehicles. It appears from the initial data that the number of overloaded vehicles is in fact increasing.
In developing any system it is important to first understand clearly what the system needs to do in order to be effective. Based on the results of the literature search and input from a limited number of stakeholders, the following is a list of the functional needs for the WIM Weight Feedback System:

- The system at a minimum should collect weight information from the WIM station (either existing or installed as part of the system), communicate the weight information to a Variable Message Sign (VMS) and display the information to the commercial vehicle operator.
  - Additional capabilities could be:
    - Ability to display additional information such as vehicle speed
    - Digital snapshot unit that could be used to take pictures of overweight vehicles
    - Flash Unit

- The feedback system should reduce the number of overweight commercial vehicles on Minnesota roads by encouraging driver compliance with weight requirements
  - Deployment of the feedback system should not increase overweight vehicles on alternate routes

- The feedback system should not reduce the effectiveness of other weight enforcement systems or activities
  - The visibility of virtual weigh stations to commercial vehicle operators should not be increased by the feedback system
  - Information should not be provided to commercial vehicle operators in such a way that it could be used to challenge future citations or other enforcement activities

- Provide valuable information to drivers in a format that can be easily seen and understood
- Clear messages
- Only the information that is needed
- Message displayed to reach the intended driver
  - Message must be displayed for a length of time that allows it to be read and understood by most drivers
  - Message should be displayed only for drivers of the targeted vehicles
    - Weight information should be displayed only for heavy vehicles
  - Display of the message must be timed so that it is visible to drivers traveling at different speeds
- High visibility and readability under different lighting and weather conditions
- The message display should not confuse or distract drivers
  - It should be clear who the message is intended for
  - The message must not conflict with information provided by other static or variable message signs
- System should be flexible
  - Easy to add or replace components to the system
  - Capable of displaying a variety of information in addition to weight if desired
  - Open standards for data collection, data reporting and information sharing
- Provide accurate weight information
  - Gross weight should be within the accuracy limits recommended by the ASTM specifications
  - WIM system can be easily calibrated to reduce the effects of “drift”

- Moderate Cost

- Operate unmanned

- Minimal maintenance requirements and costs

- Components must be installed in or adjacent to the right-of-way

- Weight data should be collected and processed on-site
## 6.7 Vendor Equipment Comparison

<table>
<thead>
<tr>
<th>Optional accessories available from mfgr</th>
<th>IRD</th>
<th>PEEK</th>
<th>ECM</th>
<th>MT</th>
<th>Cardinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Image capture</td>
<td>Yes</td>
<td>Possible</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>Video capture</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>License Plate reader</td>
<td>Yes</td>
<td>Possible</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible</td>
</tr>
<tr>
<td>ESAL calculation user customizable</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Requires custom integration</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual Calibration Ease</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto Calibration Potential</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrated Accuracy</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outputs a relay closure upon a user-defined violation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>User friendly, mature data manipulation software</td>
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<td>Possible</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>Yes</td>
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<td>Proven integration with digital imaging</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Peripheral equipment required (internal vs. external)</td>
<td>Int</td>
<td>Ext</td>
<td>Ext</td>
<td>Ext</td>
<td>Ext</td>
</tr>
</tbody>
</table>

1 Available, but requires a new I-Sync Controller from IRD
2 Demonstrated with Mettler-Toledo products
3 Possible with 3rd party products, but not commonly done.
4 Available as an option, but not demonstrated in this project
5 Limited standard reports. Custom vender reports may be needed
### Appendix 6.8 Communications Plan

#### Table #1. Communication System Options

<table>
<thead>
<tr>
<th>Feature</th>
<th>Current Practice</th>
<th>Recommended Configuration</th>
<th>Custom Configuration</th>
<th>Centralized</th>
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<tr>
<td></td>
<td></td>
<td>Without Imaging</td>
<td>With Imaging</td>
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<tr>
<td><strong>Cabinet to Mn/DOT</strong></td>
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<td></td>
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<tr>
<td>Dial Up</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<td>No</td>
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<td>Would support</td>
</tr>
<tr>
<td>Cellular Broadband</td>
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<td>Yes</td>
<td>Yes</td>
<td>Location Specific</td>
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<td><strong>Cabinet to Vehicle</strong></td>
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<tr>
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<td>Would support</td>
</tr>
<tr>
<td>Cellular Broadband</td>
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<td>Yes</td>
<td>Yes</td>
<td>Location Specific</td>
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<td>Slow Scan Video</td>
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<td>Would support</td>
</tr>
<tr>
<td>Dual Access</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Simultaneous Access</td>
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<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td></td>
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<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Advantages**
- Low cost
- Simple maintenance
- Supports imaging and video
- Simple maintenance
- Modest cost
- Website not required
- Eliminates need for land line
- Enables covert enforcement
- Allows safer vehicle staging
- Can eliminate some monthly service fees
- Enables simultaneous viewing
- No downloading of data required by end user
- Enables automated report generation

**Disadvantages**
- Does not support imaging
- Officer must have line of sight to cabinet
- May not be available everywhere
- Higher initial costs
- Higher maintenance costs
- Higher cost
- Specialized equipment required
- Multiple equipment in vehicles may be needed
- Higher development costs
Another consideration for the digital imaging portion of this project involves a review of off-the-shelf solutions that are available from qualified vendors. After discussions with several different vendors, it is clear that a solution as envisioned by Mn/DOT would require a leading edge technology that only a couple of vendors currently provide; Mettler-Toledo and IRD. The following is a brief discussion of each of these vendor supplied systems:

**Mettler-Toledo:** The Mettler-Toledo system uses a standard WIM Controller to collect the scale data. The WIM Controller data is then passed on to a hardened PC running Windows XP. This PC processes the data, controls the camera actuation, and provides the appropriate communications interface. The Mettler-Toledo system supports both serial and Ethernet interfaces, which allows it to support any type of communications equipment. Furthermore, this system is capable of displaying the data and vehicle picture as a web page either at the WIM site or at the Central location. One benefit of having a separate hardened PC for post processing and image capture is that it allows easy upgrades to existing WIM stations regardless of WIM controller manufacturer. Another benefit of this approach is that it enables additional devices to be added to the system, such as speed monitoring, infrared tire/wheel temperature monitoring, and acoustic devices that expand the usefulness of the VWS site.

**International Road Dynamics (IRD):** The IRD system provides similar functionality, but the IRD system differs from the Mettler-Toledo system in that the IRD system functionality is built into the IRD WIM controller. The IRD WIM Controller collects the data, processes the data, controls the cameras, and provides the web pages from a single device. This produces a simpler cabinet installation but limits flexibility as described above.

As time goes on, it is expected that other vendors will develop similar solutions. As Mn/DOT deploys WIM systems throughout the state, emphasis should be placed on developing systems that are interoperable as well as interchangeable. While this approach may increase the short-term cost of implementing WIM sites, in the long run this approach will provide lower overall cost. To accomplish interoperability and interchangeability, national standards such as NTCIP protocols, Internet protocols, and Mn/DOT state-developed standards should be implemented.

---

### Communications Service Provider Options

**Landline Low Speed (LS) / Dial-Up**

This type of communication link relies on standard phone lines to provide a connection. Dial-Up provides inconsistent levels of communication speeds and quality from site to site. The communication speed can vary from as low as 15Kbps to a theoretical maximum of 32Kbps. The driving factors behind the various communication speeds and quality are the quality of the phone line available at any given WIM site as well as its proximity to the telephone switch station. The farther the WIM site is from the switch station the lower the speed and quality of the connection. One advantage of Dial-Up is that it is the most available form of Landline communications. Furthermore, Dial-Up cost for both capital and reoccurring are lower than any of the other communication options.

**Landline High Speed (HS) / DSL**

This type of communications link is capable of providing high-speed communication with upload speeds of 128Kbps and download speeds of 1.5Mbps. DSL can provide up to 1.5Mbs upload speeds but phone companies charge considerable more for this type of link since they are considered more of a commercial service. DSL uses the same communications cable as Dial-Up (twisted pair cooper cable), and as a result it also suffers from the same issues as Dial-Up links. Additionally, DSL is more sensitive as to how far the WIM site can be from the phone central switch station. Typically this is between two to three miles. Therefore, the availability of DSL in rural areas is very limited. DSL links are designed to provide connection to the Internet. DSL modems are designed with an Ethernet port for local interface.
Communications Plan

**Landline High Speed (HS) / Cable Modem**

This type of communications technology can provide high-speed communications with download speeds of 6Mbps and upload speeds of 384Kbps. Cable Modems, as the name implies, use cable TV infrastructure. As a result, service is only available in urban areas at this time. Similar to DSL, Cable Modems are designed to provide connection to the Internet only, and their main local interface is an Ethernet port.

**Wireless LAN (802.11a, b, and g)**

This type of wireless communication uses radio frequencies in the 2.4GHz and 5GHz range that are available to the public without licensing. This type of wireless technology was originally developed to support short distance (<400’) wireless connections between several computers. Under ideal conditions and short distances, Wireless LAN can achieve speeds up to 50Mbps. Using high gain external directional antennas wireless LAN can support point-to-point communications over distances ranging from one to 20 miles. How far wireless LAN can communicate is heavily dependent on line of sight between stations as well as topological features. As a result, each installation requires a propagation study to determine how far the stations can be from each other. In addition, wireless LAN bandwidth decreases significantly as the distance between stations increases to about 1Mbps at 3 miles. Wireless LAN can provide reliable communication when properly implemented. Wireless LAN installations require an upfront capital expenditure, but have minimum recurring cost. Wireless LAN radios use Ethernet as the local communication interface.

**Satellite**

This type of communications technology is capable of providing communication at any location where the southern skies are visible. Satellite communications can support upload speeds between 128Kbps to 512Kbps and download speeds between 1.0Mbps to 1.5Mbps. Satellite communications require a dish antenna, which limits mobility and portability of the system. All communications through a satellite network are routed through a ground base station. Connection to the ground base station can either be through dedicated links such as T1 or through the Internet using VPN technology. Satellite equipment can support multiple interfaces such as T1, serial, and Ethernet.

**Cellular Broadband**

This type of communications link can provide bandwidth in the range of 70Kbps to 2.4Mbps, and is available through most cellular networks vendors. The bandwidth available for a given network is dependent on the technology deployed by the cellular vendor. Cellular Broadband networks are primarily designed to connect the user to the Internet, but some vendors are capable of providing private connections. The following table shows the different available cellular data networks in the project area and their corresponding technology and bandwidth by provider.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Technology</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
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<td>Cingular</td>
<td>EDGE</td>
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<td>Sprint</td>
<td>1xEV-DO</td>
<td>400-700</td>
</tr>
<tr>
<td>Verizon Wireless</td>
<td>1xEV-DO</td>
<td>400-700</td>
</tr>
</tbody>
</table>

**Communications Architecture**

Because communications systems provide a support function for the end devices they must meet the needs of those end devices. To help identify those needs, Mn/DOT WIM systems can be broken down into three primary links/devices that must communicate with each other as shown in the following two diagrams. The difference lies mainly in how the vehicle gets its information. In Architecture “A” the vehicle communicates directly with the WIM cabinet. In “B” the vehicle gets WIM information relayed via the Central Server. Architecture “A” is recommended as the preferred architecture, at least for the near term, because it enables immediate use of existing WIMs without the need for a Central Server.
Communications Plan

At some point in the future, however, it may be more effective to switch to Architecture “B” to increase functionality and save on costs when a central server is operational.

Architecture “A”

Architecture “B”

Cost Factors

Cost is a critical element when considering communication infrastructure. Cost for communication systems has two components: Capital cost and recurring cost. The following table shows the different communication options previously discussed and their overall cost:

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<th>Communication Type</th>
<th>Speed</th>
<th>Typical Cost</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Download</td>
<td>Upload</td>
<td>Capital</td>
</tr>
<tr>
<td>Dial-Up</td>
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<td>15-32 Kbps</td>
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<tr>
<td>DSL</td>
<td>1.5 Mbps</td>
<td>128 Kbps</td>
<td>&lt; $500.00</td>
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<tr>
<td>Cable Modem</td>
<td>6 Mbps</td>
<td>384 Kbps</td>
<td>&lt; $500.00</td>
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<td>Cellular Data</td>
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<td>Satellite</td>
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<td>$5,000.00</td>
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</table>

* Maintenance Cost
**Communications Plan**

**Edge Device Communication Needs**

Each of the edge devices (i.e. MSP Laptop, WIM Site, and Central) has different communication needs and as a result the best communications option for each device may be different. The following paragraphs discuss those needs and summarize the appropriate communications technology that may be implemented.

**Central:** Central communication bandwidth requirements will depend heavily on the selected architecture. Architecture A will require considerably less bandwidth than Architecture B because the Central would be collecting data from the WIM sites sequentially. Furthermore, the collection could occur at night over long periods of time. For Architecture B, all of the WIM data would have to be collected in real time and re-transmitted to multiple MSP laptops requesting the information/data. While communications for Architecture A could operate using multiple low speed connections, Architecture B would require Central to use a high speed connection (Central site is a fixed location in an urban setting where landline connections would be easy to establish and would be inexpensive). Depending on which architecture is selected and the total number of virtual WIM sites ultimately deployed, either a High Speed or Low Speed landline could be implemented for providing the Central communications link.

**MSP Laptop:** Because the MSP laptops are mobile, only wireless technology can be implemented such as; Satellite, Wireless LAN, and Cellular Data. Satellite, unlike Wireless LAN, and Cellular Data, requires a dish antenna, which makes it impractical for installation on an MSP cruiser. As a result only Cellular Data and Wireless LAN should be considered as viable options. Of the different Cellular Data services available in the project area, those providing high speed services such as, Sprint and Verizon Wireless would be preferable assuming that a 60Kbyte file is generated for each vehicle violation. Due to Wireless LAN high capital cost, it should only be considered for sites where no Cellular Data services are available. Wireless LAN is a point to point link between the MSP laptop and the WIM site. As a result Wireless LAN can only be implemented using Architecture A.

**WIM Site:** The communication requirements of WIM sites will vary depending on which architecture is selected. For Architecture A, communications requirements to Central can be low since the file transfer is not time dependent. Therefore connections such as Dial-Up would suffice. On the other hand, the communications link to the MSP laptop needs to be high speed to support real time data transfer such as Wireless LAN, Cellular Data, Satellite, or High Speed Landline. For Architecture B, all of the data is sent to Central in real time requiring the communications link to be high speed as well.
Figure #1
Vehicle Link Options
Mn/DOT VWS
Communications Choices

- Is Wireless Internet Available?
  - Yes: Use Wireless Internet
  - No:
    - Is DSL or Cable Available?
      - Yes: Use DSL or Cable to WiFi Hot Spot
      - No: Is Satellite Available?
        - Yes: Use Satellite to WiFi Hot Spot
        - No: Use R cabinet to vehicle direct (no cabinet or service provider)

Done
### WIM CALIBRATION

**FACTORY REPRESENTATIVE:**
- Roger Hille
- Date: 1/12/200
- Site name: Fisher
- Site Location: TH 2, MP 8

**Mn/DOT REPRESENTATIVE:**
- 1, left
- Lane #: WBL
- Sensors: 1,2,3,4

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<th>Speed</th>
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<th>Front</th>
<th>1st tandem</th>
<th>rear tridem</th>
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## WIM CALIBRATION

**FACTORY REPRESENTATIVE:** Mn/DOT REPRESENTATIVE: Roger Hille  
Date: 1/17/2006  
Site name: Fisher  
Site Location: TH 2, MP 8  
Sensor #5, 6, 7, 8

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**WIM CALIBRATION**

**FACTORY REPRESENTATIVE:**  
Roger Hille  
Date: 9/06/06  
Site Name: Fisher  
Site Location: TH 2, MP 8

**Mn/DOT REPRESENTATIVE:**  
Lane #: 1, right WBL (driving lane)  
Sensors: 1,2,3,4

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### WIM CALIBRATION

**ECM Controller**

**FACTORY REPRESENTATIVE:** Roger Hille  
**Mn/DOT REPRESENTATIVE:**  
**DATE:** 10/10/2006  
**Site name:** Fisher  
**Site Location:** TH 2, MP 8  
**Lane #**  
**Sensors:** 1,2,3,4  
**3. EB driving lane**

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- **-5% Length** actual +5%  
- **-15% Weight** Static +15%

### Comment

- 1st tandem
- 2nd tandem
- 3rd tandem
- 4th tandem
- 5th tandem
- 1st tandem
- rear tandem

- 1st axle
- 2nd axle
- 3rd axle
- 4th axle
- 5th axle

- 1st tandem
- rear tandem
**SENSORS:** Kistler lineas quartz piezo

**CONTROLLER:** ECM

**FACTORY REPRESENTATIVE:**

**DATE:** 11/2/2006  
**Site name:** Fisher  
**Lane #:** 3, EB driving lane

**SITE LOCATION:** TH 2, MP 8

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## WIM CALIBRATION

**SENSORS:** Kistler lineas quartz piezo

**CONTROLLER:** ECM

**FACTORY REPRESENTATIVE:**

**DATE:** 1/10/2007  Site name  Fisher       Lane #  3, EB driving lane

**TEMP:** 19  Site Location TH 2, MP 8

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-5% **Length** actual +5%  -15% **Weight** Static +15%

-100% **Stdn Dev** 2001.54

-100% **avg** 2001.547

-97% **Std Dev** 02
**SENSORS:** Kistler lineas quartz piezo

**CONTROLLER:** IRD

**FACTORY REPRESENTATIVE:** Mn/DOT REPRESENTATIVE:
Roger Hille, Dean Smith

**DATE:** 1/23/2007 **Site name:** Fisher
**TEMP:** 22 **Site Location:** TH 2, MP 8

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**1st tandem (axle 2 & 3)**
**rear tridem (axle 4, 5, & 6)**

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**Page 126**
**WIM CALIBRATION**

**SENSORS:** Kistler lineas quartz piezo

**CONTROLLER:** IRD

**FACTORY REPRESENTATIVE:** Mn/DOT REPRESENTATIVE: Roger Hille, Dean Smith

**DATE:** 1/24/2007  **Site name** Fisher  **Lane #** 2, left  **WBL**

**TEMP:** 25  **Site Location** TH 2, MP 8  **Sensor #** 5,6,7,8

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**WIM CALIBRATION**

**SENSORS:** Kistler lineas quartz piezo

**CONTROLLER:** ECM

**FACTORY REPRESENTATIVE:** Ron White, Jared Preuss

**DATE:** 07/10/2007  
**TEMP:** 68  

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**Mn/DOT REPRESENTATIVE:** Roger Hille

**DATE:** 07/10/2007  
**TEMP:** 68  

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P1 Cal  P2 Cal  Speed  Axle spacings, inches  var  -f  1st tandem  rear tridem

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