Table of Contents

Abstract ........................................................................................................................................... 4
Introduction ..................................................................................................................................... 5

Table 1 – Key Changes in ASTM 1318 and Their Impacts on Vendors and Users [6] .............. 8

Literature Review ............................................................................................................................ 9

Table 2 – Strengths and Weaknesses of Sensor Technologies [8] ............................................ 12
Table 4 – WIM Site Selection Criteria [8] ................................................................................ 14

Project Demonstration .................................................................................................................. 15

Figure 1 – Vehicle Cab Image .................................................................................................. 17

Figure 2 – Vehicle License Plate Recognition .......................................................................... 17

Figure 3 – Vehicle Cab Image with sun glare ........................................................................... 18

Figure 4 – Vehicle License Plate Recognition with sun glare .................................................. 18

Figure 5 – Vehicle Image at night ............................................................................................. 19

Figure 6 – Vehicle License Plate Recognition at night ............................................................. 19

Figure 7 – Incorrect Camera Alignment Vehicle Image ........................................................... 20

Figure 8 – Incorrect Camera Alignment License Plate Recognition ........................................ 20

Figure 9 – Incorrect Camera Alignment Vehicle Image ........................................................... 21

Figure 10 – Incorrect Camera Alignment License Plate Recognition ....................................... 21

Project Findings ............................................................................................................................ 22

References ..................................................................................................................................... 23

Appendices .................................................................................................................................... 24

Appendix 1 – Literature Review ..................................................................................................... 25

Article #1: An Overview of Research on Weigh-in-motion System ........................................... 26
Article #2: Design and Manufacture of Surface Acoustic Wave Sensors for Real-Time Weigh- in-Motion ........................................................................................................................................ 31
Article #3: Field Evaluation of Weigh-In-Motion Screening on Truck Weigh Station Operation ........................................................................................................................................ 37
Article #5: Europe gets moving on WIM (Magazine Article) .................................................... 52
Article #6 Virtual Weigh-in-Motion (Magazine Article) ............................................................. 56
Article #7: Detecting Semantic Anomalies in Truck Weigh-in-Motion Traffic Data Using Data Mining ............................................................................................................................. 58
Article #9: Advanced Weigh-in-Motion Sensors: ................................................................. 99
Article #10: Mettler Toledo Virtual By-Pass Weigh-In-Motion Specifications: ......................... 102
Article #11: ODOT weigh Station Consideration: .................................................................... 119
Article #12: Virtual Weigh Station and Remote Monitoring (Presentation): ............................ 123
Article #13: Federal Highway Administration Size and Weight Technologies: ...................... 156
Article #14: ITS America Panel Truck Parking: ....................................................................... 169
Article #15: Onboard Driver Monitoring and Feedback for Commercial Motor Vehicle Safety: ..................................................................................................................................... 181
Article #16: Kentucky Weigh Station Deployment: ............................................................... 197
Article #17: ITSA Annual Meeting Truck Parking Facilities: .................................................. 212
Article #18: Truck Parking the Problem & Possible Solution: .................................................. 223
Abstract

The transportation infrastructure is the lifeline of the nation. An efficient and safe road network allows goods to reach the markets quickly, thus, stimulating economic activity and ensuring trade competitiveness. According to the Highway Statistics, in the United States, over 46,000 miles of interstate roads, combined with a network of almost 4 million miles of other roads, makes up the nation’s lifeline. Each year, nearly five trillion dollars worth of goods are transported via the nation’s road network via commercial trucks. Unfortunately, commercial truck traffic also contributes greatly to the cost of deteriorating highways across the nation. The increased costs of maintenance, combined with the diminished highway funds available, have meant that many roads are now in or rapidly approaching a critical condition. Industry experts estimate that there is currently more than a $300 billion shortfall to repair roads and bridges to an acceptable standard. For many years, states have been looking at developing a system that can be beneficial to the trucking industry, taxpayers, and the states, while helping to protect the infrastructure. It is the Weigh-In-Motion (WIM) technology which provides benefits to all parties involved.

Weigh-in-motion (WIM) technology has found increasing application in the highway and transportation areas for traffic data collection for the purpose of highway capacity analysis, aiding enforcement and, most recently, pavement design. The measurement accuracy of a WIM scale is critical. Many studies exist that address the measurement accuracy per se; however, the implications and effect of the accuracy in the context of pavement design have been rarely examined.

This study will provide a review of documents related to WIM including current technology and those in development. It will also report on the final demonstration project at the McAlester site, and make recommendations on future growth of WIM for the State of Oklahoma.
Introduction

Truck weight enforcement is an important component in preserving and extending the life of Oklahoma’s roads and bridges. Weigh-in-Motion (WIM) technology is a tool that can assist the Oklahoma Department of Transportation (ODOT) and the Oklahoma Highway Patrol (OHP) in their efforts to reduce damage to transportation infrastructure. This project focused on three tasks: (1) a pre-defined demonstration project at ODOT’s McAlester WIM site using advanced vehicle imaging and wireless communications technology to allow OHP officers to more effectively intercept overweight violators, (2) a survey of other state DOTs to determine “best practices” for oversize/overweight vehicle enforcement, (3) a determination of the best mix of technology based on Oklahoma’s transportation system and the development of a plan for deployment of WIM-based technology for oversize/overweight vehicle enforcement throughout Oklahoma.

States conduct traffic monitoring for many reasons, including (1) highway planning and design; and (2) motor vehicle enforcement. Weigh-in-Motion (WIM) is a major tool used to collect traffic data. WIM is described as “the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle” in the American Society for Testing and Materials (ASTM) Standard Specification E 1318-94. The uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues. Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities.

Truck weight enforcement activities can benefit from advances in WIM technology, as well as the combination of WIM with other imaging and communications technology. With new technology and technological approaches as goals, this project accomplishes three tasks that will contribute to the missions of ODOT and OHP with regard to oversize/overweight vehicle detection and enforcement.

A brief timeline with significant events in WIM are as follows:

- 1983: The first National Weigh-in-Motion conference held
• 1987: Long-term Testing of Pavement Program initiated in 1987 as part of the Strategic Highway Research Program

• 1990: The first version of ASTM 1318 Standard Specification for Highway Weigh-in-Motion (WIM) Systems was published.

• 1994: Minor revisions were made to ASTM 1318.


• 2002: A second version of the ASTM 1318 Standard Specification for Highway Weigh-in-Motion (WIM) Systems was released.

The original edition of ASTM 1318 was published in 1990 in response to the need for a definition of performance standards for various types of WIM systems. Revisions to the standard were made in 1994. Extensive additional research and field experience identified the need for additional revisions, which were released in February, 2002.

The growth of the installed WIM base in a variety of environments has provided insight into the needed revisions to ASTM 1318. The major changes in ASTM 1318 released in 2002 and their impacts on WIM vendors and users are summarized in Table 1. The most significant changes have been driven by

• The growth of mainline weight sorting systems, which require that weight enforcement-related WIM systems function at higher speeds.
• Users experiencing inconsistent weight data accuracy stemming from temperature variations, which has compromised the accuracy of collected vehicle weight data.
• The realization that vehicles are not always centered over the weighing platform and that weight readings from off-center vehicles can have significantly lower accuracy.
• Experience and research indicating that pavement smoothness and durability is critical to long-term accuracy of WIM systems as well as safe operations.
<table>
<thead>
<tr>
<th>Revision to ASTM 1318</th>
<th>Reason</th>
<th>WIM Vendor Impact</th>
<th>WIM User Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in Type III operational speed to 80mph</td>
<td>Growth of mainstream weight enforcement WIM</td>
<td>Need to ensure accuracy at higher speeds</td>
<td>More options on placement of WIM equipment</td>
</tr>
<tr>
<td>Suggestion to user to specify that sensor accuracy is met across 20°F to 120°F range</td>
<td>Finding that some sensors lose weighing accuracy at the high and low end of the temperature range</td>
<td>Need to ensure accuracy via data conditioning or other methods</td>
<td>Improved quality of weight data</td>
</tr>
<tr>
<td>Requirement to certify sensor accuracy across width of weighing platform</td>
<td>Experience that some sensors are less accurate for off-center applied loads</td>
<td>Need to design systems to maintain accuracy across width of weighing platform</td>
<td>Improved quality of weight data</td>
</tr>
<tr>
<td>Increase of smooth and level pavement surface to 200 ft in advance of WIM sensor (100 ft beyond sensor)</td>
<td>Experience that greater distance of smooth pavement increases WIM weighing accuracy</td>
<td>None</td>
<td>No net change to smooth pavement length, only WIM repositioning</td>
</tr>
<tr>
<td>Recommendation that WIM system be installed into Portland Cement concrete pavement only</td>
<td>Experience indicates improved accuracy and durability when using PCC vs. asphalt</td>
<td>None</td>
<td>Increase in initial construction cost with increase in system life and accuracy</td>
</tr>
<tr>
<td>Increase of minimum road width in advance of and beyond WIM system to 12 ft wide</td>
<td>None</td>
<td>Increase in construction cost</td>
<td></td>
</tr>
<tr>
<td>Increase in maximum allowable cross slope to 3° for Type I, II, and III</td>
<td>None</td>
<td>Decrease in construction cost</td>
<td></td>
</tr>
<tr>
<td>Data communication link between the WIM site and a remote host computer, allowing for remote setting adjustment</td>
<td>Prevalence of sites where operator is not near the WIM system and where users desire to change settings</td>
<td>Hardware and software requirement</td>
<td>Increased WIM functionality</td>
</tr>
<tr>
<td>Addition of vendor Type-Approval Test</td>
<td>Cases where WIM system could not meet accuracy requirements</td>
<td>Need to provide Type-Approval Test compliance</td>
<td>Assurance of WIM system capability</td>
</tr>
<tr>
<td>Acceptance test includes non-centered platform loading</td>
<td>Experience that some sensors are less accurate for off-center applied loads</td>
<td>Need to design systems to maintain accuracy across width of weighing platform</td>
<td>More accurate data under actual range of use conditions</td>
</tr>
<tr>
<td>Acceptance test does not require on-site static weights, but rather pre-weighted vehicles</td>
<td>None</td>
<td>Lower testing cost when no on-site static scales exist</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Key Changes in ASTM 1318 and Their Impacts on Vendors and Users [6]
Literature Review

The intended use of WIM data should determine the approach the state chooses in developing the WIM data collection site and the resources required to maintain the site over the expected site design life. WIM equipment provides highway planners and designers with traffic volume and classification data by time of day and day of week. In addition, WIM equipment also provides planners and designers with equivalent single axle loadings that heavy vehicles place on pavements. This task will investigate how other states utilize WIM technology for oversize/overweight vehicle enforcement.

Preliminary background research indicates that other states have successfully combined WIM-based technology with mobile enforcement activities to reduce overweight vehicles [1-5]. Montana reported a 22% decrease in the percentage of overweight vehicles, with a reduction in the amount overweight by nearly 16% [1]. States have various types of WIM systems in place, for example, California is using bending plates, Missouri is using piezoelectric sensors, and Oregon is using load cells, to name a few. The focus will not be limited to these states, but where successful practices and procedures from other states are available, they will be investigated.

Technology

The PrePass™ systems have the mainline WIM capability that automatically pre-screen commercial vehicles traveling at highway speeds up to 80 mph. By allowing for a static scale to be used for only the most likely violators, the systems facilitate overweight vehicle enforcement activities, being effective especially in the regions with a high volume of truck traffic. However, the systems are limited to the transponder-equipped vehicles and still required trucks without transponders to stop at the weigh stations for inspection.
Recent advances in sensor and communication technologies lead to the emergence of advanced WIM technologies that have the potential for further improvement of existing weigh station operations. New technologies involving WIM systems include Automated Vehicle Identification systems. Integration of AVI with WIM technology creates new methods of screening commercial vehicles traveling on the mainline at high speeds in an unattended mode for their conformity to weights, dimensions and other regulations.

Newer forms of technology also include a photo WIM system and mainline automated clearance system.

**Automated Vehicle Identification Systems**

Automated vehicle identification (AVI) is the application of sensor technologies to make more informed screening decisions at weigh stations for commercial vehicles. It may be described as containing three components, the transducer, a signal processing device, and a data processing device. The transducer detects the passage or presence of a vehicle or its axles. The signal processing device typically converts the transducer output into an electrical signal. The data processing device usually converts the electrical signal to traffic parameters.

A sensor is a key component of any AVI system. Depending on the installation location, sensors are categorized into two types, intrusive and non-intrusive [9]. Intrusive sensors are those that require the installation of the sensor directly onto or into the road surface, including inductive loops, magnetometers, microloop probes, pneumatic road tubes, piezoelectric cables and other WIM sensors. On the other hand, non-intrusive sensors are mounted overhead or on the side of the roadway. The video image processors, microwave radar, active and passive infrared sensors, and ultrasonic sensors fall in this category.
In Table 2, the strengths and weaknesses of the sensors are summarized with respect to installation, parameters measured, performance in inclement weather and variable lighting conditions, and suitability for wireless communication. The types of data typically available from each sensor technology are listed in Table 3, including coverage area, communication bandwidth requirements, and purchase costs. Several technologies are capable of supporting multiple detection zone applications with one or a limited number of units. These devices may be cost effective when larger numbers of detection zones are needed to implement the traffic management strategy.

Inductive loop detectors have been most widely used to monitor traffic flow and control signals because of their relatively low cost, maturity, aesthetics, and policy issues. Some of the overhead technologies, such as video image processing and multi-zone microwave and infrared sensors, may replace several inductive loops since the higher cost of the aboveground sensors can offset the costs associated with installing and maintaining multiple inductive loops. In addition, most overhead sensors have the advantages over intrusive sensors of being compact and not roadway invasive, thus making installation and maintenance relatively easy.

AVI technologies have already been used to a limited extent in some locations, but it is expected that most WIM systems will eventually be integrated with this new technology. Properly implemented, electronic screening using AVI results in significant improvement of weigh station operations in a cost effective manner.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive Loop</td>
<td>* Flexible design to satisfy large variety of application * Maneuver, well understood technology * Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap) * High frequency excitation models provide classification data</td>
<td>* Installation requires pavement cut * Decreases pavement life * Installation and maintenance require lane closure * Wire loops subject to stresses of traffic and temperature * Multiple detectors usually required to instrument a location</td>
</tr>
<tr>
<td>Magnetometer (Two-axis thangate Magnetometer)</td>
<td>* Less susceptible than loops to stresses of traffic * Some models transmit data over wireless RF link</td>
<td>* Installation requires pavement cut or milling under roadway * Cannot detect stopped vehicles</td>
</tr>
<tr>
<td>Magnetic (Induction or search coil magnetometer)</td>
<td>* Can be used where loops are not feasible (e.g., bridge decks) * Some models installed under roadway without need for pavement cuts * Less susceptible than loops to stresses of traffic</td>
<td></td>
</tr>
<tr>
<td>Microwave Radar</td>
<td>* Generally insensitive to inclement weather * Direct measurement of speed * Multiple lane operation available</td>
<td>* Antenna beamwidth and transmitted waveform must be suitable for the application * Doppler sensors cannot detect stopped vehicles</td>
</tr>
<tr>
<td>Infrared</td>
<td>* Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class * Multipurpose passive sensors measure speed * Multiple lane operation available</td>
<td>* Operation of active sensor may be affected by fog when visibility is less than 20–30 ft or blowing snow is present * Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>* Multiple lane operation available</td>
<td>* Some environmental conditions such as temperature changes and extreme air turbulence can affect performance * Temperature compensation is built into some models * Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds</td>
</tr>
<tr>
<td>Acoustic</td>
<td>* Passive detection * Inertial to precipitation * Multiple lane operation available</td>
<td>* Cold temperatures have been reported as affecting data accuracy * Specific models are not recommended with slow moving vehicles in step and go traffic</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>* Monitors multiple lanes and multiple zones/lane * Rich array of data available * Provides wide-area detection when information gathered at one camera location can be linked to another</td>
<td>* Inclement weather, shadows, vehicle projection into adjacent lanes, occlusion, day-to-night transition, vehicle-road contrast, and water, salt grime, ice, and cobwebs on camera lens can affect performance * Require 50–60 ft camera mounting height (in a side-mountain configuration) for optimum presence detection and speed measurement * Some models susceptible to camera motion caused by strong winds * Generally cost-effective only if many detection zones are required within the field of view of the camera</td>
</tr>
</tbody>
</table>

Table 2 – Strengths and Weaknesses of Sensor Technologies [8]
Table 3 – Traffic Sensor Output Data, Bandwidth, and Cost [7]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Output data</th>
<th>Multiple Lane, Multiple Detection Zone Data</th>
<th>Communication Bandwidth</th>
<th>Sensor Purchase Cost 1 (Each in 1990 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Presence</td>
<td>Speed</td>
<td>Occupancy</td>
</tr>
<tr>
<td>Inductive Loop</td>
<td>X</td>
<td>X</td>
<td>X^2</td>
<td>X</td>
</tr>
<tr>
<td>Magnetometer (Two-axis fluxgate)</td>
<td>X</td>
<td>X</td>
<td>X^2</td>
<td>X</td>
</tr>
<tr>
<td>Magnetic Induction or search coil</td>
<td>X</td>
<td>X^2</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Microwave radar</td>
<td>X</td>
<td>X^2</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Infrared</td>
<td>X</td>
<td>X</td>
<td>X^3</td>
<td>X</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Acoustic array</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Note: 1. Installation, maintenance, and repair costs must also be included to arrive at the true cost of a sensor solution as discussed in the text.
2. With specialized electronics unit containing embedded firmware that classifies vehicles.
3. From microwave radar sensors that transmit the proper waveform and have appropriate signal processing.
4. With multi-detection zone passive or active mode infrared sensors.
5. With active mode infrared sensor.
6. Models with appropriate beam forming and signal processing.
7. Depends on whether higher-bandwidth raw data, lower-bandwidth processed data, or video imagery is transmitted to the traffic management center.
8. Includes underground sensor and local receiver electronics. Receiver options are available for multiple sensor, multiple lane coverage.

**Site Selection**

Although the actual system characteristics of different WIM systems are different, the layout and the considerations that should be made are essentially the same. Generally speaking, cost will most likely be a key concern, but it is also important to carefully study the location that is chosen for the WIM system. The design speed of WIM systems is an important issue in designing the geometry of a WIM facility. In evaluation of the geometric design of the location, horizontal grade, roadway grade, cross slope, and lane width must be within acceptable levels. In cases where a long design life for pavements is established, the reliance on the WIM data will most likely be high. Additional considerations for a good site location are availability of access to power and phone, adequate location for the controller cabinet, proper drainage facilities and freeway traffic conditions.
In the preliminary site evaluation, steps need to be taken to find that there are no alternative routes to circumvent the system by overweight trucks. The site chosen should be such that it is not a point of high congestion such that more delays may creep into the highway traffic. Table 4 shows some the general checklist site selection criteria.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Objective</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distance from controller unit</td>
<td>Drive time (minutes)</td>
</tr>
<tr>
<td>2</td>
<td>Roadway geometry</td>
<td>Alignment, cross-slope, lane width</td>
</tr>
<tr>
<td>3</td>
<td>Pavement structure</td>
<td>Thickness</td>
</tr>
<tr>
<td>4</td>
<td>Traffic max</td>
<td>Percent trucks and total volume</td>
</tr>
<tr>
<td>5</td>
<td>Multiple lanes</td>
<td>Number of lanes</td>
</tr>
<tr>
<td>6</td>
<td>Power and communication</td>
<td>Distance to service</td>
</tr>
<tr>
<td>7</td>
<td>Right-of-way</td>
<td>Distance to safe parking</td>
</tr>
<tr>
<td>8</td>
<td>Adjacent space</td>
<td>Park calibration truck</td>
</tr>
<tr>
<td>9</td>
<td>Space for structure</td>
<td>Area for building</td>
</tr>
<tr>
<td>10</td>
<td>Sign bridge structure</td>
<td>For mounting overhead Devices</td>
</tr>
<tr>
<td>11</td>
<td>Roadside pole</td>
<td>For mounting overhead Devices</td>
</tr>
<tr>
<td>12</td>
<td>Lighting</td>
<td>Security and night visibility</td>
</tr>
<tr>
<td>13</td>
<td>Pavement condition</td>
<td>Rutting, cracking, Smoothness</td>
</tr>
<tr>
<td>14</td>
<td>Pavement rehabilitation</td>
<td>Rehabilitation schedule</td>
</tr>
<tr>
<td>15</td>
<td>Circuit time for calibration truck</td>
<td>Cycle time</td>
</tr>
<tr>
<td>16</td>
<td>Sight distance</td>
<td>For clear visibility of traffic</td>
</tr>
<tr>
<td>17</td>
<td>Proximity to highway patrol and enforcement site</td>
<td>For ground truth weights</td>
</tr>
<tr>
<td>18</td>
<td>Access to satellite sites</td>
<td>Distance from primary site</td>
</tr>
<tr>
<td>19</td>
<td>Safety features</td>
<td>Longitudinal barriers</td>
</tr>
<tr>
<td>20</td>
<td>Traffic congestion</td>
<td>Free-flow or stop-and-go</td>
</tr>
<tr>
<td>21</td>
<td>Bending plate WIM</td>
<td>Existing, buildable, or not buildable</td>
</tr>
</tbody>
</table>

Source: Middleton, et al., 2004

Table 4 – WIM Site Selection Criteria [8]

Appendix 1 provides the report for the survey of other states WIM activities and installations.

Appendix 2 provides an encyclopedia of documentation used during this project. Vendor technologies are included for reference to technology used for WIM and several papers providing background, design considerations, and lessons learned are also included and reviewed.
Project Demonstration

The Oklahoma Highway Patrol (OHP) has responsibility for commercial vehicle enforcement in the State of Oklahoma. In discussions with ODOT Planning and Research Division and OHP Troop S, a need exists for a system that can detect overweight vehicles and notify OHP officers located down road for enforcement. Photos of the vehicle, driver, and load as well as weight, speed, and height should be made available remotely. The OHP trooper could sit down road near a “hot spot” to receive the information, but must not be physically connected.

The fixed WIM site selected by ODOT for the prototype system is near McAlester, Oklahoma, on US-69 - 4.75 miles North of SH-113 South. The project included the evaluation of video capture capability, integration into the existing WIM site, and provision of on-event video via wireless link to a remote trooper.

A description of the demonstration is provided in Appendix 3 - Truck Weight Enforcement Using Advanced Weigh-in-motion Systems – System Requirements Document. A final report for the demonstration is provided in Appendix 4 - Demonstration Final Report.

In summary, the demonstration proved that fixed cameras running License Plate recognition software can be installed to capture mainline traffic. A view of the vehicle cab and license plate are shown in Figure 1 and 2 for one vehicle and Figure 3 and 4 for another vehicle with lots of sun glare. The Infrared camera technology is very capable of eliminating sun glare to render a usable image. Nighttime images are also possible using the Infrared camera technology as show in Figure 5 and 6.

Our experience with the camera technology used is that without a fixed aligned camera, false and no-read images will occur. See Figure 7, 8, 9, and 10 for results of incorrect alignment of the camera.
The Weigh-In-Motion system installed at the demonstration location uses the Piezoelectric sensor technology. While this technology works well for counting and classifying vehicle traffic, the accuracy is the least of all technologies in use. As a result, vehicles indicating overweight (in excess of 80,000 lbs) on the sensor had static weights under the limit. Several vehicles were stopped and weighed by the OHP to verify this finding.
Figure 1 – Vehicle Cab Image

Figure 2 – Vehicle License Plate Recognition
Figure 3 – Vehicle Cab Image with sun glare

Figure 4 – Vehicle License Plate Recognition with sun glare
Figure 5 – Vehicle Image at night

Figure 6 – Vehicle License Plate Recognition at night
Figure 7 – Incorrect Camera Alignment Vehicle Image

Figure 8 – Incorrect Camera Alignment License Plate Recognition
Figure 9 – Incorrect Camera Alignment Vehicle Image

Figure 10 – Incorrect Camera Alignment License Plate Recognition
Project Findings

Advanced Weigh-in-Motion is a technology that can be used to reduce wear and increase the life of roads. While this technology is not capable of performing the task itself, it is capable of providing a deterrent to truck operators who may contemplate operating over the weight limit. Advanced WIM sites can be set up in a cost effective manner and do not need to be manned 24 hours a day. By manning these sites at random, truck operators cannot predict their safe passage while operating overweight.

The camera and network technology that was demonstrated with this project proves that unmanned sites also have value. By capturing images and license plate information, suspected violators can be inspected at any point down the road for compliance. Repeated tagging of suspected vehicles could lead to a more extensive inspection of the operator and their operations.

Sensor technology is still lacking in accuracy when thinking of unmanned weight enforcement. Road geometries, truck dynamics, and weather have too great of an effect on sensor accuracy. While modern sensors have good accuracy, their cost of installation, maintenance, and need for periodic calibration make them unattractive.
References


Appendices
Article #1: An Overview of Research on Weigh-in-motion System.

This paper gives an overview about the damage caused by overweight vehicles and talks about the role of WIM in solving that problem. Overweight trucks cause huge structural damage to roads and bridges, what leads into permanent transfiguration, and limits its lifespan to 8 years instead of the standard 30 years.

In addition to that structural road damage, There is a great loss in the state’s regulation fees and tax income, the harm to the traffic Security.

Moreover, this paper talks how the German WIM company “PAT” ranked first in the 30 months test on the practical use condition of the WIM system, and take lead in that field.

After that, the author talks about the current development of different types of WIM system. And concluded, by urging everybody to start developing more advanced systems to solve the overweight problem and stop road damage.
An Overview of Research on Weigh-in-motion System

Jianming Wang and Mingmuang Wu
Institute of Infrastructure Power Control
Zhejiang University

Abstract: This paper provides an overview of research on weigh-in-motion systems. It first looks at the problem of overweight in the construction and operation of roads and traffic facilities. Then, it analyzes the causes of this problem and gives a vision on the current research in China. The overview aims to introduce the fundamentals of the weigh-in-motion system and the latest developments in this field. The study also discusses the potential benefits of implementing such systems in improving traffic safety and reducing environmental impact.

1. Introduction

With the rapid development of the economy in our country, the transportation has made great progress, and the highway mileage has been increasing. However, the increasing vehicles have also caused some problems, such as overweight and fatigue damage to the road network and bridges. Hence, the government has attached great importance to this subject. In recent years, the Ministry of Transport has issued several regulations and policies to control the overload of vehicles. The weigh-in-motion (WIM) system, which is widely used in the world, is also an effective tool to control the overload of vehicles. The WIM system can weigh the vehicles in real-time and provide real-time feedback to the drivers, thus helping to reduce the overweight problem.

2. Theoretical Background

The WIM system is a set of sensors and algorithms that are used to measure the weight and speed of vehicles passing over them. The sensors are typically mounted on a bridge or over the road, and they measure the impact forces generated by the passage of a vehicle. These forces are then used to calculate the weight of the vehicle. The WIM system can be used to detect and prevent overloaded vehicles from passing over the road, thus reducing the risk of damaging the road infrastructure.

3. Current Research

Research in the field of WIM systems is ongoing, with new technologies and algorithms being developed to improve the accuracy and efficiency of the system. The main challenges in the development of WIM systems are the need for high accuracy, real-time processing, and robustness in harsh environments. Several research projects have been carried out in recent years to address these challenges. Some of the recent developments include the use of advanced sensor technologies, such as infrared and radar sensors, which can provide more accurate and real-time data. Other research focuses on developing more efficient algorithms for data processing and analysis.

4. Conclusion

In summary, the WIM system is a powerful tool for controlling the overweight problem in transportation. It helps to reduce the risk of damaging the road infrastructure and improves traffic safety. However, there is still a need for further research to improve the accuracy and efficiency of the system. Future research should focus on developing more robust and high-accuracy WIM systems that can be widely used in the transportation sector.

27
the driving difficulty when the vehicles have to reverse. All these will cause traffic accidents.

D. Conclusion

There are five major facets of public transportation in our country: road transportation, railway transportation, air transportation, water transportation, and pipeline transportation, among which the road transportation takes the leading position. The overweight damages the power of the transportation in many ways. The roads are easier to twist, bend, and twist to pass over, causing not only the destruction of the roads but also the roads.

This causes the usual condition in the transportation market and a vicious circle of "overweight damages transportationלות transportation weight damage".

III. THEORETICAL ANALYSIS OF THE OVERWEIGHT PROBLEM

A. The Transmision Caused by the Static Load

As shown in Fig. 1, the load depends on the transmision line when the load is low or heavy. The transmision line is proportionally to the load increasing. In the range above, the road surface experiences elastic compression. But when the load exceeds the value $P_{0}$, the load is no longer proportionally to the transmision line and the road surface experiences elastic transmision. When the load increases continuously, the value $P_{0}$ is the transmision line and the road surface is destroyed.

When overweight vehicles run on the road, the road surface will undergo transmision, some of which can be measured as static transmision. The static transmision is called static transmision. When the load weight on the road is less than the designed load, the road is elastic, and the transmision line is elastic. The static transmision is very large, the road can work normally. When the load exceeds the pole weight limit, the road is in the plastic stage, the transmision line is elastic, the road is destroyed.

B. Relationship Between the Load and the Lifespan of the Road

Road Administrations Department in many countries have done many experiments on the relationship between the load weight and the lifespan of the road. In 1958, USA put forward the Fourth Power Rule, stating that the lifespan of the road is in direct proportion to the load weight by square root. The formula of which is as follows:

$$F(t) = P(t)^{0.5}$$

In this formula, $F(t)$ is the load weight, $P(t)$ the standard load weight, and $F(t)$ is the conversion parameter in converting the load to the road to the time of $P(t)$, doing damage to the road, namely the destruction parameter. In general, $F(t)$ between 4 and 5, $F(t)$ is not $4.2$ in America, $3.4$ in Japan, $2.5$ in England and $4.0$ in China. The value of $F(t)$ is more than 1 when the vehicle is overweight, so the damage which the overweight causes is very obvious and the after-effect serious. For example, when the standard load weight is $1.0$, if the actual load weight is added to $2.0$, the damage will be six times more.

IV. DEVELOPMENT OF THE WAVE NAVIGATION SYSTEMS

Early in 1980's many countries have begun to research and develop the overweight vehicle detection systems. The early practice is to weigh the vehicles statically, using the weigh-station, the build-in scale, etc. Some methods only measure the overall weight of the vehicles. For the weight, on each axle, they find difficulty. And specificities of weighing station has to be held in the machine or near the road, which decreases the efficiency.

The new development brought about the portable weigh-in-motion system, weigh-in-motion systems and the WIM technology to detect the load weight when the vehicles are running. This technology has been adopted widely in many European countries for over twenty years and has proved the various traffic environment and measurable results that due to the ineffectiveness in manufacturing set equipment. This has been successfully in the WIM technology. Therefore, in 1997, following the procedure by the European Committee, Europe has initiated the COST 292 plan which aimed at the current research in determining the load weight of the passing vehicles dynamically. One of the most important items is the 30-kg unit put on the practical use of the WIM system since it introduced. In the last, all the vehicle systems were realized on the same principle in the weigh station and compared in capability and the stability. The resulting main order is as follows: German BMT, the coordinated systems of Scandinavia RIT and INRE, Indian, Finnish, EGM, B. and Golden River. In 1994, the Federal of European High Road Institute carried out the WAVE (Weighing In Motion of Axle and Vehicles) for European plan, that is, the Future Car/Truck Environment P3.31 The measuring data is as follows: BMT (1990), Korter (1990), 961, etc. of the Institute of Transportation.

The conclusion is that it can be seen that the German BMI system has a lot of prestige in the world. They have accepted most of the European and American markets and have been widely adopted in Asian countries and areas like Japan, Singapore, Taiwan, and Hong Kong. In 1990 BMI system accepted the advance market and put the Prewning of Weighing Instruments market by the National Technology Supervision Bureau in August 1990. The Yunhui Space Technology Co. Ltd. has adopted the BMI system. On 16 th May they conducted an aerial test of the SAW-AF system performing real vehicular testing and got the above-mentioned results and predictions.

![Diagram](image-url)
V. CLIMATE DYNAMIC DEVELOPMENT OF WEIGHT-MISDETECTOR SYSTEM

We have been in the research and manufacture of the weight-in-motion system for several years. At present, many domestic enterprises have developed various kinds of weight-detection systems, such as the GCS-3820 weighing platform produced by the Beijing Zhonghong New Technology Institute. Its single axle weight range is 5000 kg, its dynamic precision is 1100—3300 kg, its driving speed is 30—100 km/h, and the weight range is 1325—3300 kg. The design idea is to use the same platform, less cost, and higher precision. The platform is a rectangular platform with a length of 1250 mm and a width of 1000 mm. Two such weigh-plates are placed on each roadway, with a distance of 2500—2150 mm between each pair. These weigh-plates detect the vehicle's weight and send the signals to the computer. The signals are then transmitted to the control center where the vehicle's weight is calculated and displayed.

VI. WEIGHT-IN-MOTION SYSTEM DEVELOPED BY PAT COMPANY

The German PAT Company is famous for its weight-in-motion systems and has developed various types of weight-in-motion systems. It was the first company to develop a fully automatic weight-in-motion system in the world. The company has successfully developed a high-speed dynamic scale system that is installed on the road and can measure the weight of vehicles as they pass. The system is designed to be simple and easy to install, and it can be installed on existing roadways without the need for major modifications.

A. HIGH-SPEED DYNAMIC SCALE SYSTEM

B. INSTALLATION OF THE HIGH-SPEED DYNAMIC SCALE SYSTEM

The high-speed dynamic scale system is installed on the roadway in such a way that the weigh-plates are located at the center of the road. The weigh-plates are designed to be as inconspicuous as possible, and they are covered by a layer of asphalt to blend in with the road. The weigh-plates are connected to the computer through cables, and the data is transmitted to the computer in real-time. The computer then analyzes the data and determines whether the vehicle is overweight. If the vehicle is overweight, the computer sends a signal to the weigh-plates, and the weigh-plates display the weight of the vehicle.

C. INSTALLATION OF THE HIGH-SPEED DYNAMIC SCALE SYSTEM

The high-speed dynamic scale system is installed on the roadway in such a way that the weigh-plates are located at the center of the road. The weigh-plates are designed to be as inconspicuous as possible, and they are covered by a layer of asphalt to blend in with the road. The weigh-plates are connected to the computer through cables, and the data is transmitted to the computer in real-time. The computer then analyzes the data and determines whether the vehicle is overweight. If the vehicle is overweight, the computer sends a signal to the weigh-plates, and the weigh-plates display the weight of the vehicle.

D. INSTALLATION OF THE HIGH-SPEED DYNAMIC SCALE SYSTEM

The high-speed dynamic scale system is installed on the roadway in such a way that the weigh-plates are located at the center of the road. The weigh-plates are designed to be as inconspicuous as possible, and they are covered by a layer of asphalt to blend in with the road. The weigh-plates are connected to the computer through cables, and the data is transmitted to the computer in real-time. The computer then analyzes the data and determines whether the vehicle is overweight. If the vehicle is overweight, the computer sends a signal to the weigh-plates, and the weigh-plates display the weight of the vehicle.

E. INSTALLATION OF THE HIGH-SPEED DYNAMIC SCALE SYSTEM

The high-speed dynamic scale system is installed on the roadway in such a way that the weigh-plates are located at the center of the road. The weigh-plates are designed to be as inconspicuous as possible, and they are covered by a layer of asphalt to blend in with the road. The weigh-plates are connected to the computer through cables, and the data is transmitted to the computer in real-time. The computer then analyzes the data and determines whether the vehicle is overweight. If the vehicle is overweight, the computer sends a signal to the weigh-plates, and the weigh-plates display the weight of the vehicle.
The system is designed to have a high-speed dynamic scale, which can accurately measure the weight of vehicles. A high-speed, high-precision scale system is essential for ensuring the accuracy of weight measurements. The system can handle up to three vehicles simultaneously. The weight of each vehicle is measured in real-time, and the system can display the weight on a digital screen.

VI. CONCLUSION

The system has been designed to address the issue of overweight vehicles in the transportation industry. It has been tested in various environments and has shown promising results. The system is easy to use and can be implemented in various settings, including highways and parking lots. Future research should focus on improving the accuracy and efficiency of the system.
Article #2: Design and Manufacture of Surface Acoustic Wave Sensors for Real-Time Weigh-in-Motion

This paper describes the designing of the SAW (Surface Acoustic Wave) strain sensor that can be interrogated wirelessly and without a power supply for RTWIM (real-time WIM). This kind of sensors has various advantages over other sensors as a wide temperature range for extreme climates operation. The sensors send data thru wireless RF links to the interrogation Unit that sends it to the vehicle tracking unit which has a GSM link with the fleet control unit to monitor both weight and position of the truck. The SAW sensors have the following attributes: Low attenuation, selective bandwidth, clearly defined sensor response, and consistent space-independent interrogation. The 1-port SAW resonator is used in this project with the Rayleigh-type wave and in case of multiple sensors FDMA (Frequency Division Multiple Access) is used. The size of the die that has the SAW sensors on it is 6x6 mm. This project resulted in a RTWIM SAW strain sensors designed for a multi-sensor environment.
Design and Manufacture of Surface Acoustic Wave Sensors for Real-Time Weigh-in-Motion

Brian Mc Cormack¹, Dermot Geraghy¹, Margaret O'Mahony²

¹Department of Mechanical and Manufacturing Engineering, Trinity College Dublin, Dublin 2, Ireland
Phone: +353 1 6083935, Fax: +353 1 6775554, E-mail: mccomb@tcd.ie
²Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Dublin 2, Ireland

Abstract—This paper presents the design and manufacture of Surface Acoustic Wave (SAW) strain sensors which can be produced in a university environment. These sensors can be interrogated wirelessly and operated without a power supply, which allows for greater measurement flexibility than conventional strain gauge systems.

The design of an optimised sensor requires accurate experimental data on a number of process parameters and configurations, which for this project required the testing of several prototype designs. The large prototyping costs typical of SAW devices can be significantly reduced if the design and manufacturing processes are integrated. This paper outlines such a system, where device function and processing issues are integrated at each stage. The result is a range of sensors which have been "designed for manufacture", optimising both the variety of devices per wafer and the yield.

Keywords— Weigh-in-Motion, SAW, sensor design

I. INTRODUCTION

New sensor technology is an important aspect of future Intelligent Transportation Systems (ITS), which aim to best utilise existing infrastructure and provide sustainable transport solutions. A practical Weigh-in-Motion (WIM) system (i.e. one which calculates the gross vehicle weights of heavy vehicles travelling at highway speeds [1]) could be a key ITS application, providing:

1. Vehicle taxation based on gross vehicle weight, distance traveled, exhaust emission class etc.
2. Regulatory enforcement of maximum vehicle weight, to improve public safety.
3. Fleet management for hauliers.
4. Vehicle condition monitoring for preventative maintenance.
5. Point of delivery weighing and billing of bulk loads.

To date, no low-cost WIM system has been available for real-time measurements, i.e., at arbitrary positions on the road network. Existing systems are either road-based, which only provide point measurements, or vehicle-based, which require expensive transducers and long installation times.

In this project, it is proposed that strain-sensitive Surface Acoustic Wave (SAW) sensors will be used to measure axle strain on Heavy Goods Vehicles in real-time, and that this will be used to infer the gross weight of the vehicle. SAW sensors can be operated both passively and wirelessly [2],[3], and are well suited to automotive applications [4],[5]. An added advantage is that the sensors can operate within a wide temperature range, which is essential for operation in extreme climates. Figure 1 shows the proposed system layout, as implemented in a fleet management system for hauliers. Each SAW sensor is networked using a wireless RF link to a central interrogation unit, which collects and processes the strain information to calculate vehicle weight. This data is then passed via a standard interface to a commercial off-the-shelf (COTS) vehicle tracking unit, which incorporates a GSM link for data transmission to the fleet control centre. Thus the haulier can monitor both vehicle position and weight at any time.

This paper focuses on the design and manufacturing processes used to transform SAW sensor specifications into physical devices for testing. The traditional method of producing SAW devices is described, and an integrated design and manufacturing process flow is then presented. This integrated system is more suitable for low-volume research purposes in a university environment as it allows a larger variety of prototype designs to be created, and affords more visibility of the manufacturing process to aid future design work.

II. PROPOSED APPROACH

The design of an optimised sensor requires accurate experimental data on a number of process parameters and device configurations, which for this project required the testing of several prototype designs. Traditionally, a client who requires a custom-designed SAW device (e.g. for a new communications
application specifies a number of important parameters (e.g. resonant frequency, amplitude of resonant peak etc.) required of the device to the SAW manufacturer, who then produces a prototype wafer of devices. These experimental devices are usually adapted from existing designs, and are tested to select the best design for production. While successful for mainstream SAW devices (which are produced in bulk and used for electronic applications), there are two major disadvantages for SAW sensor research:

1. Cost of development: the cost of a design run, which may have to be iterated as specifications change, is prohibitive for a university research project. These prototyping costs are excessive given the small production volumes used for research purposes.

2. Separation of design and manufacture: for research purposes it is essential that each stage of the project is visible, i.e., that the processes used can be easily examined. This is especially true of this project, as both the electrical and mechanical characteristics of the SAW sensors need to be considered. Mainstream SAW manufacturers use proprietary techniques to fine-tune device performance, effectively separating the design and manufacturing processes.

In light of these disadvantages, it was decided to implement an integrated design and manufacturing system for this project, which will allow the devices to be fabricated in a university research environment. Figure 2 shows a flowchart for the system. At each stage of the process, the different (and sometimes conflicting) requirements of design and manufacture must be considered. This coordinated approach should reduce production problems, as the sensors have effectively been "designed for manufacture". Production costs are significantly reduced as the devices can be produced in small microelectronics laboratories, and at every stage the effect of design decisions on production can be examined.

The initial inputs to the system are the SAW sensor specifications. These describe the sensors' behaviour both as a wireless, passive device and as a strain sensor. The wireless, passive measurement capabilities are only useful if the sensors can operate according to existing standards for low-power RF devices (e.g. [6]). Similarly, the performance of the devices as strain sensors must be comparable to that of existing foil resistive strain gauges. Following an evaluation of the specifications, the finished sensors should have the following attributes:

- Low attenuation: the sensors are passive, and thus insertion attenuation must be minimised to return the maximum signal power.

- Selective bandwidth: due to fabrication constraints and European frequency regulations [6], the devices are restricted to wireless operation within the European ISM band of 433.05-434.7MHz, which is quite narrow for a multi-sensor environment. Strain sensitivity must be such that the measurand can be detected over the operating range, without interfering with the response from...
other sensors.

- **Clearly defined sensor response:** the RF channel is likely to be noisy, with interference from the vehicle and from other devices in the frequency band.
- **Consistent, space-independent interrogation:** the multiple sensors will be distributed around the vehicle, and thus will have different signal paths, line-of-sight etc. The position of the sensor should not affect the resolution of the measurement.

The subsequent process steps are described below:

1. **SAW device type selection:** the first process stage is the choice of SAW device to be developed as a sensor. Basic device types include SAW resonator and SAW delay line [7]. The 1-port SAW resonator was chosen for development, as it combines narrowband operation, low device attenuation, low interrogation system cost [8] and small die size; all of these characteristics are required for the RTWIM sensors. The manufacturing steps for most types of SAW device are common, and thus the performance of the available photolithography equipment (a KarlSuss MJB3 mask aligner) is the only input here.

2. **Substrate selection:** Rayleigh-type SAW were chosen as the wave type for the sensors, and for optimum performance the piezoelectric coupling must be maximised and temperature dependence minimised. For multiple sensor operation within the ISM band, narrowband behaviour is preferable. SAW quartz displays both low temperature dependence and narrowband piezoelectric performance. The piezoelectric coupling can be maximised by appropriate choice of propagation direction (0° and 35° in this case) [10]. Many sizes of wafer are available at reasonable cost.

3. **Multiple sensors:** several sensors will be required in the measurement system, and this must be considered early in the design cycle. As the SAW resonator was chosen for development, Frequency Division Multiple Access (FDMA) [11] may be used for interrogation of multiple devices. The operating frequency of each sensor is largely dependent on the SAW velocity \( v_s \) (which is a function of the SAW propagation angle on the substrate) and the electrode pitch \( p \) [9]. Tight control of electrode linewidth is thus needed to maximise the number of sensors in the band. In order to minimise variations in electrode widths due to rounding of dimensions, the photomask was designed to match the 0.35mm address size of the photomask machine (an Etec Systems Alpha1000). Three different finger widths (1.8247, 1.81594 and 1.80761mm) were chosen, which give a range of operating frequencies close to the ISM band. This choice of machine-matched dimensions will show the effect of data conversion and machine tolerances on mask dimensions ±0.05μm is expected. This spread of device frequencies will allow a wider study of the parameters affecting SAW strain sensors (see below).

4. **Wafer layout:** modern SAW devices for communications have a surface area of c. 2x1mm, which makes them far too small for manual handling as strain sensors. A normal die size of 6x6mm was chosen for the SAW sensor, allowing compatibility with existing strain gages, space for different electrode configurations and connection pads for external antennas and circuits. Larger die of 7.5x7.5mm were used for 'multiple' sensor, where several SAW resonators on a single die are used for measurement. The wafer layout is designed for easy dicing into individual sensors, and on a 3" wafer yields 48 single and 18 'multiple' sensors.

5. **Die details:** as the sensors have been custom designed for the project, there is scope to prototype many different varieties of device. Centre frequencies, reflector bar sizes etc. have been varied across the wafer, giving 24 single and 9 'multiple' sensor types. This will allow a novel parametric study of device specifications for SAW strain sensors.

**III. RESULTS**

The main output of this design and manufacturing process was a photomask design, and the resulting mask is being used in a lift-off photolithography process [12] to produce the SAW sensors. An example of a sample die from the photomask is shown in Figure 3. The SAW resonator structure is in the centre of the die, with connection pads on each side; orientation marks are also added for installation purposes. A section of the resonator structure is shown in Figure 4. As mentioned above, linewidth control is essential to ensure a narrow spread of device frequencies. Variations in linewidth from the original design are caused primarily by manufacturing tolerances on the photomask machine; rounding during data conversion
accounts for a small error. Figure 5 shows the measured error in linewidth across an electrode section: nominal linewidth is 1.8076 μm. The photomask dimensions all lie within the specified ±0.05μm tolerance. Small deviations in sensor operating frequency due to linewidth bias can be corrected by adjusting the wave propagation direction and/or the electrode thickness.

Preliminary resist patterns of a sample sensor are shown in Figure 6. Although the available manufacturing equipment was a key consideration during the design process, the exposure and development times during fabrication must still be optimised manually [13]. This optimisation is essential in order to produce the required high-definition resist patterns. The wafers can then be metalised by sputtering or evaporation to produce the sensor electrodes and grating elements. Individual die can subsequently be tested as standard SAW devices (e.g. for measurement of resonant frequency, quality factor, response bandwidth) before implementation as strain sensors.

Although the optimisation is still in progress, some preliminary results may be drawn. The integration of design and manufacture provides a relationship between the critical dimensions in a design and those on the actual device. This allows future designs to be designed and manufactured to tighter frequency tolerances. A consequence of this is that more sensors can be designed to operate in a narrow frequency band, which is a crucial requirement for a multi-sensor environment like RTWM. The wide variety of device designs will provide experimental data over a range of configurations, which can then be used as parameters for device modelling techniques such as Coupling-of-Modes (COM) analysis [14,15].

IV. CONCLUSIONS

In summary, an integrated design and manufacturing system has been implemented for Real-Time Weigh-in-Motion SAW strain sensors. This system manages the development of SAW sensors from basic specifications to finished devices, while increasing process visibility and lowering costs relative to traditional design and manufacturing processes. The resulting devices have thus been custom designed for a demanding multi-sensor environment.
ACKNOWLEDGEMENTS

This work is funded by the Centre for Transport Research and Innovation for People (TRIP) at Trinity College Dublin, which forms part of the HEA’s PRTLI initiative. Device fabrication is carried out with the assistance of the SFI Trinity Nanoscience Laboratory.

REFERENCES

[6] Radio Frequency is to be used in the 2 GHz to 4 GHz range with power levels ranging up to 500 mW. European Telecommunications Standards Institute (ETSI) Std. EN 300 220, 2000.
**Article #3: Field Evaluation of Weigh-In-Motion Screening on Truck Weigh Station Operation**

This paper talks about the WIM system being a pre-process for the static weigh station, in a way to improve its capacity by screening trucks while traveling at high speeds and only requiring trucks within a threshold of a maximum permissible weight to be weighed on a more accurate static scales, thus reduces delays. Accurate WIM stations are a major requirement to get a realistic number of trucks that enter the static scale. 30 percent of the trucks were not weighed simply because queues were too long and thus were allowed to bypass the static scales in order to prevent queue spillbacks. in many instances trucks with legal weights experienced unnecessary delays at the weigh station because they were requested to enter the static scales. The Illinois Department of Transportation considered” the addition of an Automatic Vehicle Identification (AVI) system to the existing WIM system. The study concluded that should the weigh station integrate AVI and WIM, there would be a reduction of delays and an increase in productivity”. 
FIELD EVALUATION OF WEIGHT-IN-MOTION SCREENING ON TRUCK
WEIGH STATION OPERATIONS

Hisham Rakkah1, Bryan Katz2, and Ahmad Al-Kaisy3

ABSTRACT

Weight-in-Motion (WIM) systems can improve the operations of weigh station operations by screening trucks while driving at high speeds and with requirements under a threshold of a maximum permissible weight to be weighed in a non-required state scale. Consequently, the operation of a weigh station is highly dependent on the accuracy of the screening WIM system. This paper describes a novel procedure for selecting, site, and gross weight accuracy for evaluating the accuracy of a WIM system. In addition, the paper evaluates the WIM scale operation at the Virginia City weigh station in Virginia to present a case study evaluation of the operation of a weigh station that is equipped with WIM screening. The case study evaluates the accuracy of the WIM technology in addition to the operations of the weigh station in terms of service time, system rate, and their impact on the metrics scales.

Key words: Weight-in-Motion (WIM), Weight station operations, Heavy, Intelligent Transportation System.

1. INTRODUCTION

1.1 Background

The design of pavement and bridge structures requires precise predictions of vehicle axle loads and vehicle classifications. Vehicles' gross weight and axle weight restrictions have been imposed in order to ensure that vehicles do not exceed the design limits of these roadways and bridge structures. In order to ensure that trucks with axle and vehicle axle weight restrictions have been imposed in order to ensure that vehicles do not exceed the design limits of these roadways and bridge structures, an accurate and reliable system must be developed for screening trucks. Weight-in-Motion (WIM) technology. These WIM systems, which allow for screening of trucks at high speeds, reduce delays that would otherwise have been caused by trucks weighed on state scales. In a typical WIM system, weights that are substantially less than the legal weight range are allowed to bypass a state scale while trucks with weights that exceed the limits of the range are required to be weighed on the state scale. Consequently, accuracy of these WIM systems plays an important role in governing the number of trucks that enter the state scale. Furthermore, the effect incurred on a weigh station is a function of the accuracy of the WIM system, the threshold of weight error, the truck arrival rate and distribution, and the weight distribution of these trucks.

1.2 Paper Objective

The objective of this paper is three-fold. First, this paper presents a methodology for evaluating the operation of a weigh station in the field. The proposed methodology evaluates the operation of the weigh station by insulating vehicle service times and grading times at the state scale and the total time spent traveling to the state scale lane. Second, the paper applies this methodology to evaluate the accuracy of a load cell WIM technology as a case study application. Third, the paper develops an analytical procedure for rating the state scale and state weight accuracy.

1.3 Research Approach

The research approach involves setting up two video cameras focused at the entrance and egress of the state scale lane. In the case of the study presented in this paper, both cameras were set up in the scale house. The entrance ramp camera serves two purposes. First, it measures the arrival rate at the state scale. Second, it measures the traffic time of entering trucks at the state scale which together with

1. New Mexico State University, Department of Civil Engineering, Las Cruces, NM 88003, E-mail: hisham@nmsu.edu
2. Transportation Research, 1601 Pennsylvania Ave, Suite 500, VA 22201, E-mail: bryan.katz@gmail.com
3. University of Virginia, Department of Civil Engineering, Charlottesville, VA 22904, E-mail: akaisy@virginia.edu

0-7803-7548-2/03/$17.00 ©2003 IEEE 76
with the time stamp as the input of the static load line is utilized to compute the total time speed in the system. In order to apply this methodology at both, low and high volume locations, it is important to set the correct time level in order to record the vehicle time as well as the number of trucks in the queue waiting to be served at the traffic

The proposed methodology attempts to reduce the operation of the weigh station by incurring static loads and WIM weights. Comparing the static and WIM weights provides an estimate of the accuracy of the WIM system. Establishing the accuracy and performance of the system provides a benchmark for further research, in that the system can be evaluated using analytical and simulation tools in order to quantify the impact of the WIM system accuracy on the weigh station operation.

The proposed methodology was applied to the Stephens City weigh station in the state of Virginia, which is located in the northern part of the state near Interstate 81. Specifically, data were collected for the northbound and southbound directions, which included three days worth of data for the northbound-scale and a single day's worth of data for the southbound scale. Unfortunately, it was not possible to collect further data for the southbound since the weigh station was under construction during the remainder of the study.

1.4 Paper Layout

The paper first describes the current state of practice WIM technologies and the findings of other studies that have evaluated these technologies. Subsequently, the paper describes the Stephens City weigh station configuration, operational procedures, and evaluation of the data. Finally, a characterization of the traffic is presented, followed by an analysis of the system's accuracy. Next, an analysis of the system operation is presented followed by conclusions and recommendations for further research.

2. WIM TECHNOLOGIES

The three major types of WIM technologies used in practice include bending beam, piezoelectric sensors, and load cell technologies [2]. A bending beam WIM system utilizes metal brain beams placed with strain gages to measure truck weights. The dynamic load is calculated using strain readings when a vehicle travels over the beam. Subsequently, using calibrated parameters, the truck load is determined. Alternatively, a piezoelectric WIM system records the change in voltage induced in a piezoelectric wafer over time. The system load is determined from the readings through the wafer, using a calibration procedure. A static load is determined. Finally, a load cell WIM system utilizes a single or multiple load cells that are placed across the traffic lanes, each load cell has two scales that detect an axle and weigh both the right and left sides simultaneously. Then, a sum of masses of the two scales is determined to estimate the total axle weight.

Only a few states have evaluated the operation of a weigh station. One of those states was a field evaluation of the Williamsonville weigh station in Springfield, Illinois [2]. The study attempted to measure the delay and traffic condition experienced by trucks at the weigh station. The goal of the study was to specifically determine the delay of the weigh station in order to evaluate the effectiveness of Automatic Vehicle Identification (AVI) in a WIM system environment as well as to measure potential benefits of Intelligent Transportation System (ITS) technologies. In the study, delay was determined to be the difference between the travel time and the observed travel time. The study indicated that 30 percent of the trucks were not weighed, similar because drivers were too long and thus were allowed to bypass the static scales in order to avoid travel delays. The study also demonstrated that in interchanges, trucks with legal weights experienced unnecessary delays at the weigh station because they were required to enter the static scales. Based on the analysis of the study, the Illinois Department of Transportation concluded that the addition of an Automatic Vehicle Identification (AVI) system to the existing WIM system would significantly reduce the number of delays and improve productivity.

2. CASE STUDY DESCRIPTION

2.1 Site Description

The Stephens City weigh station is located on Interstate 81 in Virginia, approximately 50 kilometers (30 miles) south of the West Virginia border. It is the first weigh station in the state for northbound traffic, and the second weigh station for southbound traffic, near Interstate 81. Both the Stephens City weigh station and Trouxville weigh station, located approximately 28 kilometers (18 miles) south of the Stephens City weigh station on Interstate 81, use WIM systems to facilitate enforcement of new enforcement and reduce delay at the weigh stations. Before the WIM systems were installed, trucks would arrive at the weigh station and exit the weigh system, and then return to the highway. Emergency lights would be activated allowing trucks to bypass the weigh station. After the weigh station, trucks were required to enter the scale. There were two major problems with the older method. First, enforcement was inefficient because many trucks were able to bypass the scales. Second, trucks running empty and below the legal limits were required to stop and then experienced unnecessary delay.
2.2 Site Configuration

The Stephens City weigh station included a scale house adjacent to the weigh station. On December 11, 2021, with static scales on both the eventbound and out-of-bounds lane as well as a WIM scale monitoring system, as illustrated in Figure 1. The weigh station was equipped with the aid of a computer system. The Virginia Department of Motor Vehicles (DMV) transmits the weigh station operation with the Virginia State Police stationed at the static lane. Trucks were required to enter the station by leaving the highway through a decompression lane. Subsequently, the truck driver was instructed, through the use of signs, to maintain a speed of 10 mph (16 km/h) and a maximum distance of 500 ft (152 m) from the preceding truck before descending into the WIM scale. Trucks then traveled over the WIM scale in a single lane configuration, axle weights, and gross vehicle weights were determined. A calibrated sensor located 1 km (1.6 km) from the weigh station was used. Consequently, trucks that weighed 90 percent or higher of the gross or axle limits were weighed through traffic. Scales to date the WIMs to be weighed must be weighed more accurately over the state scale. Additionally, if the bridge did not pass over the interest area, or other roadblocks were observed, the total was directed to the state scale, where the truck was allowed to use the bypass lane in order to bypass the scale (still maintaining a 10 mph (16 km/h) speed limit). An audible alert was provided if the truck did not bypass the scale or if the scale did not function properly. The bypass lane is equipped with traffic lights to alert the trucker to the presence of the scale. In addition, the traffic lights also indicate the presence of other vehicles in the vicinity. In summary, the Stephens City weigh station is designed to provide a safe and efficient service for truckers.

![Figure 1: Stephens City Weight Station Layout](image)

3. Traffic Collection

Traffic data were gathered from the eventbound and out-of-bounds lane scales in order to provide a basis for comparison. Data were obtained from the WIM system using software developed by the supplier, International Road Dynamics (IRD). Accuracy and delay data were collected in both directions on Monday, May 22, 2023, and also in the outbound direction on Wednesday, May 24, and Saturday of June 15, 15, and 36, 2001, respectively. In addition, service time data were taken at both directions on Tuesday, May 21, 2003.

The accuracy of the WIM system was determined by calculating the WIM gross weight for each truck that entered the static scale and comparing the WIM gross weight to the static scale gross weight. Individual axle weights at the static scale were not recorded because the time required to record these data would have impeded the operation of the weigh station, which would have affected the service time data that were also required.

In addition to static gross weight data, other data were gathered including the number of violators and non-violators who were audited to the static scales. Static scale data were recorded by measuring the time required by each truck to travel from the point where the bypass and static scale lanes diverged to the point where the two lanes merged. In addition, audits that entered the parking lot after being weighed on the static scales were identified as well as the trucks that remained from the parking lot. Service times were measured by recording the time the trucks spent on the static scales. These service times were classified by violating or non-violating truck.

3. WIM Accuracy Analyses

The accuracy of the WIM system was determined by computing the WIM gross weight at the static scale gross weight. Because it was not possible to obtain individual axle weights from the static scale, the accuracy of the WIM system was determined by comparing the WIM gross weight to the static scale gross weight. Additionally, an estimated WIM axle weight measurement is computed for systematic bias between the WIM and static scale axle weight in addition to the random error that is a function of the accuracy of the WIM system.

An analysis of the WIM gross weight accuracy was conducted as part of this study by comparing static scale and WIM gross truck weights. Specifically, a total of 991
northbound and 122 southbound Vehicle and WDM truck weights were compared. The sample size was much larger
than the 51 trucks that were recommended in the ASTM standard [1]. The distinction between directions was important in order to compare the level of calibration for each of the WDM scales. While the north WDM (combined 34.125kgs and southbound 33.756kgs) and south
southbound 33.756kgs and southbound 32.752kgs weights were not identical for both scales, a paired t-test assuming
the same variance between WDM and truck scale measurements failed to exceed any statistical differences at
the 0.05 and 0.01 percent confidence levels. Consequently, it was concluded that both the northbound and southbound
WDM scales were sufficiently calibrated.

In addition, the error density function was found to follow a normal density function, as illustrated in Figure 1.
Specifically, a Chi-squared goodness-of-fit test revealed no statistically significant difference between the error frequency and the
normal distribution density function, at a 99 percent confidence level.

Finally, it should be noted that the data that were gathered indicated that the gross truck weights accuracy was estimated to be within 6 and 7 percent of the scale weight 95 percent of the time for the northbound and southbound WDM scales, respectively. These results are on
the border of the ASTM WDM specification for Type III WDM technology [1]. Specifically, the ASTM standard
indicates that Type III WDM functional performance requirements are 5% with a 95% probability of
conformity.

3.2 Relationship between Total and Axle Weight Accuracy

The relationship between the gross truck weights and the corresponding axle weights can be derived assuming that the
axle weight error is a random variable. Using basic statistics, the expected value of the gross weight is
consistent with the summation of the expected axle weights, as demonstrated in Equation 1. Furthermore, if the
axle weight errors are assumed to be independent random variables, then the variance of the vehicle gross weight is
computed as the summation of the variances of the individual axle weights, as demonstrated in Equations 1. If it is
assumed that the accuracy of the WDM system is similar
across the different axles (equal axle variance), then the
standard deviation of the gross vehicle weights (square root of variance) can be computed as the square root of the
delivered by the variance of the gross
weight divided by the square root of the number of vehicle
axles, assuming that the expectation of axle weights are
approximately equal.

\[ W_t = \sum W_i \]  

\[ \sigma_t = \sqrt{\sum \sigma_i^2 - \sqrt{\text{variance}}} \]  

\[ \text{COV} = \frac{\sigma_t}{W_t} \]

Where:

- \( W_t \): Expected or measured gross vehicle weight
- \( W_i \): Expected or measured weight for axle \( i \)
- \( \sigma_t \): Standard deviation of gross vehicle weight
- \( \sigma_i \): Standard deviation of weight for axle \( i \)
- \( \text{COV} \): Coefficient of variation of gross vehicle weight
- \( \text{COV}_i \): Weight coefficient of variation for axle \( i \)
- \( n \): Number of vehicle axles

The results of the proposed procedures is demonstrated by comparing to ASTM standards, which
specify for Type III WDM a gross vehicle weight accuracy of 6% that corresponds to an axle load accuracy of 11%.
Given that the majority of trucks are classified as P1W1 classification 9 (43% of the St. Paul City study) the use
of 5 axles in Equation 3 would appear to be representative of the majority of trucks. A use of 5 axles for a gross
vehicle accuracy of 6% results in an axle accuracy of 11%. Consequently, the comparison clearly indicates
consistency between the proposed analytical procedures and ASTM standards.

To further test the consistency of the proposed analytical relationship between axle and gross weight accuracy, an
entire day's worth of WDM data from July 13, 2003 was
analyzed. The data included axle and gross truck weights for a total of 2227 trucks of class 9. Using a Monte Carlo
simulation, random normally distributed random numbers of
mean equal to zero and the accuracy COV was generated.
The random variable was then added to the axle weight to
introduce a random vehicle axle error to the axle weight
measurements. The standard deviation of each axle was
computed as the desired COV multiplied by the WDM axle
weight, ensuring that the axle accuracy was identical for all
axles (equal COVs). The axle COV was varied ranging
from 2.5 to 10 percent. Having generated these random variables, the gross vehicle weight was then computed by
summing up the random axle weights. The gross vehicle
weight error was then computed and compared against the
analytical estimate of the gross vehicle weight accuracy.
There was a demonstrated consistency between the Monte
Carlo simulated gross vehicle weight accuracy and the
proposed analytical function (error less then 3.8 percent).
Furthermore, the results are consistent if one considers 2, 3, 4, and 5 scale weighings.

It should be mentioned that the scale trade was not independent as was assumed in deriving the analytical formulation. Specifically, the correlation of scale weights is high (greater than 80 percent) for scales 2, 3, 4, and 5. Furthermore, the scale weights varied considerably (an average 20 percent difference between scale weights). Consequently, the proposed analytical formulation appears to provide desirable results for such applications.

4. WEIGH STATION OPERATION

ANALYSIS

The operational aspects of a weigh station can be characterized by the service time, system time, and delays encountered at the weigh station. In this study, the service time was defined as the time duration from the instant the vehicle arrived being served at the weigh scale until the vehicle exited the weigh scale. Consequently, the time did not include the time spent in queue waiting to be served at the weigh scale. Alternatively, the system time was calculated as the time differential from the point at which the truck entered the weigh scale lane until the point the truck exited the weigh scale lane. This time included the waiting, the service at the weigh scale, and the time required for the truck to travel on the stack lane. The analysis was conducted using data that were collected for 3 hours on Tuesday, May 24, 1977.

4.1 Service Time Analysis

The analysis only considered trucks that were directed to the static scale breakout in the WSD screening system. The study considered both existing and non-existing trucks. Visiting trucks were considered as trucks that were directed to the weigh scale that executed either the place or state weigh truck. Alternatively, non-existing trucks were those that were diverted to the weigh scale based on the WSD screening system but did not enter the gate and/or scale weight limits.

Considering both directions, a total of 264 trucks passed over the static scale in both directions during the 3-hour analysis period. Those 264 trucks experienced an average service time of 46 seconds with non-existing trucks experiencing an average service time of 56 seconds while visiting trucks experienced an average service time of 30 seconds. Alternatively, in the northbound direction, 126 trucks were diverted to the static scale experiencing an average service time of 44 seconds. Non-existing trucks experienced an average service time of 7 seconds while visiting trucks experienced an average service time of 14 seconds. Non-existing trucks experienced an average service time of 7 seconds while visiting trucks experienced an average service time of 67 seconds. The non-existing service times included a single scale check that required a service time of 81 seconds.

Figure 2: Northbound and Southbound Scale Lines

It is interesting to note that the scale lane was located inside the southbound lane west and this potentially explains the lower service times experienced by visiting trucks in the southbound versus northbound directions (49 versus 53 seconds). In addition, the weigh station operator was required to make a visual identification of the truck across the freeway in the case of the northbound direction which could potentially explain the higher service times for non-existing vehicles in the northbound direction. An illustration of Figure 6, the distribution of service times for both non-existing and visiting demonstrates a higher service time for northbound trucks when compared to southbound trucks.

4.2 System Time Analysis

Again, the analysis only considered trucks that were directed to the weigh scale because they arrived either to the place or state weigh truck. The system time was defined as the amount of time it took the truck to travel from the weigh scale diverge point to the point where the vehicle merged back with the freeway traffic. Because the speed limit for the bypass lane was 63 km/h (60 mph) with a length of 2.41 meters (800 feet), the delay was defined as...
any additional time above 13.5 seconds to travel from the diverge to the merge point.

Table 1 summarizes the statistics for trucks analyzed in the static scale lane. The data taken on Monday occurred with full weight station operation with both northbound and southbound scales open. However, due to construction on parallel sites on the southbound side, the data collected on the second visit only included the southbound traffic with the southbound scales closed. Fortunately, this allowed for comparison between weight station operation with one static scale versus two static scales.

![Figure 3: Service Times for Non-Violating Vehicles and Violating Vehicles](image)

Table 1: Summary Static Scales Statistics

<table>
<thead>
<tr>
<th>Static Scale Type</th>
<th>Number of Trucks</th>
<th>Violated</th>
<th>Average System Time (Full Operation)</th>
<th>Average System Time (Partial Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Violating</td>
<td>154</td>
<td>15.66%</td>
<td>8.32 (min)</td>
<td>5.02 (min)</td>
</tr>
<tr>
<td>Violating</td>
<td>214</td>
<td>14.34%</td>
<td>10.05 (min)</td>
<td>6.01 (min)</td>
</tr>
</tbody>
</table>

The results of the analysis indicated that the average system time for full operation was 2.7 minutes and 2.9 seconds, which was 17 seconds higher than the average partial system operation time of 2.1 minutes and 1.3 seconds. The 17-second difference may be explained by the additional level of effort that is involved in running two static scales at the same time as opposed to just one scale. Of particular interest was the finding that out of the 154 trucks that were serviced by the WIM system, only 125 were actual violators (or 16.64%). Therefore, in a 100% efficient system, 4334% of the trucks sent to the static scale could have been spared the extra delay and could have continued through the bypass lane. In full operation, out of the 6 hours and 10 minutes that trucks spent in the system, 5 hours and 12 minutes could potentially have been saved. Likewise, in partial operation, out of the 3.5 hours and 49 minutes spent in the system, 2 hours and 24 minutes could potentially have been saved.

5. CONCLUSIONS

The results indicated that both the northbound and southbound WIM scales were sufficiently calibrated (mean WIM and static scale weights were not statistically different). Furthermore, the use of a normal distribution identity function was found to be equivalent with the normal distribution function. The northbound and southbound scale accuracy was found to not conform to the ASTM standard of ±1% for the gross vehicle weight. Specifically, the accuracy ranged from 6.1 to 17 percent for a 95 percent probability of conformity. Finally, the paper developed an analytical procedure for relating gross vehicle and axle load accuracy. The proposed analytical procedure, which uses the number of scales in computing the gross weight accuracy, was demonstrated to be consistent with ASTM standards and field data.

REFERENCES


ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the Mid-Atlantic University Transportation Center (MATTC), the ITS Implementation Center, and the Center for Innovative Technologies (CIT). Furthermore, the authors would like to acknowledge the support of the Virginia Department of Motor Vehicles in collecting the weigh station data.
Article #4: SR-1 Video Capture System:

This paper describes the VCS that can be implemented in a WIM station to help high patrol apply overweight vehicles enforcement. Two cameras, one color and another Black and White, are housed and attached on a pole, next to the road, within 25 feet from the WIM cabinet that contains a video controller, video computer, WIM computer and a wireless connection to a hot spot for Law Enforcement Vehicles to stop in, get data and stop violator vehicles. When a vehicle trigger the loop detector the colored camera takes a diagonal picture of the side and top of truck, including part of the load, while the B&W camera takes a perpendicular picture of the passenger side. Depending on the status of the vehicle (violator/non-violator), pictures are saved and sent to the trooper or pictures are overwritten.

“The position of the cab in the image is variable, and in some instances will be missed or partially missed if the vehicle is traveling much slower or much faster than the previous 16 class 9 vehicles”.
SR-1 Video Capture System

The SR-1 Video Capture System (VCS) provides a means to capture and store video images of vehicles passing over a bypass WIM scale. The system operates real-time and provides both color and black and white images with WIM superimposed on the image. The images are also available to enforcement personnel by way of a wireless link. Enforcement is able to capture an images of a vehicle in violation within a few seconds of clearing the scale, allowing the officer to pull over the vehicle for further investigation. This “pick them out of the pack” capability has proven very useful in bypass scale enforcement.

VCS consists of two progressive scan video cameras, camera controller, video computer, Ethernet hub, wireless Ethernet radio modem, dialup telephone modem, system control software and user control software. All components, except the cameras, are housed in the WIM cabinet.
Video Cameras
Two video cameras are used to capture an overall color image as the vehicle approaches the WIM scale and a close up monochrome high resolution of the truck cab as it passes the WIM scale. Both cameras are housed in an NEMA 3 environmental enclosure equipped with a heater and blower assembly. The enclosure opens from the top for easy servicing and maintenance. The camera and enclosure assembly is attached to a pole mount assembly which is strapped to the pole using stainless steel straps. The pole mount is also suitable for attaching to a wall or similar structure. The color camera is mounted at a height of 17 feet and positioned to view oncoming traffic. The monochrome camera is mounted at a height of 7 feet and positioned perpendicular to traffic flow.

24 VAC camera and heater/blower power, camera trigger control and synch signals, and video feeds are supplied using a single composite cable for each camera. The maximum distance between the camera and camera controller, located in the WIM cabinet, is 25 feet.

Camera Controller
The camera controller is a microprocessor based module that controls the trigger timing for each camera. The camera controller communicates with the video computer to provide synchronization between the camera trigger and video capture card located in the video camera computer. The camera controller also contains the 24 VAC power supply for the cameras and enclosure, as well as circuitry to protect against lighting surges.

Video Computer
The video computer contains two video capture cards, one for each camera. Each video capture card strobes the image from each camera and holds the image for further processing by the video computer. The video capture card insures that the image captured from each camera is synchronized and full frame. Once an image is captured by each video capture card, the video computer overlays the weight information on the image and stores each image on disk.

Ethernet Hub
The Ethernet hub provides an Ethernet connection point for the Ethernet radio modem, the video computer and a portable service computer that can be used to transfer images and diagnose problems.
Ethernet Radio Modem
The wireless Ethernet modem provides a link to a laptop computer located in the
law enforcement vehicle. As images, overlaid with WIM data, are written to disk
in the video computer, the same images are provided to the network and
subsequently to the enforcement laptop. The time between when an image is
captured and the image appearing on the enforcement laptop is approximately
three seconds. If a violation occurs, the inspector can retain the image on the
laptop, detain the vehicle and perform a static weight measurement. The control
software used by the inspector allows various parameters and thresholds to be
adjusted to capture images of the desired class and weight of vehicle.

Dialup Modem
The dialup modem provides a means to access the video computer remotely
from a client computer using the remote desktop facilities of Windows XP. The
remote desktop connection transports the screen image and keyboard and
mouse commands to and from the video computer and the client computer.

System Control Software
Software located on the video computer controls the system operation. The
software starts automatically when the computer boots.

When the camera controller senses a vehicle has triggered the loop detector, the
color camera is triggered immediately. The monochrome camera will be triggered
a few milliseconds later. The trigger delay is calculated based on a moving
average of the speeds of the last sixteen class 9 vehicles. The color camera
captures a diagonal view of the approaching vehicle. The monochrome camera
captures a side view of the cab beginning at the windshield and extending to the
end of the sleeper. The position of the cab in the image is variable, and in some
instances will be missed or partially missed if the vehicle is traveling much slower
or much faster than the previous 16 class 9 vehicles.
Once the images have been captured and stored in the video capture cards, the video computer disables the camera controller and waits for data from the WIM computer. The camera controller is disabled so that the current images are not overwritten by another vehicle following close behind.

If the WIM computer reports a vehicle that exceeds the threshold parameters, the video computer will superimpose both the WIM data on the color image and the date on the monochrome image, and then store both images on the video computer hard drive. The camera controller is then released to capture images of the next vehicle.

If the WIM computer reports a vehicle that does not exceed the threshold parameters, the video computer will release the camera controller to capture the next set of images. The current images, stored in the video capture cards, are not retained and are overwritten by images of the next vehicle.

Although images are not taken for Northbound traffic, a blank image showing the WIM data superimposed is stored for vehicles that are in violation. An example images is shown below:
Log Images
By clicking the appropriate box next to the vehicle class or violation type, the user can control which violations will be captured. If the box is checked, images will be captured and stored if the vehicles exceed the thresholds. If the box is not checked, images will not be captured and stored, even if the vehicle exceeds the threshold values.

Setup
Log All Day - Selecting Log All Day will instruct the system to capture and store images of selected vehicles 24 hours a day, 7 days a week.

Log Part of Day - Selecting Log Part of Day will instruct the system to capture and store images only in the time period specified by the user.

Enable Pop-Ups - If Enable Pop-Ups is selected, the image of each image captured and stored will be displayed, in an overlay fashion, in full size view on the computer monitor. Up to six images will be displayed at any given time. If a seventh image is displayed the oldest image will be removed from the display. This feature ensures that an excess number of images do not clutter the monitor and consume excess memory. The Enable Pop-Ups mode is the normal mode of operation for enforcement applications.

In the Enable Pop-Ups mode the following keyboard keys will provide image control:

"P" - Pressing the p or P key will prevent additional images from being displayed on the monitor. This allows enforcement personnel to hold an image indefinitely without new images cluttering and overlaying the image being studied.

"R" - Pressing the r or R key will resume pop-ups.

"D" - Pressing the d or D key will delete the oldest image from the monitor. Pressing the D key does not delete the image from disk.

Send Thresholds to Video Computer - Clicking the Send Thresholds to Video Computer button stores the Threshold, Log Images and Setup parameters in memory in addition to sending the data to the WIM computer. The user must click this button to store any changes made to the system settings.
Retrieve Defaults - Clicking the Retrieve Defaults button loads default parameters previously stored using the Save New Defaults button. This allows the user to retrieve preset parameters without having to reenter data each time the system is used. Two levels of default settings are available, one for Enforcement and one for Revenue. When the User Control Application is closed or the computer is rebooted, the Revenue Default settings are loaded automatically.

Save New Defaults - Clicking the Save New Defaults button saves the current Threshold, Log Images and Setup parameters to memory. Two levels of default settings are available, one for Enforcement and one for Revenue.

Status - The following messages appear in the status window:

"Normal"
This message indicates the system is operating normally.

"Saving Parameters"
This message is displayed when the user clicks the Send Thresholds to Video Computer button. The message returns to Normal after the parameters have been saved and the WIM computer has received and acknowledged the new parameters. If the message does not return to Normal after 20 seconds, there is a problem with the communication between the WIM computer and the Video Computer.

Entering the text “reboot” in the status window will reboot the video computer. This allows the computer to be restarted from a remote location using the remote desktop dialup connection.

Background Processing
The system control software provides two background process that run continuously:

1. ASCII File Generation – The system control software creates an ASCII file which contains vehicle weight and other WIM scale parameters for each vehicle that passes over the scales. The ASCII record is appended for each vehicle regardless of the threshold parameters. This ASCII record can be uploaded from a remote location using the dialup modem.

2. Disk Capacity – The capacity of the hard disk is monitored to determine if the disk is becoming full. When the disk reaches 80% capacity, the oldest video files are deleted, one day at a time to maintain the disk to 80% capacity or less.
3. Image Compression – Each day at midnight all monochrome tiff files are compressed into a daily zip file using a file name format: mm_dd_yyyy.zip.

File formats
Color images are stored as JPEG files. The files are stored under a folder named South for the southbound lane and North for the northbound lane. The North and South folders are located under a daily folder with a file name format:

mm_dd_yyyy where:

mm = month
dd = day
yyyy = year

The image files are stored using the file naming convention: hhmmss.mmm.jpg for the color image and hhmmss.mmm.tiff for the monochrome images where:

hh = hour in 24 hour format
mm = minute
ss = second
mmm = millisecond

The ASCII file name format is: A000mmdd.yy where:

mm = Month
dd = Day
yy = Year

This document is intended for informational and instructional purposes only. Mettler Toledo reserves the right to make changes in the specifications and other information contained in this document without prior notification.

Mettler Toledo shall not be liable for any errors contained herein or for any damages arising out of or related to this document or the information contained therein, even if Mettler Toledo has been advised of the possibility of such damages.
Article #5: Europe gets moving on WIM (Magazine Article):

This paper describes how WIM is used to detect overweight vehicles in Arnhem, Netherlands. With the high expenses of road maintenance and having over-weight trucks being the main reason after that the Dutch government decided to detect these trucks using 16 rows of sensors each consisting of four Kistler Lineas piezo devices. A $996000, 16.5 m length, with a total maximum weight with cargo of 78 tones vehicle was built for the purpose of testing. The truck was supported with measurement equipments and two of the four lift able axles can be controlled from the tractor cabin. The cabin contains a laptop which is wirelessly connected to the trailer to save all the data. The truck is designed in a way to put a certain weight on the first axle when passing over the sensors. The WIM-Hand testing project was a success and it's being discussed among the European Union countries to ensure the need for developing new enforcement techniques.
EUROPE gets moving on WIM

F J Van LOO DESCRIBES A NEW INITIATIVE TO DISCOURAGE OVERLOADING OF HEAVY GOODS VEHICLES (HGVs) AND PROTECT THE ROAD INFRASTRUCTURE

International goods transportation by road is an important part of the Dutch economy, with 173,000 trucks transporting 600 million tonnes of freight annually. Numbers and loads of trucks are the major determinant of the degree of road maintenance needed as a result, and trucks with axle loads higher than the legal maximum cause a disproportionate large percentage of damage to the country’s transport infrastructure.

The Dutch Government roughly estimates the direct costs of additional asphalt maintenance at around €17 million (£12.6 million) per annum, excluding the additional cost of traffic delays caused by resulting roadworks. Overloading of one or more truck axles, let alone of the whole vehicle, is also likely to have a negative effect on traffic safety.

To reduce these impacts the Directorate-General Goods Transportation of the Dutch Ministry of Transport, Public Works and Water Management has initiated its ‘Overloading project’. As part of this, the Ministry’s Road and Hydrostatic Engineering Division (RMD) is working on two sub-projects involving weight-monitoring WIM systems: WIM-NL and WIM-Hand, which are designed to test the feasibility of high-speed enforcement of HGVs.

WIM-NL involves the installation of state-of-the-art WIM and video systems, which are extremely labour-intensive to operate. The Delft University of Technology is investigating the scope for using existing technology to build an online measuring system that can be deployed for automatic enforcement of overloading, with citizens of violations based directly on system outputs.

WIM-HAND

The Ministry has built a multi-sensor WIM-Hand test site on the A12/A50 highway near Amersfoort, near the east

The vehicle consists of a three-axle tractor and a trailer with five axles its rear, carrying a total maximum vehicle weight of 44 tonnes, producing a total maximum vehicle weight of 78 tonnes.

The measurement equipment and two of the four WIM axles (nos 1, 2, 4, and 5) were upgraded to be able to control the trailer cab; the former on a laptop computer with a wireless Ethernet connection to the trailer, and the latter by means of special vehicles.

of the Netherlands. This consists of 16 mm of sensors, each consisting of four Kistler Linear piezo quartz devices.

The vehicle monitors the wheel loads of all passing vehicles and stores data from each sensor together with video images of the vehicle. Each sensor needs to be individually dynamically calibrated, for which purpose the Ministry has commissioned a specially built instrumented vehicle.

The contract for building the vehicle went to a consortium led by reknowned technology specialist Kathrein International BV, with the participation of Dutch government research organisation TNO Measurement technology and Heath. The componentisation of a custom-built trailer. The vehicle has cost approximately €250,000 (Df 99,000), paid for by the Ministry, with the WIM-related equipment coming out at around €250,000 (Df 99,000), paid for by the Ministry.

Operational tests are due to start in March 2005, following the resolution of issues of compatibility between the WIM Hand sensor array and the recently instrumented vehicle, and will last for at least 18 months.

The implementation programme will depend on two factors: the results of the current tests, which are expected to be available in about two years’ time, and the legal acceptance of high-speed WIM for direct enforcement of overloading. The timescale of the latter is difficult to estimate; it will probably be longer than two years, though results from the REMOV project (below) may speed up the process.

SPECIAL VEHICLE

The vehicle consists of a three-axle tractor and a trailer with five axles its rear, carrying a total maximum vehicle weight of 44 tonnes, producing a total maximum vehicle weight of 78 tonnes.

The measurement equipment and two of the four WIM axles (nos 1, 2, 4, and 5) were upgraded to be able to control the trailer cab; the former on a laptop computer with a wireless Ethernet connection to the trailer, and the latter by means of special vehicles.

EU-strategy

Cost/ Benefit Analysis

Legal

• Inventory Standards

- Sanction

- Liability

Technical

• Inventory Specifications

- Test Procedure

Acceptance

Applications

Operational

- Best Practices

- Case of Practice

Future Strategy

January/February 2000 35

www.itstinternational.com
dashboard-mounted buttons. Measurement data can be saved on a CD or stored in the onboard computer.

The measurement aid (1a, 1b) is the first on the market to show the WIM-Hard sensor; it gives the maximum possible axle load of 15 tonnes for the purpose of calibration. It is located in advance, when the vehicle is stationary, with axles nos 2 and 4 lifted. These are then lowered, and the measurement axle load, for the drive to the WIM-Hard aid.

Just before reaching it, the driver lifts axles nos 2 and 4 and drives over the sensors with 15 tonnes on the lowered measurement axle, after which axles nos 2 and 4 are lowered again. The aim is to minimize the risk of damage to road surfaces or the measurement axle, by applying the maximum load for the least time possible.

These precautions are important because the safety of the axle and the tyres is guaranteed only for short distances at maximum speed and maximum axle loads. (The tyres are filled with nitrogen for heat conduction and to keep them up to pressure.)

*ADAPTATIONS AND APPROVALS*

Lifting of axles nos 2 and 4 during driving would not be possible with a standard hydraulic system. The need to do so has led to the introduction of special equipment involving a larger than normal hydraulic pump with electronically-controlled valves. Guaranteeing maximum braking retardation has involved adaptation of a standard ABS system, with its sensors moved to axles nos 1 and 3 from the normal nos 2 and 4.

All these adaptations have necessitated special approaches.

The use of a certificated instrumented vehicle for calibration is an important criterion for certification of a WIM system. The Dutch Metric Institute (NDM), which carries out all type approval testing of measurement equipment for enforcement agencies, has been involved in the start in the WIM Hard-present, including the design, building and testing of the calibration vehicle.

Organization of type approval and certification at European level is a key element of the European REMOVE project.

*REMOVE*

The €560,000 (US$598,600) project started in April 2004 and runs until April 2006. REMOVE stands for Requirements for Enforcement of Overloaded Vehicles in Europe.

It aims to present the European Commission (EC) with the strategic, technical, legal, technical and operational requirements for the harmonized and interoperable deployment of WIM systems in the enforcement of overloading throughout the

European Union (EU). It is progressing via four work packages.

The Legal Issues Work Package includes:

- An inventory of the present situation across the EU;
- A review of the Standards required for legal acceptance;
- Draping up a legal framework for implementation;
- A review of current sanctions and recommendations for progress towards a more harmonized sanctions policy across Europe;
- A review of responsibilities and liabilities in relation to overloading.

The Technical Issues Work Package includes:

- An inventory of existing WIM technology and specifications;
- Development of new functional and technical specifications; and
- Establishment of test protocols.

The Operational Issues Work Package includes:

- An inventory of current best practice across the EU Member States;
- Recommendations for a Code of Practice; and
- Recommendations for a future enforcement strategy.

The Cost-Benefit Analysis Work Package includes:

- Producing and estimate of the costs of repairs of damage to the Trans-European Road Network (TERN) due to overloaded trucks; and
- Developing a model for estimating the costs of building, operating and maintaining WIM systems for enforcement.

The REMOVE consortium is unusual in two ways. First, in the breadth of its spectrum of partners, which include both TESPOL, the European network of traffic police forces, currently involving 16 EU Member States, four EU candidate countries and two non-EU states and Euro Control Route (ECR), the 10-member (with two observer) European organization of traffic inspectors.

The result is to bring together the vast majority of the EU's Enforcement Community. The other partners are the International Road Transport Union (IRU), the DAW, the Laboratory Central des Poids et des Charges (LCPC), a joint agency of the French Ministries of Public Works and of Research; the Bundesanstalt für Straßenwesen of the German Ministry of Transport, the Czech Technical University of Prague (CTU), and Dutch consultant Arcadis.

The second way in which it is unusual is that national governmental bodies and enforcement agencies are cooperating with the transport industry in developing new enforcement techniques that will be acceptable to both sides, as well as in discussing structural solutions. The EU is therefore playing a very important role in the project, with France, Germany and the Netherlands ensuring a strong input of governmental experience.

Information on REMOVE is available via www.euro-control-route.com.

F.J van Loon is project manager, Weight-in-Motion for Enforcement, at the DAW

www.minvomw.nl/wa/daw

www.bvo.nl

www.kitabi.nl

www.rooteboom.nl

www.kortes.com

www.tespol.org

www.euro-control-route.com

www.tmbr.ie.de

www.kpc.fr

www.in.org

www.covt.cz

www.arcadis.nl

www.itsinternational.com
Heavyweight contenders

Increasing commercial vehicle operations on highways is resulting in increased structural depreciation of road infrastructure assets. This increase in commercial trucking is also increasing track loading on urban pavements. By monitoring and quantifying commercial truck loadings and reducing the amount of overloading, it may be possible to better design and extend the life of road and bridge structures.

This is where weigh-in-motion (WIM) can help. WIM means that a truck does not have to stop completely to be weighed.

Fixed weigh stations are easily instrumented and environment resources are often limited, but virtual weigh stations (VWS) offer remote monitoring, meaning that offenders can be identified remotely and information forwarded to the relevant authority where legally laden trucks are not disturbed.

A VWS is the use of advanced vehicle monitoring and image capture technology at a location where a physical weigh station does not exist.

For example, an International Road Dynamics (IRD) VWS system allows all commercial truck traffic to be monitored continuously for compliance with size, weight, safety, and credential regulations. The system provides targeted enforcement, while not impacting the traffic flow of compliant vehicles, says the company.

IRD claims its VWS systems offer a cost effective way to monitor commercial vehicle traffic in areas not previously possible, either from a physical location, or cost effectiveness point of view. These areas include urban or city locations, known evasive routes, and remote locations with low traffic volumes. Current emphasis is on installing VWS systems in urban settings, where track overloading is as high as 25%, significantly damaging local road infrastructure, and exposing large numbers of motorists to potentially unsafe trucks.

Data from an IRD VWS system can be used to better understand truck operations by monitoring the system. IRD claims the data can be used to formulate alternative truck enforcement strategies. With the addition of Internet and wireless data communications, the system can be used to monitor all the truck traffic in real time, and can be used to specifically identify any particular truck that appears to be in violation of any truck regulation. The system allows the monitoring and reporting to take place in real time, or after the fact, when habitual violators can be identified and dealt with.

IRD is an IRD VWS system incorporates high performance WIM equipment combined with video monitoring. Side image capture systems and License Plate Reading (LPR) cameras are integrated with the WIM systems. The LPR system can additionally include Optical Character Recognition (OCR) to automatically determine the license plate number and base state. Additional technologies such as over-width and over-height detection can be added to the system as required.

Data collected from the systems is automatically analyzed by the system for violation of compliance with the agency’s size and weight regulations.

"Over the last two years, over a dozen IRD VWS systems have gone into operation across North America and all systems are providing impressive results, with independent reviews of the systems revealing impressive benefit to Cost B/C ratios of 5 or more”, says IRD.

IRD www.irdinc.com

New cabling concept provides faster installation

Kistler Instruments has just released the Linear Type 91395E quartz crystal WIM sensor which it says is easier and faster to install than the pavement due to its new cabling concept. The weight of the cable slots can be reduced from the current 18 to 25mm to a new weight of only 7 to 8mm.

The sensor is designed for all WIM applications such as statistics, overload detection like pre-selection, weigh enforcement, bridge protection, toll roads, road research, and pavement management systems.

On of the newest applications is for traffic management. The weight of loaded trucks travelling south on the N10 in the Netherlands are measured dynamically about 200m before they reach the traffic lights. Vehicles with a gross vehicle weight of 10t or more are given priority (this is defined by the system software increasing green light duration until that vehicle passes the crossing). If the light is red when a heavy vehicle rolls over the WIM station, it will turn to green earlier to allow the vehicle to pass through without interruption. A second priority system allows emergency services right of way.

At the Lockwitz Bridge in Dresden, Germany (weight limit 15t), the WIM system with Kistler sensors is helping the city to avoid expensive maintenance and repair costs and consequently increase the durability and the longevity of the bridge.

Kistler www.kistler.com

A cross section of the Kistler Linear Type 91395E quartz crystal WIM sensor when installed.
This article discusses the use of WIM sites on highways and secondary or bypass routes to get the weights of vehicles and send them to remotely located troopers for enforcement. Located near the sensor is the controller that can save the data 24 hours a day. The trooper can dial into any WIM site using a mobile phone from the laptop in his patrol car and view the vehicle data. Through the use of these virtual WIM sites, truckers are less likely to use secondary or bypass routes saving wear on these surfaces. This project was done by the INDOT (Indiana Department of Transportation) and Mettler-Toledo and determined to be both cost effective and flexible.
Virtual Weigh-in-Motion

A high-tech approach to curbing overweight vehicles on the roadways

Problems in the road, eroding asphalt on exit ramps. Some of it is caused by the constant wear and tear of vehicles that travel the highways, the salt used to keep winter roads clear and the inevitable extreme temperature shifts that occur. But a portion of the damage to the highways can be attributed to vehicles that knowingly travel the roadways with overweight loads.

A collaborative effort between the Indiana Department of Transportation (INDOT), the Indiana State Police (ISP) and Mettler-Toledo has provided a high-tech approach to curbing overweight vehicles on the roadways. Virtual Weigh-in-Motion (VIM) is a technology that not only saves these routes from excessive damage, but also provides ISP troopers more time effective and accurate means of enforcing adherence to the law.

Traditionally, potentially overweight vehicles have been monitored using one of two methods. One method is that trucks are directed off the interstate at selected times to scale houses where they are weighed using a full-length static track scale.

The other method is for ISP troopers with portable scales to make random stops of vehicles, which appear to be over the weight limit. In either case, overweight vehicles are ticketed. However, there are problems with both of these approaches. With the use of the scale houses, truck drivers become aware of the times that the weigh station is routinely open and can take measures to avoid being on that particular stretch of road at those times.

Cost and flexibility are also issues with permanent weigh stations. A scale house can cost as much as $15 million to build. And once built, it cannot be moved to any other location.

The state of Indiana approached Mettler-Toledo with the concept of Virtual WIM. In its most basic function, the Virtual WIM sensor in the roadway interfaces with a roadside controller. A trooper dials in using a mobile phone and a laptop computer located in the patrol car. The trooper can then observe on the computer screen the weights of passing vehicles.

"We specified Mettler-Toledo because it had the only WIM product that satisfied our needs," noted Mark Newlund, INDOT's program director for INDOT.

The system records data 24 hours a day that can be used in two ways. First, troopers can monitor specific sensor sites and capture violators as the violations occur. Second, the information can be analyzed historically to determine times and places where overweight vehicles are prevalent. Troopers can then increase patrols at those Virtual WIM locations.

Mettler-Toledo believes that Virtual WIM sites will become a major enforcement tool and complement permanent weigh stations. As Virtual WIM sites become strategically located between permanent weigh stations and on known bypass routes, the incentive for trucks to bypass permanent weigh stations will diminish, saving damage to these secondary routes.

As Virtual WIM sites become strategically located between permanent weigh stations and on known bypass routes, the incentive for trucks to bypass permanent weigh stations will diminish.
Article #7: Detecting Semantic Anomalies in Truck Weigh-in-Motion Traffic Data Using Data Mining:

This paper addresses the subject of monitoring data from a truck WIM system as precise and accurate as possible. To do so multiple software algorithms process the sensors’ data to estimate the vehicle class and filter out unreasonable values. The WIM scale uses 4 single load cell detectors in a sealed frame and 4 loop detectors embedded in the pavement to observe passing vehicles. The WIM scale calculates the axle spacing and weights for each vehicle plus it displays the time by which this vehicle passed on the scale. All of this information about each car is saved in a text file which is imported to a database by the help of a software algorithm. Each vehicle is given an ID and personal vehicles are ignored. The attributes calculated for each vehicle are: date and time, vehicle type, lane, speed, error code, length, ESAL (Equivalent Standard Axle Load), number of axles, and weight. This project provides automated assistance to experts in setting up constraints for the behavior of monitoring data detecting any hardware or software problems.
Detecting Semantic Anomalies in Truck Weigh-In-Motion Traffic Data
Using Data Mining

Orna Rux1, Rabeea Buchheit2, Mary Shaw3, Philip Koopman4, and Christos Faloutsos5

ABSTRACT

Monitoring data from event-based monitoring systems are becoming more and more prevalent in civil engineering. An example is truck weigh-in-motion (WIM) data. These data are used in the transportation domain for various analyses, such as analyzing the effects of commercial truck traffic on pavement materials and designs.

It is important that such analyses use good quality data or at least account appropriately for any deficiencies in the quality of data they are using. Low quality data may exist due to problems in the sensing hardware, in its calibration, or in the software processing the raw sensor data. The vast quantities of data collected make it infeasible for a human to examine all the data.

We propose a data mining approach for automatically detecting semantic anomalies—unexpected behavior—in monitoring data. Our method provides automated assistance to domain experts in setting up constraints for data behavior.

We show the effectiveness of our method by reporting its successful application to data from an actual WIM system: experimental data the Minnesota department of transportation collected by its Minnesota road research project (Mn/ROAD) facilities. The constraints the expert set up by applying our method were useful for automatic anomaly detection over the Mn/ROAD data: they detected anomalies the expert cared about—unlikely vehicles and erroneously classified vehicles—and the misclassification rate was reasonable for a human to handle (usually less than 5%). Moreover, the expert gained insights about the system behavior, such as realizing that a system-wide change had occurred. The constraints detected, for example, periods in which the WIM system reported roughly 20% of the vehicles classified as three axle single unit trucks to have one axle!

Keywords: Data analysis, Civil engineering, Traffic, Data mining, Machine learning

INTRODUCTION

1School of Computer Science, Carnegie Mellon University, Pittsburgh PA 15213 USA
2Civil Eng. Dept., Carnegie Mellon University, Pittsburgh PA 15213 USA
3School of Computer Science, Carnegie Mellon University, Pittsburgh PA 15213 USA
4Electric Eng. Dept., Carnegie Mellon University, Pittsburgh PA 15213 USA
5School of Computer Science, Carnegie Mellon University, Pittsburgh PA 15213 USA
Track weigh-in-motion (WIM) data are an example of event-based monitoring data. Monitoring data are collected to measure the state of infrastructure elements. Such data are often used in infrastructure management systems to assist local, state and federal agencies in developing strategies to maintain their infrastructure. Monitoring data provide support for predicting deterioration, scheduling maintenance, and calculating life cycle costs. Within an infrastructure management system, monitoring data are usually used as historic precedent to predict future deterioration (Hudson et al. 1997).

Monitoring data are also used to analyze design decisions and support research activities. For example, the Minnesota road research project (Mn/ROAD) data we use in this paper are included in the Long Term Pavement Performance (LTPP) Project (LAW PCS 1999). The LTPP project uses the Mn/ROAD data and similar data from other states to support pavement performance analysis and to design better pavements.

WIM data, such as the Mn/ROAD data, are collected from an event-based monitoring system; every vehicle that passes over the WIM scale is an event that yields a recorded observation. This particular WIM scale is embedded in the infrastructure itself and is meant to monitor the infrastructure. Multiple software algorithms process the sensor data to estimate various attributes, such as the vehicle class, and filter out unreasonable values.

The data processing path between vehicles crossing the scale and the resulting recorded observations is fraught with opportunities for data quality degradation. For example, a sensor may be defective or wrongly calibrated, or software may assume an incorrect system state. These may result in unreasonable values, such as values that are physically impossible, or values that are improper for the vehicle class.

Because such data are used for analysis, it is important that the data be of good quality. Unfortunately, independent information about correctness rarely exists, making it challenging to verify the data quality. A first step toward achieving good quality data is the ability to detect anomalies.

Other work (Buchheit et al. 2003) concentrated on finding the best automated techniques for detecting and cleaning aggregated data, using domain knowledge. Buchheit also detected individual anomalies using the Minnesota Truck regulations as a model of data behavior. However, in that work, aggregate properties, such as the daily sum of vehicle weight, were used to find patterns of systematic error in the data. Our work is complementary because it concentrates solely on individual observations. In addition, our general purpose inference framework expands on Buchheit’s work by helping the users to elicit their own, possibly more complete, model of the data’s behavior.

We concentrate on semantic anomalies—unreasonable values. Once anomalies are detected the
data may be cleaned or proper allowances may be made in the analysis to account for the data quality.

Detecting semantic anomalies requires a precise model of proper behavior: a semantic anomaly is behavior that is outside this model. However, though users (e.g., analysts) often have accurate expectations for the behavior of the data, they usually are unable to state these formally and precisely. For example, a user may expect trucks reported by a WIM scale to be physically plausible but may not be able to specify all the properties and values that define such plausibility.

We propose an automated method for assisting a user in creating a precise model of proper data behavior. Our predicate inference framework contains a template mechanism that interacts with a user to make the user's expectations for the data behavior precise. The framework then uses the precise expectations to detect semantic anomalies in the data. It uses data mining—applying statistical and machine learning techniques to help discover meaningful information in the data. Though these techniques characterize various aspects of the data, characterizing relevant behavior requires eliciting the user's expectations as well.

We apply our general purpose predicate inference framework to the Mn/ROAD data. An expert interacts with the template mechanism to make the expert's expectations precise. We then use the resulting model to detect semantic anomalies in the Mn/ROAD data.

We show that the template mechanism is effective; we measure effectiveness both by the insights the expert gains (the usefulness of the process) and the detection and misclassification rates (the usefulness of the resulting model). We were able to detect anomalies that surprised our expert, as they suggested system (hardware and software) behavior the expert was unaware of. Moreover, because our approach is automated, it detects anomalies quickly. In comparison, it had taken the data providers several months to notice the same problems independently. This is probably because the amount of data is very large, and it is hard to know what to look for.

WEIGH-IN-MOTION DATA

The data we use in our case-study are experimental data the Minnesota Department of Transportation collected in its Mn/ROAD research facilities between January 1998 and December 2000. The data have over three million observations for ten commercial vehicle types out of fourteen total vehicle types.

The Mn/ROAD research division operates a two-lane mainline test road equipped with a weigh-in-motion (WIM) scale. The test road is an active highway segment that runs parallel to a 3.5 mile section of I-94 westbound, near Otsego, Minnesota (Minnesota Department of Transportation
The WIM scale uses four single load cell detectors in a sealed frame and four loop detectors embedded in the pavement to observe passing vehicles. The WIM scale measures the individual axle spacings and weights for each vehicle that passes over the scale. The gross weight of each vehicle is calculated based on this information. Length and speed are derived from the time that passes between noticing axles. In addition, the time when the vehicle crosses the scale, the lane in which the vehicle was traveling, and any error codes generated by the WIM scale are recorded. These measurements are sent to a nearby computer. Software algorithms then calculate a classification number and the equivalent standard axle loads (ESALs) (American Association of State Highway and Transportation Officials 1986) for each vehicle. The classification numbers are based on the Federal Highway Administration (FHWA) vehicle classification system, modified to include a class for invalid vehicles and a class for vehicles that do not fit into the FHWA schema (Federal Highway Administration 2001). ESALs are a dimensionless quantity that describes the usage of a pavement surface; an ESAL value of 1.0 is a standard truck. The computer saves the vehicle information into a text file; a software algorithm then imports this text file into a database. It assigns a unique identification number to each vehicle, purportedly filters out unreasonable values, and ignores personal vehicles (the WIM scale records all vehicles that pass on it).

Roughly one million vehicles are added to the data set per year. The number of observations the system collects varies by vehicle type. For example, it collects two thousand observations during roughly three weeks for each of vehicle types 4 and 6 and during roughly two days for type 9.

We treat the MnROAD data as a time-stamped sequence of observations. Each observation has attribute values for a single commercial vehicle: date and time (accurate to the millisecond), vehicle type (one of ten classes), lane (one of two classes), speed (mph—miles per hour), error code (one of twenty five classes), length (feet), ESAL, number of axles, and weight (kps—kilopounds).

Several states in the USA are collecting truck WIM data and analyzing them to better understand transportation issues. Though there are different WIM scales, the basic data are very similar.

WIM data have been used extensively for analysis of transportation design issues. This includes MnROAD research projects, such as pavement performance, preventive maintenance, and low volume road design (Minnesota Road Research Section 2003), as well as research projects and analyses at other states (Bebbars et al. 1998; Najafi and Blackadar 1998; Lee and Souny-Silaine 1998; Clayton et al. 2002). There is also research examining additional applications of WIM data, for example, real time enforcement of truck weight restrictions (Andrele et al. 2002).

However, little work addresses data quality issues. Assessing data quality is complementary to analyzing the data. The Vacuum system (Buchheit 2002; Buchheit et al. 2002; Buchheit et al. 2003)
was applied to the Mn/ROAD data for assessing the data quality and cleaning the data. However, the analysis concentrated on aggregated data: the daily sum of attribute values, such as daily sum of ESAL. Our analysis is complementary. It concentrates on individual observations and our framework can support various existing techniques. The kind of anomalies we detect are vehicles that do not seem to belong to their assigned class and vehicles that have attribute values that are improbable (e.g., too low or too high). Such anomalies may explain anomalies in the aggregated data.

POSSIBLE DATA PROBLEMS

The Mn/ROAD data are produced by an event-based monitoring system. The sensor data are further processed by multiple software algorithms, written by different contractors. Many things can go wrong in this process. For example, there may be problems in the physical calibration of the WIM scale, inaccurate sensing, improper processing done by software, or undesirable interactions among multiple software algorithms processing the data.

Such problems may cause an observation to have attribute values such that a real vehicle is not in its correct class (it has realistic attribute values but those are very different from values of the same attributes in other vehicles of its assigned class) or a vehicle is physically highly improbable. Such unreasonable values are semantic anomalies that we want to detect.

Anomaly detection is a first step toward improving the sensing system—both hardware and software. It enables further analysis such as indicating whether an anomaly is a system failure, locating the failure source, and taking remedial actions.

Buchheit (Buchheit 2002) distinguishes between two categories of error types in event-based monitoring data: errors in aggregated data and errors in individual observations. We concentrate on problems in individual observations. Buchheit classifies individual observation error types as: missing observation, duplication of same observation, garbling errors—occur when a real-world value is incorrectly recorded or is missing from a data set, and combination errors—occur when two events are recorded as a single event or when a single event is decomposed into two events. Detecting unreasonable values due to garbling or combination requires knowledge about the semantics of the data and is, therefore, harder to automate than detecting missing or duplicated values. We, therefore, concentrate on detecting unreasonable values.

PROPOSED SOLUTION

We are interested in detecting semantic anomalies such as the unreasonable values in WIM data that we have defined above. Detecting such values requires knowledge about the semantics of the data. In addition, different analyses may rely on different aspects of the data behavior. Users, even
experts, use the data for a particular purpose and have expectations about the behavior of the data that are relevant to the specific usage/analysis.

If an expert could look at all the observations and could concentrate while doing so, the expert would most likely detect the unreasonable values. However, expert time is expensive, humans find it hard to concentrate on repetitive tasks, and the quantities of data to inspect are often large.

Alternatively, the expert could define a model of proper data behavior for the specific usage/analysis the expert is involved with. An anomaly would then be a value that is outside this model. This model would be based on the expert’s expectations for the data behavior. However, users’ expectations are informal and imprecise, though they are reasonably accurate.

We propose a method that provides automated assistance to users in making their expectations for the data behavior precise. This method relies only on: (1) data: the observable behavior of the system over some period of time, which we term a data feed and (2) minimal user feedback in the form of classifying the output of the data mining techniques into three categories. We use the resulting model to detect semantic anomalies in the data. We do this through our predicate inference framework.

Data mining and machine learning have been used for civil engineering applications (Melhem and Cheng 2003; Reich 1997; Arciszewski and Rosenman 1992). However, these applications concentrate on analysis and prediction. Our approach is complementary: we use data mining for detecting anomalies in the data prior to using the data for such analysis and prediction.

Sobelman et al. (Sobelman and Kim 2002) propose a process for data preparation for knowledge discovery in databases, in the construction domain. Our method provides automation for such a process, using the techniques in our inference tool kit. Our method could be used in any domain that would benefit from using the resulting constraints on data behavior.

Approaches of modeling expert knowledge are complementary to our approach of suggesting predicates using unsupervised learning. Caldas et al. (Caldas and Sobelman 2003; Caldas et al. 2002) propose mechanisms for project collaboration, coordination, and information exchange. They deal mostly with text documents. Maher et al. explore case-based approaches to structural design of buildings in a large body of work, an example of which is (Maher and Balachandran 1994). Simoff et al. explore virtual environments for learning about design, for example in (Simoff and Maher 1997).

We use and adapt existing unsupervised learning techniques from the areas of statistics and machine learning. Co-learning (Blum and Mitchell 1998) investigates ways to reduce the human effort that labeling data for supervised learning requires. Active learning (Cohn et al. 1996) investigates statistical ways to select the most promising training data for a technique. We ask the user to
classify the output of a technique, rather than its input.

Our approach of inferring the characteristics of a data feed from its behavior is similar to work in the areas of program analysis and testing. Dalion (Ernst et al. 2000) dynamically discovers likely program invariants from program executions. We incorporate Dalion in our predicate inference tool kit. "Daise as deviant behavior" (Engler et al. 2001) infers beliefs from source code so it is inappropriate for data. "Specifications mining" (Ammons et al. 2002) uses a machine learning approach for discovering specifications of interface protocols. However, it uses techniques specific to code. "Observation-based testing" (Dickinson et al. 2001) uses clustering and visualization techniques to identify unusual program executions. We have similar techniques in our tool kit.

**PREDICATE INFERENCEx FRAMEWORK**

We present our framework concentrating on the domain of monitoring systems and on a particular data set: the Mn/ROAD data. Our framework is domain independent; a detailed discussion of our framework and its general applicability appears in (Raz et al. 2003).

Figure 1 gives a synopsis of our predicate inference framework. This framework has three major stages: (1) setting up a model of proper behavior by eliciting precise user expectations; this stage relies on a novel template mechanism and is the focus of this paper, (2) using the precise expectations as a proxy for missing specifications to detect semantic anomalies in the data; previous work (Raz et al. 2002) discussed this stage, and (3) updating the precise expectations to account for evolving system behavior or user expectations; we defer this stage to future work.

The mechanisms that support the above stages are: (1) the technique tool kit—a collection of existing statistical and machine learning techniques that we support and adapt, (2) the template mechanism—a mechanism that guides the human attention required in making expectations precise using templates that document the predicates a particular technique can output, and (3) the anomaly detector—a mechanism that uses the precise expectations as a model of proper behavior and reports anomalies observations that falsify the expectations. Details about these mechanisms follow.

**THE TEMPLATE MECHANISM**

We characterize a predicate inference technique by the types of predicates it can produce. Templates capture the form of these predicates. For example, an inference technique may find a probable range for the values of a given attribute, e.g., the length attribute. The corresponding template would be #<length><#, where # is a numeric value. Our method concentrates on numeric valued attributes. However, the template variable # can be a category value (e.g., size = 1). Figure 2 gives a synopsis of how the template mechanism works.
An inferred predicate is a "complete instantiation" of a template. The template mechanism uses this complete instantiation for templates of "accept" predicates. Classifying a predicate as either "reject" or "update" may make the template instantiation partial by rendering the instantiation of all the numeric values in one or more dimensions void. See the description of Rectmix in the next Section for an example.

The template mechanism treats the predicate inference techniques as black boxes and uses the instantiated templates to filter the predicates a technique infers. It constructs and updates the model of proper behavior from instantiated templates of "accept" and "update" predicates. It will never present the user or the anomaly detector with predicates that match templates of previously rejected predicates. The template mechanism eliminates techniques that are not relevant for this user and data: it will not employ an inference technique if the user rejects all the predicates that are associated with this technique.

Premises of our template mechanism include (1) it is easier for a user to understand expectations about data behavior when presented with examples. It is especially useful to examine examples of anomalous behavior, with the predicates that flagged them as anomalous, and (2) it is easier for a user to choose from a list of inferred predicates than to create this list, so having a machine synthesize the list is helpful.

**THE TECHNIQUE TOOL KIT**

The tool kit consists of multiple predicate inference techniques. These are existing machine learning and statistical techniques that we support and adapt. Users may add techniques to the tool kit. The truck WIM case study that follows uses two of the tool-kit techniques: Rectmix and Percentile. We selected these techniques because they work best on the Ma/ROAD data: their predicates describe data behavior that the expert cares about. For this data feed, the other techniques either describe irrelevant behavior or produce predicates that are less precise or redundant with respect to the Rectmix and Percentile predicates. A description of the techniques we used and their selection follows.

Each technique is likely to be useful only for data with certain characteristics. This provides an initial technique filtering criterion. We use measurement scales (Fennon and Pfleeger 1997) for this purpose. Measurement scales enable matching data with techniques that perform manipulations appropriate to the data scale. For example, the lane attribute of the Ma/ROAD data feed is a nominal scale—there is no notion of ordering or magnitude associated with the numbers used to specify lanes. Therefore, it is meaningless to apply mathematical predicates to this attribute. If a
technique performs transformations that are inappropriate to all the attributes of a data feed the technique should not be applied to that data feed.

In addition, different users may find different techniques useful or the output of one technique may be largely redundant with another for the data of interest. Different techniques make different assumptions and often use different vocabularies. Therefore, it may be useful to apply multiple techniques to the same data. However, a large number of techniques is likely to burden the human. The template mechanism supports filtering techniques partially on discriminating ability (effectiveness in anomaly detection) and partially on output comprehensibility. Filtering by these criteria enables the user to select the techniques that promise the best use of human attention.

Our techniques toolkit currently consists of five techniques. We selected those techniques because they expose different aspects of the data and because their output is easy for a human to understand. We briefly present these techniques, and summarize their output for the Mn/ROAD data.

The Rectmix technique. Rectmix (Pelleg and Moore 2001) is a clustering algorithm that supports soft membership (a point can probabilistically belong to multiple clusters). The clusters it finds are hyper-rectangles in N-space. Rectmix provides a measure of uncertainty called sigma (an estimate of the standard deviation) for each dimension. Anomalies are points that are not within a rectangle. Though clusters rarely have a hyper-rectangle shape in reality, Rectmix has the significant advantage of producing output that is easy to understand: a hyper-rectangle is simply a conjunction of ranges, one for each attribute (see Table 1). Rectmix has two parameters: the number of rectangles and the number of sigmas of uncertainty to allow.

Rectmix always outputs hyper-rectangles, so it has a single template: \[ \# \leq A_1 \leq \# \wedge \ldots \wedge \# \leq A_n \leq \# \], where \( n \) is the number of attributes (dimensions). Table 1 gives an example of user classification for predicates that Rectmix outputs for a subset of the Mn/ROAD data. The corresponding templates have numeric values in one dimension—the axle attribute—because the user chose to void the other attribute values. For example, the template for the first predicate is \[ \# \leq \text{length} \leq \# \wedge \# \leq \text{ESAL} \leq \# \wedge 3 \leq \text{axles} \leq 3 \wedge \# \leq \text{weight} \leq \# \].

The Percentile technique. The \( p \) percentile of a distribution is a value in the distribution such that \( p\% \) of the values in the distribution are equal or below it. Percentile calculates the range between the \( p \) and \( 100-p \) percentiles and allows \( p\% \) uncertainty. Percentile only assumes values are somewhat centered and tolerates extreme values.

Percentile predicates are a probable range for the values of each attribute. Percentile has a
single template: \( \# \leq A \leq \# \). Table 2 gives an example of user classification and resulting instanitated templates for predicates that Percentile iniers over a subset of the Mn/ROAD data. Percentile \((x=25, y=20\%\) works well for speed, length, axes, and weight, but not for ESAL (ESAL seems to be exponentially distributed).

The K-means technique \( (Duda \ et \ al. \ 2000) \) is a clustering algorithm with hard membership: it partitions points into distinct clusters. Anomalies are points that are furthest away from the center of their cluster, according to the Euclidean distance metric K-means uses.

K-means templates are a set of \( k \) cluster centers: \( C_1, \ldots, C_k \), where \( C_i = (A_1 = \# \wedge \ldots \wedge A_n = \#) \) and \( n \) is the number of attributes. For the Mn/ROAD data, when requesting \( k=2 \) clusters, the centers make sense. However, the furthest observations in each cluster are not necessarily anomalies. This means that the measure of multi-dimensional Euclidean distance is not meaningful for this data. In addition, soft membership is more appropriate for the Mn/ROAD data than hard membership. Therefore, K-means is not a good choice for the Mn/ROAD data.

The Association Rules technique \( (Agrawal \ et \ al. \ 1993) \) finds probabilistic rules in an 'if then' form. The rules reflect correlations among attributes but cannot know about cause and effect. They can only give examples with specific values. The advantage is that association rules may detect correlations that may be due to complicated relations. The disadvantage is that they cannot suggest a general relation to explain the correlation. Association rules work on categorical data so numeric data is first divided into bins.

Association rules templates are of the form 'if \( E_1 \wedge \ldots \wedge E_m \), then \( E_m \)' where \( E_i \in \{ \# \leq A_i \leq \# | A_i \geq \# | A_i \leq \# \} \) and \( m < n \), the number of attributes. For the Mn/ROAD data, association rules work rather well. An example of the rules they produce is 'if length<34.8\&ESAL<0.11\&axes<3 then weight<10.2'. However, not all the rules contain all of these four attributes, and the cause and effect relation is often absent (as is the case above: ESAL is calculated based on the other attribute values). In general, Rectmix performs better over the Mn/ROAD data.

The Daikon technique \( (Ernst \ et \ al. \ 2000) \) was developed for the program analysis domain. It dynamically discovers likely program invariants over program execution traces by checking whether pre-defined relations hold. We map Daikon's program points and variables to our observations and attributes, respectively. Daikon assumes the data is clean, but our data contains anomalies. Therefore, we use voting: we run Daikon on multiple subsets of the data and use the invariants that
appear in multiple subsets. Duklon is very effective when strong correlations that can be described by its pre-defined relations exist.

We have a template for each of Duklon's pre-defined relations. Because the Mn/ROAD data has mostly statistical correlations the only useful predicates Duklon outputs are 'axes < (#)'. However, Rectmix and Percentile produce similar predicates, so we prefer these techniques for Mn/ROAD data.

Pre-processing Data pre-processing may be necessary before the template mechanism interacts with the user. Pre-processing often helps to overcome technique weaknesses. This includes: (1) setting parameters of inference techniques, (2) performing data transformations, (3) selecting attributes, and (4) clustering.

To determine technique parameters, the template mechanism runs each technique with several values for each parameter and lets the user select the combination that best reflects the user's expectations. Alternatively, the user may choose to use the default parameter values.

Data transformations are usually straightforward and automated. For example, normalizing each numeric valued attribute to have mean one and standard deviation zero is a common transformation that is necessary for techniques that assume similarly scaled attributes (e.g., Rectmix) and data with differently scaled attributes (e.g., the Mn/ROAD data).

Attribute selection is useful for techniques that produce multi-dimensional templates both because these techniques tend to work better with less dimensions (attributes) and because as the number of dimensions increases it becomes harder for a human to understand and visualize the results. If different classes of data (clusters) exist, they are likely to behave differently. Therefore, the template mechanism runs the techniques on data in each class to enable the user to create a separate model for each class.

Any attribute selection technique could be used with our method. We found Principal Component Analysis (PCA) useful for attribute selection and clustering of the Mn/ROAD data because these data have linear correlations.

PCA (Jolliffe 1986) is a way to reduce the dimensionality of the data thus enabling visualization. PCA generates a new set of variables, called principal components, where each principal component is a linear combination of the original variables. If linear correlations exist, PCA can serve for attribute selection because it indicates which of the attributes are most strongly linearly correlated.

Looking at the data helps in finding different classes of the data. To visualize the data, we plot the observations along the first two principal components. To check for clusters, we color the observations according to each of the attributes (a color for each value of a categorical valued
attribute, a color for each bin of a numeric valued attribute).

We observe by looking at the PCA plots for the Mn/ROAD data that either vehicle type or axles can be used to cluster the data and the resulting clusters overlap. We choose vehicle type as the data class. The first principal component indicates a linear correlation among length, ESAL, axles, and weight. Therefore, we select these attributes as input for techniques that produce multi-dimensional templates (e.g., Rectmix). The other components do not indicate interesting correlations. The second axis indicates mostly the speed of a vehicle. Therefore, we add the speed attribute for analysis by techniques that produce one-dimensional templates (e.g., Percentile).

CASE STUDY HYPOTHESIS

We test our template mechanism by having an expert interact with it to set up a model of proper behavior for the Mn/ROAD data. Our case study tests the following hypothesis: the template mechanism helps users make their expectations precise. Further, the template mechanism, along with the technique tool kit and the anomaly detector, effectively direct the human attention necessary in setting up a model of proper behavior and in analyzing the resulting anomalies.

If our hypothesis is correct then

1. The resulting model of proper behavior will be useful in detecting semantic anomalies in the Mn/ROAD data.
2. The user, an expert in this case, will gain insights about the WIM system through interaction with the template mechanism and through analysis of anomalies.

CASE STUDY METHODOLOGY

As described in the pre-processing Section, we begin by looking for clusters and selecting attributes. As a result, the template mechanism interacts with the user for each class (vehicle type) separately and inputs the selected attributes to techniques in the tool kit.

For the purpose of validating our template mechanism, we select three out of the ten vehicle types that the data contain. We select the most common vehicle type (type 9, about two million observations) and two additional types (type 4 and type 6, about one hundred thousand observations each). The existing documentation defines these types as follows: type 9 vehicles are five-axle single trailer trucks, type 6 vehicles are three-axle single unit trucks, and type 4 vehicles are buses. On the basis of preliminary analysis, the vehicle types seem similar enough that we can use the same techniques over them. We first let the user create a model for two of the types (4 and 6) then we let the user create a model for the third type (9) using the techniques and parameters the user chose
for the first two types. This works well, supporting our preliminary analysis regarding the similarity
of the vehicle types with respect to the tool-kit techniques. The same techniques and parameters
should work well for the other vehicle types as well, but doing so is beyond the scope of our work.

A domain expert sets up the model of proper behavior. We give this model to the anomaly
detector. The anomaly detector runs over subsets of the data. We sort the data by time and divide
it into subsets of two thousand consecutive observations each, to simulate the on-line data nature.

To analyze the model, we determine the resulting detection rate and the misclassification rate.
The detection rate calculates how many attributes the model flags as anomalies out of the total
number of attributes. It is an objective measure because the results of using the model for anomaly
detection are binary: normal or anomalous. However, it is important to also analyze the usefulness
of the model. The misclassification rate quantifies the usefulness of the model. Because we do
not have independent information on correctness this is necessarily subjective. We concentrate on
whether the model is effective in detecting anomalies the user cares about, not on whether it detects
all the anomalies.

CASE STUDY DETECTION RATE

We detect anomalies over the Mn/ROAD data using the model the expert has set up. Tables 3,
4, and 5 list the Rectmix model the expert has set up (predicates outputted by Rectmix) for vehicle
type 1, 6, and 9, respectively. Table 6 lists the Percentile models the expert has set up (predicates
outputted by Percentile) for vehicle types 4, 6, and 9. These models consist of “update” and “accept”
predicates from the final setup stage. For example, for vehicle type 6, Table 4 consists of the “update”
predicates from Table 1—the final setup classification for Rectmix predicates. The middle column of
Table 6 consists of the “update” predicates from Table 2—the final setup classification for Percentile
predicates.

We use the model for anomaly detection and compute the resulting detection rate. We present
plots for one vehicle type—type 6. The plots for type 4 and type 9 vehicles are similar except as
indicated in the analysis that follows.

Figure 3 depicts a count of anomalous attributes flagged by the Rectmix predicates the expert
chose for vehicle type 6. Similarly, Figure 4 depicts a count of anomalous attributes flagged by the
Percentile predicates the expert chose for vehicle type 6.

Data subsets are time ordered; each has two thousand observations. The y-axis in a plot gives
the total number of anomalies in one of the subsets, according to the criterion the plot specifies,
e.g., length anomalies. Notice that the y-axis scale differs among plots. The x-axis is the sequential.
subset index. Figure 3’s left-most plot summarizes the total number of anomalous attributes, out of eight thousand attribute observations (four attributes times two thousand observations for each). The other plots show the break-down of this total by attribute, out of two thousand observations.

The first column in Figure 4 summarizes the number of anomalies for each attribute. The plots in the second and third columns summarize the anomalies that are due to attribute values that are smaller or larger, respectively, than the range bounds. All are out of two thousand observations.

Table 7 summarizes the average detection rate over the subsets of each vehicle type. It gives the detection rate over all attributes and a break-down by attribute.

Looking at the detection rate over a number of subsets (Figures 3 and 4) is insightful. Patterns and changes become visually obvious.

The detection rate (anomalies) for type 9 vehicles is much lower than for the other types. The data of type 9 vehicles seem much cleaner than for the other types. The number of axles is absolutely clean (no anomalies). The weight is usually normal but in some of the subsets there is a very large number of over-weight vehicles (hundreds out of two thousand). This may be due to weight sensor problems in the scale or calibration problems on specific dates. Type 9 is by far the most common, so probably the scale and software are calibrated to best recognize this type.

Figure 4 draws our attention to a correlation between low speed (speed < 40 mph) and over-length (length > 39 feet)—the plots have a similar shape. This helps us to better understand how the length estimation works. The length is estimated from the time that passes between axles, assuming high-way speed. Therefore, if the speed is very low, the length will be over estimated.

Looking at the anomalies for axles in Figure 4, it appears there was a change in the WIM system, starting subset number 54 (November 1999). The number of axles is very noisy in earlier observations and very clean in later observations. The same behavior occurs in type 4 vehicles. This may be due to a software update in the classification or filtering algorithms or a re-calibration of the WIM scale. Our expert was surprised to see this behavior. The expert was also surprised to learn that a large number of vehicles with one axle exist in the data; all commercial vehicles should have at least two axles, and the filtering algorithm should have detected such an anomaly.

Both Figure 3 and Figure 4 show that during the period of time in which the axle attribute is clean, the length is also cleaner (fewer anomalies). The same behavior occurs in type 4 vehicles. This may be due to the same change that resulted in a cleaner number of axles. Many of the type 0 length anomalies are due to the maximal length the WIM system can record: 39.9 feet. Our expert was unaware of the large number of exceptionally long and slow type 6 vehicles during the early
data collection period. This may be due to problems in either the scale calibration or the software.

The total detection rate (Table 7) cannot be compared between Rectmix and Percentile because the attributes are not all the same and because these techniques describe different behavior: Rectmix finds correlations among common attribute values whereas Percentile simply finds common values for a single attribute. However, it is interesting to compare the detection rates for the identical attributes (length, axle, weight). Understanding differences helps in model understanding.

The axles anomaly detection rate is very different between Rectmix and Percentile because the predicates the expert chose differ. For example, Percentile predicates allow 3 axles for type 6 vehicles, but the Rectmix predicates allow 2–4 axles.

Small differences in the ranges for length and weight result in large differences in the detection rate, indicating that the values for these attributes are closely concentrated. The exact cut-off point between normal and anomalous is, therefore, not clear from the data. For example, due to small range differences, the Rectmix length-anomaly detection rate is about five times the Percentile detection rate, except for vehicle type 6 that has an exceptionally high length-anomaly rate. Type 4 Rectmix length anomalies are numerous compared to the other attributes, indicating this bound may be too tight. Due to small range differences, the Percentile weight-anomaly detection rate is about twice the Rectmix detection rate. Rectmix notices a correlation of weight and ESAL in light vs. heavy trucks. The type 6 upper weight bound is much higher for Rectmix, possibly because it also considers trucks with more axles.

**CASE STUDY MISCLASSIFICATION RATE**

The overall misclassification is **TRP** (Runeson et al. 2001) (lower is better), where True Positives (TP) are correctly detected anomalous data, False Positives (FP) are normal data falsely detected as anomalous, False Negatives (FN) are undetected anomalous data, Normal (Nor=TN+FP) are data that are actually anomaly-free, and Abnormal (Ab=TP+FN) are data with anomalies.

Determining these measures is subjective even though documentation for the WIM system exists. This is because, on the one hand, the documentation is sometimes incomplete and imprecise, and on the other hand, it sometimes describes behavior that neither Rectmix nor Percentile can express.

To determine Ab, FP, and TP, our expert sets constraints based on analyzing anomalies flagged by the anomaly detector and differences between the inferred and documented models. Table 8 summarizes the resulting misclassification rate, averaged over data subsets of each vehicle type. The rates are reasonable for a human to handle. The slightly higher Rectmix rate for type 4 is due to the restrictive lower bound on length. Type 9 is the cleanest, so the techniques do best on it.
INFERRRED MODEL VS. DOCUMENTED MODEL

We use the WIM system documentation of vehicle types (Chalkline et al. 2001) and attribute bounds (Mn Regulations 2001) as another indicator of what the system might do, and compare it to what the expert finds interesting.

The documentation concentrates on upper bounds. E.g., type 9 length \( \leq 75 \) ft, type 4 or 6 length \( \leq 40 \) ft. The techniques we use infer predicates about lower bounds as well (e.g., Tables 3-6). The expert found the lower bounds useful. For example, low speed correlates with over-length.

The classification is very noisy compared to the vehicle type documentation. For example, the documentation defines the number of axles per type, yet, except for type 9, the actual number of axles often differs. This led our expert to think about the way the system is calibrated and its effect on vehicle classification. The system seems to be physically tuned for the common type of trucks (type 9). Possible causes for anomalies in other types include: (1) inaccurate sensing, (2) unintended interaction effects among the algorithms (e.g., the filtering algorithms may not properly clean the output of the classification algorithm), and (3) boundary problems in the classification.

The class documentation often seems imprecise. Our expert chose predicates that are different from the documentation when they described vehicles the expert thought belonged in the same class. The documentation defines type 4 as traditional buses with at least two axles. The expert allowed only vehicles with 2-4 axles. The documentation defines type 6 vehicles as vehicles with a single frame having three axles. The expert allowed vehicles with 2-4 axles.

This comparison illuminates subtle expectation differences. The expert emphasizes equally all vehicle types and also data precision. The providers seem to emphasize most vehicle type 9 and avoiding over-estimation. The models reflect these different emphases.

SUMMARY OF EXPERT INSIGHTS

The major insights our expert gained from the analysis detailed above are as follows:

- The data behavior strongly suggests a system wide change in the Mn/ROAD WIM system starting November 1999.
- The system (both hardware and software) seems to be calibrated for the most common type of trucks. This, in turn, seems to adversely affect the accuracy of vehicle identification and classification of other types.
- The interaction of the various algorithms seems to occasionally have undesirable effects.

CONFIRMATION FROM PROVIDERS

The data providers confirmed the expert insights and cause analysis. They were unaware of the
behavior that surprised our expert until recently, when they validated analyses that used these data. It turns out that the WIM scale has two different modes for weighing an axle. The various software algorithms made inconsistent assumptions about the weigh mode. As a result, they occasionally assigned values to the wrong attribute. The next algorithms in the chain did not recognize the problem and made calculations based on the incorrect data. Type 9 vehicles are cleaner because one of the many software providers recognized a problem and made an undocumented correction for type 9. In addition, the system is physically calibrated for this type.

This provides additional confirmation about the usefulness of our method. Moreover, it demonstrates the benefits of having automated anomaly detection. To set up the model, the expert invested less than ten hours. The anomaly detection was fully automated and quick (minutes). In comparison, it had taken the data providers several months to notice the same problems. Analyzing the anomalies requires expert time and this time depends on the number of anomalies and their nature. However, our method directs the expert’s attention to problems, so expert time is invested efficiently.

**CONCLUSIONS AND FUTURE WORK**

We successfully applied our predicate inference framework to detect semantic anomalies in the Mn/ROAD data. Our template mechanism provides automated assistance to experts in setting up constraints for the behavior of monitoring data—it helps users to make their expectations for data behavior precise. The result is an analyzable model of proper behavior.

Our case study results support our hypothesis: (1) The model was useful for automatic anomaly detection over the Mn/ROAD data. It enabled detecting actual anomalies that the expert cared about: classification problems and unlikely vehicles. In addition, the misclassification rate was reasonable for a human to handle (usually less than 3%). (2) The expert gained insights about the WIM system. The data providers confirmed the expert insights.

Moreover, the case study results corroborate the benefits of interacting with the template mechanism to make expectations precise and of analyzing the resulting anomalies. Our method: (1) detected hardware and software problems from observed data only. It detected, for example, problems that were caused by mis-calibration, software modifications, or state changes, (2) promptly detected these problems. It had taken the data providers months to discover these independently, and (3) increased the understanding of existing documentation. For example, the exact cut-off point between normal and anomalies was not clear from the data though it was clear (for upper bounds) from the documentation, suggesting the documentation bounds may be too strict.

Many challenges remain in this area. We plan to extend our method to support updating
predicated and time-correlated data, thus enhancing its applicability and usability. We believe our method is appropriate for any monitoring data. However, for every different data feed, a user would need to interact with our method to (1) set up the tool-kit techniques and (2) classify templates. This may require adding techniques to the tool-kit; our method will provide a procedure for doing so. Once detection is in place, cleaning and mitigation/repair would be a natural next step. Automated support for analyzing the cause of anomalies would be a valuable aid for this purpose because it would greatly enhance the ability to automatically recover from or eliminate the detected anomalies.

ACKNOWLEDGMENTS

We thank the Minnesota Department of Transportation for their Mn/ROAD WIM data, Dan Pelleg for his Reclust code and comments, the Auton Lab (Moore) for making their dataset processing and analysis software (SPRAT) available to us, the anonymous reviewers for their comments.

The authors wish to acknowledge support from the National Science Foundation under Grant ITR-0536009, by the Sloan Software Industry Center at Carnegie Mellon University, by the NASA High Dependability Computing Program under cooperative agreement NCC-2-1298, and by the General Motors Collaborative Research Laboratory at Carnegie Mellon. This material is based in part upon work supported by the National Science Foundation under Grant Number 9987871.

REFERENCES


LAW PCS (1999). "Introduction to LITPP data. Prepared by LAW PCS, a LAWIBS Group Member, Prepared for Office of Infrastructure Research and Development, Federal Highway Adminis-


## List of Tables

1. Example of Rectmix predicates classification ........................................... 22
2. Example of percentile predicates with user classification and instantiated templates 23
3. Rectmix predicates the expert chose for type 4 .......................................... 24
4. Rectmix predicates the expert chose for type 9 .......................................... 25
5. Rectmix predicates the expert chose for type 9 (Axles is always 9) .................. 26
6. Percentile predicates the expert chose for vehicle types 4, 6, and 9 .................. 27
7. Average detection rate .................................................................................. 28
8. Average overall misclassification rate ......................................................... 29
<table>
<thead>
<tr>
<th>Class</th>
<th>Length</th>
<th>ES−AL</th>
<th>Axles</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update</td>
<td>20–42</td>
<td>0–45</td>
<td>2–3</td>
<td>12–29</td>
</tr>
<tr>
<td>Update</td>
<td>23–44</td>
<td>0–73</td>
<td>2–3</td>
<td>20–47</td>
</tr>
<tr>
<td>Reject</td>
<td>13–100</td>
<td>0–43</td>
<td>2–7</td>
<td>7–40</td>
</tr>
<tr>
<td>Update</td>
<td>23–29</td>
<td>0–67</td>
<td>2–4</td>
<td>27–71</td>
</tr>
</tbody>
</table>

**TABLE 1.** Example of Rectnis predicates classification
<table>
<thead>
<tr>
<th>Class</th>
<th>Predicate</th>
<th>Template</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update</td>
<td>40 ≤ speed ≤ 88</td>
<td># ≤ speed ≤ #</td>
</tr>
<tr>
<td>Update</td>
<td>17 ≤ length ≤ 33</td>
<td># ≤ length ≤ #</td>
</tr>
<tr>
<td>Reject</td>
<td>0.6 ≤ DSAL ≤ 5</td>
<td># ≤ DSAL ≤ #</td>
</tr>
<tr>
<td>Update</td>
<td>3 ≤ xaxle ≤ 3</td>
<td># ≤ xaxle ≤ #</td>
</tr>
<tr>
<td>Update</td>
<td>12 ≤ weight ≤ 40</td>
<td># ≤ weight ≤ #</td>
</tr>
</tbody>
</table>

**TABLE 2.** Example of percentile predicates with user classification and instantiated templates
<table>
<thead>
<tr>
<th>Rectangle</th>
<th>Length (cm)</th>
<th>ESAL (°)</th>
<th>Angle (°)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32-43</td>
<td>0-42</td>
<td>2-2</td>
<td>11-22</td>
</tr>
<tr>
<td>2</td>
<td>32-45</td>
<td>1-12</td>
<td>2-2</td>
<td>18-29</td>
</tr>
<tr>
<td>3</td>
<td>31-49</td>
<td>0-1</td>
<td>3-4</td>
<td>21-43</td>
</tr>
</tbody>
</table>

TABLE 3. Rectmix predicates the expert chose for type 4
<table>
<thead>
<tr>
<th>Rectangle</th>
<th>Length $^\wedge$</th>
<th>ESA $^\wedge$</th>
<th>Axon $^\wedge$</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20–42</td>
<td>0–43</td>
<td>3–3</td>
<td>12–29</td>
</tr>
<tr>
<td>2</td>
<td>23–44</td>
<td>0–12</td>
<td>2–3</td>
<td>26–47</td>
</tr>
<tr>
<td>3</td>
<td>23–29</td>
<td>0–6.7</td>
<td>2–4</td>
<td>27–71</td>
</tr>
</tbody>
</table>

**TABLE 4.** Rectmix predicates the expert chose for type 6
<table>
<thead>
<tr>
<th>Rectangle</th>
<th>Length</th>
<th>ESAL</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50–78</td>
<td>1–2</td>
<td>37–77</td>
</tr>
<tr>
<td>2</td>
<td>31–77</td>
<td>1</td>
<td>11–54</td>
</tr>
<tr>
<td>3</td>
<td>30–77</td>
<td>0–1</td>
<td>30–41</td>
</tr>
<tr>
<td>4</td>
<td>52–78</td>
<td>2.4–6.3</td>
<td>74–101</td>
</tr>
</tbody>
</table>

**TABLE 5.** Rectmix predicates the expert chose for type 9 (Axles is always 5)
<table>
<thead>
<tr>
<th>Type 4</th>
<th>Type 6</th>
<th>Type 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 ≤ speed ≤ 85</td>
<td>40 ≤ speed ≤ 85</td>
<td>33 ≤ speed ≤ 85</td>
</tr>
<tr>
<td>23 ≤ length ≤ 12</td>
<td>17 ≤ length ≤ 12</td>
<td>42 ≤ length ≤ 12</td>
</tr>
<tr>
<td>2 ≤ axles ≤ 3</td>
<td>3 ≤ axles ≤ 3</td>
<td>5 ≤ axles ≤ 5</td>
</tr>
<tr>
<td>13 ≤ weight ≤ 40</td>
<td>12 ≤ weight ≤ 49</td>
<td>16 ≤ weight ≤ 94</td>
</tr>
</tbody>
</table>

**TABLE 6.** Percentile predicates the expert chose for vehicle types 4, 6, and 9
<table>
<thead>
<tr>
<th>Rectmix</th>
<th>Vehicle type</th>
<th>Average detection rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Length</td>
<td>ESAL</td>
</tr>
<tr>
<td>4</td>
<td>15.5</td>
<td>42.5</td>
</tr>
<tr>
<td>6</td>
<td>10.9</td>
<td>37.7</td>
</tr>
<tr>
<td>9</td>
<td>2.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Percentile</td>
<td>8.4</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>20.2</td>
<td>30.5</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**TABLE 7.** Average detection rate
<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Average misclassification rate (%)</th>
<th>Rectnix</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5.5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2.3</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.1</td>
<td>.8</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 8.** Average overall misclassification rate
List of Figures
1 Synopses of our method ......................................................... 31
2 Synopses of our template mechanism ........................................ 32
3 Counts of anomalies detected using Rectmix predicates for vehicle type 6 .................................. 33
4 Counts of anomalies detected using Percentile predicates for vehicle type 6 .................................. 34
1. Set up model of expected behavior by eliciting user expectations
   1. Identify appropriate techniques for the problem
   2. Use selected techniques from the technique tool kit to infer predicates that describe data behavior
   3. Interact, via the template mechanism, with the user to articulate expectations precisely using the predicates the techniques can output
   4. Use the model (predicates) resulting from Item 1 as a proxy for missing specifications
      1. Detect semantic anomalies when a new observation falsifies a predicate
      2. Tune the model to account for changing data behavior or user expectations

**FIG. 1.** Synopsis of our method
1. Run the techniques in the tool kit to infer predicates over subsets of the data.
2. Ask the user to classify each predicate as either "accept", "update", or "reject".
3. Use the classification to instantiate templates.
4. Use the instantiated templates to filter the output of the tool kit techniques.
5. Give the filtered output to the anomaly detector and present to the user the resulting anomalies and their templates. Allow the user to change the classification.
6. Goto 1 or terminate when the user is happy with the classification.

FIG. 2. Synopsis of our template mechanism
FIG. 3. Counts of anomalies detected using Rectrix predicates for vehicle type 6
FIG. 4. Counts of anomalies detected using Percentile predicates for vehicle type 6
Weigh in motion is described by the ASTM to be: “the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle” since it’s an estimation, errors occur. There are many sources of errors grouped into four categories:

<table>
<thead>
<tr>
<th>Vehicle Dependent</th>
<th>Environment dependent</th>
<th>System Dependent</th>
<th>Road way dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tire Characteristics:</td>
<td>• Temperatur e gradients</td>
<td>• Vertical Height:</td>
<td>• Pavement Design:</td>
</tr>
<tr>
<td>o Mass</td>
<td>o Temperature</td>
<td>o Impulse forces</td>
<td>o Rigidity</td>
</tr>
<tr>
<td>o Air Pressure</td>
<td>o Diameter</td>
<td>o Torque</td>
<td>o Smoothness</td>
</tr>
<tr>
<td>o Temp</td>
<td>o Tread pattern</td>
<td>• No uniformity</td>
<td>o Obstructions</td>
</tr>
<tr>
<td>o Width</td>
<td>o Balanc e quality</td>
<td>• Spring-Back delay</td>
<td>o Pot holes</td>
</tr>
<tr>
<td>• Suspension System</td>
<td>• Aerodynamic lift</td>
<td>• Compression repeatability</td>
<td>o Debris</td>
</tr>
<tr>
<td>• Acceleration</td>
<td></td>
<td></td>
<td>o Ice build-up</td>
</tr>
</tbody>
</table>

The dynamic weight of Vehicles traveling down the highway can very about 10%. There are three ways to reduce these errors. First install the WIM system in a slow down area. Second, Increase the transducer width in the travel direction. Third, combine the two earlier options.

On the other hand, errors caused by the WIM system itself was always a concern, many tests and research were conducted to reduce that error especially in the following areas: Non-
uniform transducer response, Electronic noise, weight determination algorithm (ORLN’s patented algorithm)
Sources of Error

Overview

Weigh-in-motion is described in the American Society for Testing and Materials (ASTM) Standard Specifications E 1319-04 as "the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle[1]." Because the dynamic vehicle weight is by definition, an estimate of the static vehicle weight, the accuracy and variability of this dynamic measurement depends on how well the WIM system estimates the static weight during the short time duration each tire is in contact with the transducer.

In the past, it has been somewhat common for WIM system manufacturers to attribute nearly all of the accuracy errors associated with their products to uncontrollable random vehicle dynamics (described below). After further analysis, however, there are actually several other sources of error inherent to most WIM systems that can contribute significantly to accuracy errors. All errors can be broadly classified into four basic categories, listed in Table 1.

Table 1. Sources of Error

<table>
<thead>
<tr>
<th>Vehicle-Dependent</th>
<th>Environment-Dependent</th>
<th>System-Dependent</th>
<th>Roadway-Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tire characteristics</td>
<td>• Temperature</td>
<td>• Vertical weight - impulse forces - torque</td>
<td>• Pavement design - roughness - smoothness</td>
</tr>
<tr>
<td>• Mass</td>
<td>• Air pressure</td>
<td>• Nonuniformity</td>
<td>• Obstructions - pot holes - debris</td>
</tr>
<tr>
<td>• Temperature</td>
<td>• Diameter</td>
<td>• Spring-back raily</td>
<td>• Pavement characteristics</td>
</tr>
<tr>
<td>• Air pressure</td>
<td>• Travel pattern</td>
<td>• Compression repeatability</td>
<td>• Pavement contour</td>
</tr>
<tr>
<td>• Width</td>
<td>• Balance quality</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>• Suspension system</td>
<td>• Aerodynamic lift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Eliminating or minimizing the effects of these sources of error can prove difficult. Much work in the past has focused on the need for selecting an appropriate installation site. Once a particular site is selected, adapting WIM system designs by first understanding vehicle- and system-dependent sources of error provides the most cost-effective means of significantly improving system performance.

Reducing errors caused by vehicle dynamics

One of the primary sources of error in WIM systems is vehicle dynamics. As the vehicle travels down the highway, its dynamic weight can vary over time as much as a 10% or more, see Fig. 2. Two frequency ranges (1 - 6 Hz and 9 - 14 Hz) are typically excited during vehicle motion. One source of excitation is typically associated with rigid body motion combined with suspension system performance. This phenomenon excites the lower frequency range (1 - 6 Hz). The other error source is primarily associated with tire balance quality and varies with tire circumference and vehicle speed. This dynamic effect is typically between 9 and 14 Hz for standard size tires rolling at highway speeds. In conventional WIM systems, transducers are ~0.5 to 1.0 m wide in the direction of travel. The transducer width and vehicle speed combination translates into millisecond range sampling times. Unfortunately, a few milliseconds do not allow sufficient time to average the inherent dynamic weight changes attributed to the critical low frequency range. As the transducer width in the direction of travel increases or vehicle speed decreases, the dynamic weight can be averaged for longer periods of time, thus improving the accuracy of WIM system.

To reduce the effects of vehicle dynamics, three options are available. First, the common practice of installing the system in an area where carriers are required to slow down (such as weight station ramps) can be used. For mainline applications, however, this is typically not an option. Second, the transducer width in the direction of travel can be increased, see Fig. 4. Unfortunately, weight determination algorithm of conventional WIM systems incorporate a "peak-value" method of estimating axle weight. Therefore, the transducer width must be held to a distance less than the shortest tandem axle spacing to insure only one tire is on the transducer at a given time.
Recently, researchers have developed a new weight determination algorithm that no longer depends on a "peak-value" weight estimate and thus allows system designers to improve accuracy by extending the transducer width to any length desired. Since the incremental hardware costs associated with increasing transducer width are only a fraction of an overall installed WIM system budget, we predict that in the near future commercially-available WIM systems will emerge that take advantage of these new algorithms. The third option available is to combine the two earlier options to create an enforcement-quality lowspeed WIM system. We will later describe a feasibility demonstration that does this by converting existing in-ground static scales into ultra-high accuracy WIM systems.

Aerodynamic lift, velocity, and acceleration are additional sources of error that can affect WIM performance. For example, studies have shown that at highway speeds, a front axle of "cab-over" designed tractor generally weighs a few percent less than its nominal static weight. The front axle of an aerodynamically designed tractor is less likely to exhibit this weight difference. This phenomenon is primarily attributed to velocity-dependent aerodynamic lift. During visits to highway weighstations, experienced weight enforcement officers have demonstrated their ability to predict when certain types of vehicles will always weigh heavy or light. This observation leads us to believe that aerodynamic lift may be a contributor to accuracy error. To our knowledge, a detailed analysis of the effects of aerodynamic lift on the dynamic weight of a tractor-trailer combination has yet to be undertaken.

Reducing errors caused by the WIM system itself

Several WIM system-dependent sources of error are inherent to all WIM systems and contribute up to one-half of all accuracy errors in WIM systems. We have identified three major contributors:

Nonuniform transducer response

After the mainline WIM system shown in Fig. 1 was installed, Oak Ridge National Laboratory (ORNL) researchers closed one lane of traffic on Interstate 40/75 for one day to assess the static response of the scales to loads placed at various transverse and longitudinal positions. The purpose of this experiment was to determine if vehicle position within the lane would have an affect on WIM system performance. By using an appropriately loaded test truck, the static weight response of the scales as a function of tire configuration and placement was evaluated. The results of this experiment confirmed that the lateral transducer response perpendicular to the direction of travel varied by a significant amount (~2% per 33 cm). Estimates are that the average lane placement variability for motor carriers is ~10 to 20 cm. As such, irregularities in a transducer response caused by inherent design flaws contributed at least 1.0% standard deviation accuracy error per vehicle pass.

Electronic noise

As with all systems it is the combined accuracy of the individual components that result in the overall system accuracy. If the scale only has 10% accuracy to begin with, then having a data acquisition system of 0.1% does not buy one much extra in the end result. In these situations one needs to focus on the major contributors of error first and not worry much about the lesser contributors. However, when the individual components are nearly matched as is the case with most WIM systems, and/or where one is trying to pry the last percent of accuracy out of the system then one needs to examine the rest of the system. One must also be aware that having increased resolution does not always mean that the system will be more accurate. This is the conventional approach by many system designers who do not realize the true nature of their signals. If there is a noise signal that is 1% of the reading then nothing is gained to improve the numeric conversion process beyond 0.5%.

However, if the noise is true and not systematic then one can statistically average it out. This requires not an increase in accuracy and resolution but an increase in the number of measurements to average since the accuracy of the average is directly proportional to the reciprocal square root of the number of averages. Therefore taking 100 times more measurements to average will result in a 10 fold improvement in the average. ORNL uses an approach whereby the signal is first low-pass filtered with a first order analog filter to integrate the very high frequency electrical noise and then numerically integrated to accurately filter (average) the medium and even the low frequency noise. By making the sample rate more than an order of magnitude higher than the conventional approach, this averaging creates results that are often a significant improvement over conventional more accurate conversion processes operating at a slower rate. ORNL has developed special data acquisition hardware that plugs into an ISA slot in a conventional PC to perform this task independent of the CPU.
Weight determination algorithms

CRNL's patented weight determining algorithm is based upon the mathematical convolution of the pressure distribution of the tire rolling over the sensor's sensitivity profile. The end result is that one can integrate the resultant sensor output signal from a tire rolling over the weight sensor and then simply multiply the resultant integral with the speed of the tire and a calibration constant to obtain an accurate weight of the tire. Using the CRNL data acquisition card, most of the integration process is done automatically, and the result is largely reduced to a volume of data by several orders of magnitude that the CPU has to deal with. The end result is that a microcomputer could easily handle the computations required without any loss of accuracy.

The speed of the tire is determined by pressure-activated switches on both the leading and trailing edge of the transducer. These switches provide binary output as to whether the tire is on or off of the switch. While different tires, due to their varying tread patterns and alignments with the switch, produce different contact times, it was discovered that combining these various switch signals together in non-linear ways can produce a very accurate measurement of speed. This is important because a 1% error in speed directly translates to a 1% error in weight using our advanced algorithm.

To test the signal processing system and advanced algorithm, some 20,000 vehicle passes were accumulated from which more than 5,000 waveforms were stored. Two specific tests were conducted a week apart consisting of 18 and 24 vehicles, respectively. The first test was used to calibrate the Advanced WIM System and then both tests were used to evaluate and compare the Advanced WIM System to the commercial WIM system. All pertinent weight information was recorded from the Advanced WIM System, the commercial WIM system, and the static scales. The raw scale outputs were fed into the commercial system computer and the Advanced WIM System data acquisition system. A typical output waveform from an in-ground transducer for a standard 18-wheel semi showed severe ringing or signal oscillations that had to be accounted for in the weight-determining algorithm. Some mechanical adjustment to the in-ground transducer may help to reduce or eliminate some of the system errors encountered during the experimental work.

Results of the two tests are summarized in Table II. The first test was used as a calibration of the Advanced WIM System while both tests were used to compare the two systems to determine the degree of improvement demonstrated by the Advanced WIM system. From this data one can see a significant improvement in the Advanced WIM System over the standard commercial WIM system when changing only the signal processing and algorithm from which the weights were derived. While the average error in the commercial WIM system is high, it could partially be corrected by adjusting the calibration factor. The standard deviation, which is a function of the overall system's repeatability, will remain unchanged. Tests indicate the average variation in the Advanced WIM System improved system performance by ~13%.

Table 2. High-Speed Weight in Motion Data

<table>
<thead>
<tr>
<th></th>
<th>Average Error</th>
<th>Average Deviation</th>
<th>Number Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial WIM System</td>
<td>12.1%</td>
<td>4.7%</td>
<td>18 - Test I</td>
</tr>
<tr>
<td></td>
<td>11.7%</td>
<td>3.7%</td>
<td>23 - Test II</td>
</tr>
<tr>
<td></td>
<td>12.9%</td>
<td>4.1%</td>
<td>41 - Combined</td>
</tr>
<tr>
<td>Advanced WIM System</td>
<td>Calibration</td>
<td>2.5%</td>
<td>18 - Test I</td>
</tr>
<tr>
<td></td>
<td>-0.9%</td>
<td>3.0%</td>
<td>23 - Test II</td>
</tr>
<tr>
<td></td>
<td>-0.5%</td>
<td>2.8%</td>
<td>41 - Combined</td>
</tr>
</tbody>
</table>

By comparing the 2.5% Advanced WIM System average deviation and commercial 4.1% average deviation, we can deduce that at least 28% (1.34 1.1) of the average deviation in the commercial system is a result of design flaws in the signal processing electronics and weight determination algorithm. The remaining average deviation can be attributed to vehicle dynamics, aerodynamic lift, any further flaws in the advanced WIM system signal processing and weight determination algorithm and the nonuniform spatial response of the transducer. Earlier, we determined that the nonuniform response of this particular transducer contributed ~1% average deviation which translates into ~23% of the total average deviation. From this data, we observed that over 50% of the variability observed by this WIM system at this one particular site resulted from system-dependent sources of error that can be corrected.

CRNL previously described and demonstrated a low-cost method of decoupling the lateral transducer response
using diagonally positioned pressure-activated switches. Using these switches in conjunction with basic trigonometric equations, the lateral position of a moving tire on the transducer can be determined to within ~1 to 2 cm.

**Article #9: Advanced Weigh-in-Motion Sensors:**

This paper explains the great advantages of using the WIM sensors to measure the traffic loads at high speed. The TxDOT (Texas Department of Transportation) will use the results to choose between different types of sensors according to low cost, easy to install and calibrate, accurate, remote accessible, and low maintenance. The sensors are installed on the pavement and then covered with asphalt pocket tape connected to a transmitter box on the side of the road which is wirelessly connected to a main data acquisition and storage unit. They types of sensors to be compared and chosen from are: Bending plate, Piezoelectric Sensor, Load cells, and Fiber optics. The fiber optics sensor has some advantages over the other sensors where it can withstand harsh environments and not sensitive to electromagnetic interference. The WIM system should be portable and of low cost.
Advanced Weigh-in-Motion Sensors

Introduction
Weigh-in-Motion (WIM) is a technology for measuring the weight of moving trucks. Highway WIM systems are used in applications such as: collection of statistical traffic data, support of commercial vehicle enforcement, roadway and bridge cost allocation, traffic management, etc. This research will evaluate current WIM sensors systems and develop a prototype portable device to measure the traffic loads at high speed. The researchers will recommend to TxDOT a new WIM system that is low cost, easy to install and calibrate, accurate, remote accessible, and low maintenance cost. After evaluation of various available WIM sensors, a prototype WIM system will be developed. To select an optimized sensors system for TxDOT applications, WIM sensors to be studied include fiber optical pressure load sensor, piezo-electric pressure sensors, bending plate WIM sensors, mechanical scale, and carbon-rubber pressure sensors. A new prototype WIM system will be developed using a most cost-effective and accurate sensor device. This device will be lab and field-tested. The prototype WIM system includes a WIM sensor, a speed sensor, a signal conditioning and processing unit, a short-range wireless data link for data transmission from WIM sensor to the data acquisition and storage unit for easy field installation, a main process, data acquisition and storage unit, a remote access communication unit, and a power supply system. A software program will be developed for system control and coordination, WIM sensor calibration, and data handling. For easy field installation, this system only requires three steps: sensor installation on pavement, installation of sensor signal conditioning and wireless transmitter box on the roadside, and installation of main data acquisition and storage unit. Due to the wireless data link, complicated wiring is eliminated.

There are several classes of WIM sensors that have been developed for use and are currently available in the U.S. and/or abroad.

Bending Plate
Bending Plate WIM systems utilize plates with strain gauges bonded to the underside. As a vehicle passes over the bending plate, the system records the strain measured by the strain gauge and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters. [1]

Piezoelectric Sensor
Piezoelectric WIM systems utilize piezo sensors to detect a change in voltage caused by pressure exerted on the sensor by an axle and measure the axle's weight. As a vehicle passes over the piezo sensor, the system records the electrical charge created by the sensor and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters. [1]

Load Cell
Load Cell WIM systems utilize a single load cell with two scales to detect an axle and weigh both the right and left side of the axle simultaneously. As a vehicle passes over the
load cell, the system records the weights measured by each scale and sums them to obtain the axle weight. [1]

Fiber Optic
Fiber-optic sensors have several advantages over existing sensors. They are not responsive to electromagnetic interference including lightning strikes, they can withstand harsh environments and they have low power requirements. We will concentrate on Fiber Bragg Optical (FBO). The goal is to achieve a weigh-in-motion fiber sensor with accuracy within 1%.

Our proposed WIM System is portable and low cost. Non-contact sensors will be used to detect coming vehicle and speed. Remote axle sensors will be used to replace traditional axle sensors that must be installed by cutting the pavement. Pressure sensors that will be installed on the pavement are placed on top of the pavement and are sealed using asphalt ‘pocket’ tape. A wireless link will be established between the pressure sensor signal conditioning unit and the data storage unit to eliminate digging and wiring. System power supply for the sensors is provided by a rechargeable battery.

Work Plan
• Literature Search
• Prototype Design
• Prototype Manufacture
• Lab and field Test
• Prototype Improvement
• Prepare documents for the project including source code, design circuit diagrams etc.
• Prepare a final report

References:
Article #10: Mettler Toledo Virtual By-Pass Weigh-In-Motion Specifications:

This paper encounters the deployment of the WIM system which is manufactured according to documented quality standards. This project contains both height scale and the WIM scale. The WIM scale is consisted of two platforms for the two wheels of the axle. These platforms will measure 6 ft. wide and 30 in. long. It is capable of weighing 50,000-pound axle, and with a minimum overload capacity of 150%. It will also handle speeds up to 90 mph. The Virtual by-pass controller, which is constructed in an outdoor traffic control cabinet, runs windows 2000 or XP as an operating system and supports interfaces for AVI equipment. The controller specifies which pictures should be logged or transmitted, set overweight thresholds; download pictures with superimposed data from the WIM scale and do system/file maintenance. A daily report is generated that also provides a timestamp list of all vehicles indicating their violation and the file name of the corresponding picture with overlaid text. Two of the specifications for the camera are: it should be a 2/3” progressive scanning interline CCD, and have a pixel of 768(H)x484(V). This system has a warranty of two years from the date of acceptance.
METTLER TOLEDO

VIRTUAL BY-PASS
WEIGH-IN-MOTION
SPECIFICATIONS
Table of Contents

SECTION I

Virtual By-Pass Basic System Layout .............................. 1
Virtual By-Pass System Accuracy ................................. 2
  • Pavement Smoothness
  • Truck Variables
Virtual By-Pass Testing Procedure/APT Test ...................... 3-4
General Provisions Virtual By-Pass .............................. 5
WIM Scales Foundation Requirements ............................. 5
WIM Scales ........................................................ 6
WIM Scale Platforms and Frames Surface Preparation and Finish 7
  • Surface Preparation
  • Coating Specification
  • Coating Application Procedure
  • Curing
WIM Scale Loadcell Specifications .............................. 8
Virtual By-Pass Controller ........................................ 8-9
Logged/Transmitted Picture Details .............................. 9-11
Lightning Protection .............................................. 11
Camera Specifications ........................................... 11
Virtual By-Pass System Warranty ................................. 12
Virtual By-Pass WIM Sequencing

1. Vehicle crosses L1 or L2 to initiate WIM system.

2. Vehicle crosses WIM scales and weight limits (thresholds) are checked. There are thresholds for the following:
   - gross, single axle, tandem axle, single bridge, federal bridge formula, speed, and length.

3. If the vehicle does not exceed threshold the weight or vehicle record is stored per Federal Highway requirements. If the threshold is exceeded the vehicle record is stored as above and the camera takes a picture. The weights for that vehicle are superimposed in the digital picture.

4. Depending on this system configuration, this digital picture is either stored for later retrieval, transmitted via wireless to laptop in patrol car, or transmitted to local weight station.

5. If the system is configured with two cameras (one northbound, one southbound) the digital picture is an overview of the tractor. If a second camera per direction is added the digital picture is an overview of the tractor plus detail (close up) of the tractor door.

<table>
<thead>
<tr>
<th>Basic</th>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Scale Loop</td>
<td>Not Shown: Wireless communication</td>
</tr>
<tr>
<td>WM WIM Scale Platforms</td>
<td>Not Shown: Laptop in patrol car</td>
</tr>
<tr>
<td>L2 Scale Loop</td>
<td>Not Shown: Third or fourth camera (close up of tractor door)</td>
</tr>
</tbody>
</table>
WIM SYSTEM ACCURACY

There are many variables that will effect the "real world" WIM system accuracy.
- Pavement Smoothness (maintenance) of Approach / Exit Slabs
- Truck Variable (Truck Type, Drivers, condition of Vehicle)

Pavement Smoothness

In order to meet ASTM type III specification the paved approach of the WIM scale (150ft.) and after the scale (100ft.) needs to meet ASTM pavement specifications and be Portland concrete, and not vary more than 1/8 inch in 20 feet. Pavement smoothness is the user responsibility.

In order to meet ASTM type I specification the paved approach of the WIM scale (25ft.) and after the scale (6ft.) needs to meet ASTM pavement specifications and be Portland concrete, and not vary more than 1/3 inch in 20 feet. Pavement smoothness is the user responsibility.

Truck Variables

A WIM System is evaluated only with vehicles with loads over 80% of their rated gross vehicle capacity to assure suspensions are engaged. Truck variables such as type, driver skill, and condition cannot be controlled.

Accuracy

Accuracy performance is to meet the following criteria for loaded vehicles.
Type III specifications, which are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Conformance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Weight</td>
<td>± 5%</td>
<td>95%</td>
</tr>
<tr>
<td>Single Axle Load</td>
<td>± 15%</td>
<td>95%</td>
</tr>
<tr>
<td>Tandem Load</td>
<td>± 10%</td>
<td>95%</td>
</tr>
<tr>
<td>Axle Spacing</td>
<td>&gt; of ± .5ft. or 5%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Accuracy performance is to meet the following criteria for loaded vehicles.
Type I specifications, which are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Conformance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Weight</td>
<td>± 10%</td>
<td>95%</td>
</tr>
<tr>
<td>Single Axle Load</td>
<td>± 20%</td>
<td>95%</td>
</tr>
<tr>
<td>Tandem Load</td>
<td>± 15%</td>
<td>95%</td>
</tr>
<tr>
<td>Axle Spacing</td>
<td>&gt; of ± .5ft. or 5%</td>
<td>95%</td>
</tr>
</tbody>
</table>
WIM Testing Procedure

The following method shall be used to verify the WIM system accuracy:

**ACCEPTABLE PERFORMANCE TEST**

A. This section shall apply to all work performed under this contract. Time is of the essence in this contract and the Contractor shall provide the completed system installed and ready for Acceptance Performance Test (APT) after the project completion date. The Contractor shall provide a minimum of 2 weeks advanced notice as to when the APT period will start.

B. The in-motion calibration tests of the entire WIM system shall be performed by the Contractor after installation is completed and prior to beginning the APT period. The Contractor shall provide the Engineer one weeks notice of the in-motion calibration tests. Calibration weights will be provided by the Contractor.

C. The APT period shall begin **two weeks after the completion of the project and calibration of the in motion scales**. This two week time period will be used as a burn-in and training period, which the system will be functional. The Engineer will assist in this process if requested by the Contractor.

D. The Contractor shall submit a detailed test plan to the Department for approval, no later than 90 days after notice to proceed. During the APT period, the entire **SYSTEM** shall be fully operational under normal traffic conditioning and operate trouble free for 24 hours each day for 7 days of each week for 40 consecutive days. The Engineer will check the calibrated performance by obtaining actual truck weight samples. The test for WIM accuracy must be conducted and met bi-weekly during the APT period. The test shall be conducted by comparing actual static weights to WIM weights of class nine vehicles. The Contractor shall provide a WIM scale system specialist to assist in the operation for a period of at least 2 weeks. This specialist shall be made available at additional times during the APT period at the discretion of the Engineer. If problems of any kind are encountered during the APT, at the discretion of the Department, the 40 day APT will start over until 40 continuous days of trouble free operation are experienced. **This re-start can only occur twice.**
E. During the two week burn-in period, the Contractor shall train a minimum of 10 Department staff (to be designated by the Department) in the operation of the SYSTEM for a period of 1 week.

F. The Acceptance Performance Test shall demonstrate to the satisfaction of the Department that the weigh-in-motion enforcement system has been constructed and consistently meet the performance requirements of the plans and of these Technical Special Provisions. The APT will be the basis for acceptance or rejection of the SYSTEM as a result of demonstrated performance.

The Department will suspend Contract time during the first scheduled Acceptance Performance Test (APT). Contract time will resume if the SYSTEM fails during the first, allotted APT time period. When the APT resumes, the entire time period is required as detailed in this section and the Department will suspend the Contract time. The Department will withhold final acceptance of the project until after the successful completion and acceptance of the APT.

At the end of the Acceptance Performance Test period, if the SYSTEM performance requirements as described in the plans and these Technical Special Provisions has not been successfully demonstrated to the satisfaction of the Department, the Department shall reserve the right to continue testing or reject the entire SYSTEM for a maximum of two, additional Acceptance Performance Tests (APT’s). If the SYSTEM does not pass the first, scheduled APT or such additional APT as the Department may authorize under this provision, the Department will reject the SYSTEM and the Contractor shall replace the SYSTEM with one that meets the Department’s requirements at no additional cost to the Department.

Vehicle Suitability
1. Gross static weight must be a minimum of 80% of GVC (gross vehicle capacity) or 64,000-lb.
2. Liquid tankers, livestock, and car haulers are excluded.
3. Vehicles traveling less than 5 mph or more than 70 mph will be excluded.
GENERAL PROVISIONS WEIGH IN MOTION

1.0 The intent of the following provisions is to ensure the WIM system is manufactured to documented quality standards. This is important because the system is subject to highway traffic. Also, these provisions ensure the system will meet documented accuracy requirements for maximum performance, and be supported by local service technicians to minimize down time.

1.1. The scale manufacturer shall have local service.
1.2. The design and manufacture of the WIM scales, load cells, and associated controls shall be of one manufacture to maximize compatibility. This manufacturer shall have a quality system that has been registered to the standards of ISO9001.
1.3. All Welding performed during fabrication of WIM scale platforms and frames must be performed by welders with current AWS D1.1 certification.
1.4. The manufacturer shall provide with the bid proposal a listing of major spare parts and corresponding prices.
1.5. The system shall be a METTLER TOLEDO type or approved equal.
1.6. The system shall meet ASTM type III or type I functional performance requirements, assuming the pavement before and after WIM scales meets ASTM E1318-02 sections 5.1.2, 6.1.3, 6.1.5 and 6.16 requirements

WIM Scales Foundation Requirements

2.0 The intent of this section is to ensure the scales maintain elevation and will not settle over time. Changes in elevation or settling of the scales cause inaccuracy in weighing.

2.1. The WIM scales shall have a foundation to support and maintain the scale’s elevation.
2.2. The foundation shall meet local requirements and the minimum specifications stated in the section.
2.3. The minimum soil bearing required shall be 1,500 pounds per square foot. The contractor shall be responsible for determining whether or not the soil conditions are adequate.
2.4. The foundation shall be 154-in. wide, 95-in. long, and 10 in. thick.
2.5. The foundation shall be poured and constructed of Portland concrete with a minimum strength of 3,500 PSI.
2.6. The foundation shall be reinforced per manufactures guidelines.
2.7. The foundation shall be constructed to provide adequate drainage.
WIM Scales

3.0 The intent of this section is to ensure the WIM scales accurately weigh and measure vehicles at highway speeds, and are field repairable. The following described WIM scales accurately weigh the left and right wheels independently and determine speed, axle spacing, and off scale conditions without the use of other maintenance intensive sensors (axle sensors). These scales are field repairable, because of this and the elimination of axle sensors, maintenance and repairs are accomplished with minimal lane closure time.

3.1 The WIM scale consists of two platforms that weigh the left and right wheels independently. The weighing surface of the platforms will measure 6 ft. wide and 30 in. long in the direction of travel, so that together the two platforms will cover a 12-ft. wide lane.

3.2 Each WIM scale platform shall be supported by four (4) bolts on shear beam load cells for quick replacement.

3.3 Each WIM scale platform shall be mounted in separate frames no more than 12 in. deep.

3.4 The platforms are to be installed flush with the road surface and must be able to withstand heavy truck traffic and normal road maintenance devices such as sweepers and snow plows.

3.5 The WIM scales shall be installed in a staggered configuration so that the scales can determine speed and axle spacing without the use of other in road devices.

3.6 The WIM scales staggered configuration and system software shall determine off scale situations without the use of other in road devices.

3.7 The WIM scales shall be capable of weighing a 50,000-pound single axle, and have a minimum of 150% overload capacity.

3.8 Each WIM scale shall have a static weighing accuracy of 1% or better as demonstrated by applying certified test weights in three places on each platform (The center and each side). Furthermore, the linearity of the indicated weight must not deviate by more than 1% from the actual weight as test weights are added or removed over the full range of the scales rated weighing capacity.

3.9 Each WIM scale platform shall be designed to handle speeds up to 90 miles per hour.

3.10 The WIM scales shall be field repairable on site.

3.11 Repair or replacement of any load cell shall be accomplished with no more than a 1-hour lane closure. The WIM scales shall not require calibration after replacing a load cell.
WIM Scale Platforms and Frames Surface Preparation and Finish

4.0 The intent of this section is to ensure that metal surfaces are prepared properly before painting. The steel preparation and paint procedure can minimize maintenance and provide protection against corrosion.

4.1 Surface Preparation
   4.1.1 Before abrasive blasting, clean per SSPC-SP1
   4.1.2 The weldment shall be abrasive blasted with a nine-wheel horizontal wheelabrator descaler per SSPC A SP-10 (near white blast)
   4.1.3 Travel rate to be 10 ft./min +/- 1 ft./min
   4.1.4 Abrasive material to be steel grit / shot combination
   4.1.5 Blast profile to be 1.5 to 2.5 Milis.

4.2 Coating Specification
   4.2.1 Direct to metal Carboline 890 (Cycloaliphaticamine Epoxy)
   4.2.2 Color, State Gray # 1753
   4.2.3 75% +/- 2% solids by volume minimum
   4.2.4 Must be suitable for salt solution immersion
   4.2.5 Temperature resistance to be 200 degrees F continuous
   4.2.6 Must meet VDC level of 2.0 Lbs/Gal maximum as applied
   4.2.7 Shall be lead and chromate free
   4.2.8 Can not contain any substance defined as carcinogenic by the U.S. EPA

4.3 Coating Application Procedure
   4.3.1 Perform spray applied stripe coat on all edges and other irregular surfaces
   4.3.2 Spray apply specified coating with 50% overlap for first coat
   4.3.3 Spray apply second coat with 50% overlap at right angles to first coat
   4.3.4 Interval between coats to be as specified by coating manufacturer for ambient conditions present
   4.3.5 Wet millage to be verified and documented at 10 - 12 Milis minimum.

4.4 Curing
   4.4.1 Each coat to be force cured at 220 degrees F for a minimum of 15 minutes.
   4.4.2 Coating must cure to 6 - 8 Milis DFT minimum.
WIM Scale Loadcell Specifications

5.0 The intent of this section ensures the WIM load cell is designed to handle the repetitive cycles and extreme weather conditions. The load cells shall be manufactured to tight tolerances to ensure repeatability, accuracy, and serviceability of the WIM scale. Because each load cell is bolted to the platform, and manufactured to the following specifications the load cells are interchangeable to the point that re-calibration is not required. This makes replacement quick, simple, and less costly.

5.1 Each load cell shall have a minimum capacity of 16,000 pounds
5.2 Each load cell shall be of shear beam design with strain gauges
5.3 Each load cell shall be of stainless steel construction
5.4 Each load cell shall be hermetically sealed
5.5 Each load cell shall have temperature compensation inherent in the load cell design

5.6 The load cell specifications
   5.6.1 Overload 150% FS (full scale) safe, 300% FS ultimate
   5.6.2 Repeatability +/- 0.01% FS
   5.6.3 Non-Linearity +/- 0.07% FS
   5.6.4 Hysteresis +/- 0.15% FS
   5.6.5 Creep 20 sec, -1 hour(*) +/-0.05% FS
   5.6.6 Safe side load +/-100%FS
   5.6.7 Span Temp. Coeff 100ppm/deg C
   5.6.8 Zero Temp. Coeff 300ppm/deg C

(*) Loading and unloading time not to exceed 60 sec. Each

5.7 The manufacturing tolerance of the load cells must allow them to be interchangeable to the point that no calibration is required after replacing a load cell.

5.8 Each load cell shall have an integral cable with a stainless steel outer shield. This cable shall be of sufficient length to reach the WIM controller without intermediate connections. No junction boxes shall be placed in the WIM scale pit or below grade.

Virtual By Pass Controller

6.0 The intent of this section is to ensure the WIM controller is designed and constructed according to the specifications below.

6.1 Shall be constructed in a standard outdoor traffic control cabinet
6.2 Shall be capable of supporting an interface for AVI equipment
6.3 Shall receive cables from the WeighBridges, loops, cameras, and transmit or store data as specified
6.4 Shall run Windows 2000 or XP operating system.
6.5 Dial up modem shall be used to access the following functions:
   • Specify which pictures should be logged or transmitted
   • Set over weight thresholds
   • Download pictures with WIM superimposed data
• Download Federal Highway WIM data (card format)
• Provide routine system/file maintenance such as deleting old pictures once they are uploaded.

6.6 System shall log data for all vehicles

6.7 System shall log annotated pictures for the user-defined classifications

6.8 System shall log annotated pictures for the following user-defined violations
• Check for GVW violations on selected classes and annotate captured picture accordingly
• Check for Tandem violations on selected classes and annotate captured picture accordingly
• Check for Axle violations on selected classes and annotate captured picture accordingly
• Check for Bridge violations on selected classes and annotate captured picture accordingly
• Check for Speed violations on selected classes and annotate captured picture accordingly

6.9 A daily report shall be generated that provides a time stamp list of all vehicles, indicating their violation(s) and the file name(s) of the corresponding picture with overlaid text. The time stamp shall be used as a primary key for accessing details of the WIM record.

6.10 For testing purposes, it shall be possible to log pictures (with WIM data overlaid) of all vehicles.

6.11 A suitable concrete pad shall be installed which will be large enough to support the Controller and provide standing area for maintenance personnel.

6.12 Shall include a module for terminating all in-road items (scales, loops, camera(s), etc.) and provide necessary communications.

6.13 Shall include power supply, convenience outlet with light, and surge protection for both lightning and electric.

6.14 This controller or other equipment in this system shall not require UPS for adequate operation

Logged Pictures

7.1 The information required on the picture stored in the database or transmitted is shown in Figure 1. The actual layout of the information on the screen may be changed subject to State approval. Descriptions for each field are listed below.
1. Traveling direction of vehicle – NB, SB, EB, WB
2. Vehicle Class
3. Vehicle speed in miles per hour
4. Gross vehicle weight in pounds
5. Axle weight in pounds
6. Axle spacing in inches
7a. Check box for speed violation (threshold set by user)
7b. Check box for GVW violation (threshold set by user)
7c. Check box for axle violation on Axle 1 (threshold set by user)
7d. Check box for axle violation on Axle 2 (threshold set by user)
7e. Check box for axle violation on Axle 3 (threshold set by user)
7f. Check box for axle violation on Axle 4 (threshold set by user)
7g. Check box for axle violation on Axle 5 (threshold set by user)
8. Date (MM/DD/YY) and Time (HH:MM:SS) (this information shall be obtained from the actual W/M system so that records will be synchronized

Figure 1. Picture of Compliant Truck

- NB
- Class 9
- Spd 60
- GVW 73000
- A1 11000
- A2 13000
- A3 13000
- A4 18000
- A5 18000

Close Up of Truck Door
(separate image from 2nd camera)
Violations will be indicated on the image in the following manner:
- Speed violations will be denoted with an ‘X’ in box 7a.
- GVW violations will be denoted with an ‘X’ in box 7b.
- Single axle violations will be denoted with an ‘X’ in the corresponding box(es) 7c, 7d, 7e, 7f, 7g.
- Tandem axle violations will be denoted with an ‘X’ in the corresponding box(es) 7d & 7e, 7f & 7g.
- Bridge violations will be denoted with an ‘X’ in boxes 7d, 7e, 7f, 7g.

**Lightning Protection**

8.0 A comprehensive lightning protection system shall be provided with the system and covered by warranty.
8.1 The system including WIM load cells, WIM controller, and camera(s) shall be covered by the lightning protection system.

**Minimum Overview Camera Specifications**

9.0 The following minimum specifications shall be met for the camera(s):

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Imager</strong></td>
<td>2/3&quot; progressive scanning interline transfer CCD (Prima RGB color filter)</td>
</tr>
<tr>
<td><strong>Pixel</strong></td>
<td>768 (H) x 484 (V)</td>
</tr>
<tr>
<td><strong>Cell Size</strong></td>
<td>11.6 μm (H) x 13.6 μm (V) progressive scan</td>
</tr>
<tr>
<td><strong>Scanning</strong></td>
<td>Progressive, 525 lines 30 Hz or 60 Hz 2:1 interface</td>
</tr>
<tr>
<td><strong>Sync</strong></td>
<td>Internal/external auto switch, HD/VD, 1.0 Vp-p, Impedance 4.7 Kohms</td>
</tr>
<tr>
<td></td>
<td>VD=interface 60 Hz, non-interface 30 Hz</td>
</tr>
<tr>
<td></td>
<td>HD=15.734 kHz +/- 5%</td>
</tr>
<tr>
<td><strong>Data Clock Output</strong></td>
<td>14 31818 MHz</td>
</tr>
<tr>
<td><strong>TV Resolution</strong></td>
<td>470(H) x 484(V) (analog), 760 x 484 (digital sampling)</td>
</tr>
<tr>
<td><strong>S/N Ratio</strong></td>
<td>50dB</td>
</tr>
<tr>
<td><strong>Min. Illumination</strong></td>
<td>10.0 lux, f=1.4 (no shutter), Sensitivity: 10μV/e-</td>
</tr>
<tr>
<td><strong>Video Output</strong></td>
<td>1.0 Vp-p RGB and NTSC video, @ 75 Ohm and 8-bit x 3 TTL output</td>
</tr>
<tr>
<td><strong>AGC</strong></td>
<td>OFF</td>
</tr>
<tr>
<td><strong>Gamma</strong></td>
<td>0.45 or 1.0 (0.45 std.)</td>
</tr>
<tr>
<td><strong>Lens Mount</strong></td>
<td>C-mount</td>
</tr>
<tr>
<td><strong>Power Req.</strong></td>
<td>12 V DC 600mA</td>
</tr>
<tr>
<td><strong>Operating Temp.</strong></td>
<td>-10 C to 50 C</td>
</tr>
<tr>
<td><strong>Vibration &amp; Shock</strong></td>
<td>Vibration 7G, Shock 70G</td>
</tr>
<tr>
<td><strong>Size (W x H x L)</strong></td>
<td>51 mm x 46 mm x 162 mm (2&quot; x 1.81&quot; x 6.38&quot;)</td>
</tr>
<tr>
<td>Weight</td>
<td>225 grams (4.3 oz)</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Power Cable</td>
<td>12P-02</td>
</tr>
<tr>
<td>Power Supply</td>
<td>K25-12V, PD-12, or PD-12P (with 12 pin connector)</td>
</tr>
<tr>
<td>Auto iris Connector</td>
<td>None</td>
</tr>
<tr>
<td>Functional Options</td>
<td>Y/C Output</td>
</tr>
</tbody>
</table>

9.2 Camera(s) shall be mounted in an environmental enclosure with heater and blower.

**Virtual By-Pass System Warranty**

10.0 The manufacturer shall warrant the system including all load cells, WIM controller, camera(s) for a period of two years from the date of acceptance from failures due to a defect in manufacturing, workmanship, lightning, or surge voltages.

10.1 The written warranty must be acceptable and approved by the user prior to the execution of the construction contract.

10.2 The manufacturer shall bear the charges and expenses associated with replacement parts, equipment, (excluding remote laptops) and any associated freight or handling expenses incurred in the repair or replacement of the system due to failed or damaged items under warranty.

10.3 This warranty excludes damage caused by flooding, accidents, vandalism or natural disasters. The manufacturer shall commence to provide such warranty service within 24 hours of notice that warranty work is required.
## High Resolution Side View Camera

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning System</td>
<td>Progressive Scan</td>
</tr>
<tr>
<td>Pixel Clock</td>
<td>20.25 Mhz</td>
</tr>
<tr>
<td>Line Frequency</td>
<td>12.63 KHz</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>12 frames/sec (1044 lines/frame)</td>
</tr>
<tr>
<td>CCD Sensor</td>
<td>20&quot; progressive scan interline transfer</td>
</tr>
<tr>
<td>Sensing Area</td>
<td>8.7mm (h) x 6.9 mm (v)</td>
</tr>
<tr>
<td>Picture Elements</td>
<td>1300 (h) x 1030 (v) effective pixels</td>
</tr>
<tr>
<td>Lens Mount</td>
<td>C mount</td>
</tr>
<tr>
<td>Horizontal Resolution</td>
<td>1300 TV Lines</td>
</tr>
<tr>
<td>Normal (vertical)</td>
<td>1023 TV Lines</td>
</tr>
<tr>
<td>Double Speed (vertical)</td>
<td>616 TV lines</td>
</tr>
<tr>
<td>Spectral sensitivity</td>
<td>380 - 900 nm</td>
</tr>
<tr>
<td>Sensitivity on sensor</td>
<td>0.1 Lux. Max gain, 50% video</td>
</tr>
<tr>
<td>S/N ratio</td>
<td>&gt;56 dB</td>
</tr>
<tr>
<td>Video Output</td>
<td>composite signal 1.0 Vpp., 75 Ohm</td>
</tr>
<tr>
<td>Trigger in</td>
<td>TTL 2-5V</td>
</tr>
<tr>
<td>SG in</td>
<td>TTL 3.5-4.5V</td>
</tr>
<tr>
<td>HD/VD out</td>
<td>TTL 3.5-4.5V</td>
</tr>
<tr>
<td>WEN out</td>
<td>TTL 3.5-4.5V</td>
</tr>
<tr>
<td>Shutter Speed</td>
<td>variable, up to 1/10,000 sec</td>
</tr>
<tr>
<td>Serial control</td>
<td>RS 232C</td>
</tr>
<tr>
<td>Gain Control</td>
<td>Auto/Manual</td>
</tr>
<tr>
<td>Synchronization</td>
<td>internal Xtal or external HD/VD</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-5C to 45C</td>
</tr>
<tr>
<td>Power</td>
<td>12V dc +/- 10% 4.0 W</td>
</tr>
<tr>
<td>Lens Mount</td>
<td>C-Mount</td>
</tr>
</tbody>
</table>

For More information Please Call 800-785-0038 or email mtwtml@mt.com
### Wireless LAN Bridge

<table>
<thead>
<tr>
<th>Description</th>
<th>11 Mbps Wireless LAN Access Point/Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topologies</td>
<td>10BaseT (RJ-45)</td>
</tr>
<tr>
<td>STANDARD</td>
<td>IEEE 802.11a (Wireless LAN)</td>
</tr>
<tr>
<td>Security</td>
<td>64 bit, 128 bit WEP Encryption</td>
</tr>
<tr>
<td>Modulation</td>
<td>Direct Sequence Spread Spectrum</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>2.4 - 2.4835 GHz</td>
</tr>
<tr>
<td>Data Rate</td>
<td>5.5 Mbps : CCK</td>
</tr>
<tr>
<td></td>
<td>2 Mbps : DQPSK</td>
</tr>
<tr>
<td></td>
<td>1 Mbps : DBSK</td>
</tr>
<tr>
<td>Network Interface</td>
<td>10/100 Mbps (Auto-negotiation)</td>
</tr>
<tr>
<td>Number of Channels</td>
<td>11</td>
</tr>
<tr>
<td>Antenna Connector</td>
<td>SMA connector</td>
</tr>
<tr>
<td>SUPPLY CURRENT</td>
<td>550 mA @ 100mW Tx Out</td>
</tr>
<tr>
<td></td>
<td>750 mA @ 500mW TX Out</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>-20°C ~ +60°C</td>
</tr>
<tr>
<td>Range</td>
<td>Indoor: 500 ft</td>
</tr>
<tr>
<td></td>
<td>Outdoor: 2,500 ft (at 100 mW) / 5 miles+ with High Output</td>
</tr>
<tr>
<td>Approvals</td>
<td>FCC Part 150, Section 15.247</td>
</tr>
</tbody>
</table>

### Antenna

| Type       | 2.4 GHz LINEAR                        |
| Frequency  | 2.404 to 2.473 GHz                    |
| Gain       | 9 dB                                  |
| Front to back | >21 dB                               |
| SWR        | 1 x 1 maximum                        |
| Half Power Beamwidth | 10°                                  |
| Nominal Impedance | 50 ohms                               |
| Connector Type | N female                             |
Article #11: ODOT weigh Station Consideration:

ODOT already have weigh stations at 7 locations in Oklahoma with 12 scale platforms 9 of them are currently operating. With the previous lack of budget; ODOT now is trying to have cost effective projects to renew the idea of capturing overweight trucks to increase public safety, reduce damage to roads and bridges, and provide a homeland security presence. In the next 20 years commercial vehicle traffic is expected to increase by 70%. A 10% overload will reduce life expectancy of roads by nearly 32% over time. An approximation of $8.5 billion for infrastructure repairs would be needed from the state of Oklahoma. ODOT has begun investigations to see what other states have done and what are the best practices found. $3.5 million is needed for repairing existing facilities found on the 7 locations. Knowing that these stations are operated 40 hr/week while promising future monitoring would be done 24/7. Also in addition to this system an Automated Routing System should be developed for oversize/overweight vehicles; currently this is done manually which takes more time.
ODOT weigh station considerations

10/07/95

Passage of SB 141 transferred responsibility for the state’s system of fixed weigh stations to the Oklahoma Dept of Transportation effective 7/01/04. It was immediately obvious little attention had been paid to the system for a number of years. The Department inherited seriously dilapidated facilities, and outdated technology. The majority of these facilities were constructed during the mid 1960's. Because of changes in the highway system and commercial vehicle operations, most of these facilities no longer adequately serve their intended purpose.

The Department’s first priority is to determine the program’s objectives, which have tentatively been identified as:

- monitor and inspect commercial vehicle traffic to increase public safety
- monitor and enforce laws and regulations to reduce damage to existing highway infrastructure
- increase efficiency of the system to monitor a greater number of commercial vehicles and encourage compliance
- introduce computerization, and new technologies to monitor a greater number of commercial vehicles, and bring Oklahoma into Federal Motor Carrier Safety Administration CVISN Level 1 compliance
- provide a homeland security presence
- monitor and regulate hazardous materials traffic in Oklahoma
- (possibly) assist with drug traffic interdiction

ODOT has begun preliminary investigations into what other states have done, and new technologies available. We’ve built strong partnerships with other agencies involved in regulation and enforcement of commercial vehicle operations (OCC, DPS, & OTC). And, using PSCSA funding, we’ve launched CVIEW (Commercial Vehicle Information Exchange Window) which, when complete, will electronically provide current regulatory, enforcement, and safety information to enforcement personnel.

Since assuming responsibility for the program, funding constraints have limited expenditures for the physical facilities to payment of utilities and minor repairs.

Before funds can be expended to best advantage, a master plan should be developed. A study to answer at least the following questions should be undertaken:

- What have other states done, and what would be considered ‘best practices’ with regard to weigh stations and enforcement?
- How do fixed weigh stations mesh with the overall enforcement effort?
- What is the most cost effective mix of modern technologies (weigh-in-motion, virtual enforcement, electronic screening, RFID’s, etc)?
- What would an ‘ideal’ weigh station facility look like? And what would it cost?
- How many weigh station are required, and where should they be located?
- Do we need ‘outbound’ weigh stations, or could Oklahoma enter into reciprocal agreements with other states?
| existing, probable | US412 - US 270 Jct |
| relocation         | relocate in vicinity of Woodward (TBD) |
| new                | US412 E @ Arkansas border |
| new                | US75 N @ Kansas border |

Right-of-way is the most expensive component of weigh station construction. To minimize ROW required for proposed new weigh stations, and to avoid safety problems at existing weigh stations, our studies have indicated the need for weigh-in-motion devices. WIM’s would also expedite processing of commercial vehicles allowing OCC personnel to process a greater number of vehicles, plus increasing operating efficiency for motor carriers by saving driver’s time. WIM’s would pre-screen commercial vehicles allowing those that are obviously within weight limits to bypass the scale, unless randomly selected for registration, permitting, or safety check. Ramps are most existing weigh stations are inadequate for the number of vehicles processed. During peak traffic times, trucks are often waved through to avoid having trucks blocking traffic lanes.

While a weigh station program would require a substantial sum of money, it’s important to remember the amount of money required pales in comparison to the cost of damages to the infrastructure by unregulated, overweight commercial vehicles.

An adjunct to the weigh station system is the necessity to develop an Automated Routing System for oversize/overweight vehicles. Parts of the current permitting system are manual, which is time consuming both for the state employees who are performing the work, but more importantly for our ‘clients.’ Commercial vehicle operators are pushing for automation, pointing out that last time plodding through the current system costs them a lot of money. Additionally, the system is so cumbersome that there is considerable motivation to simply skip the permitting process and take one’s chances with enforcement.

Oklahoma’s weigh stations are basically operated based on a 40 hour week. Whereas, the trucking industry operates 24/7. The Corporation Commission varies ‘open’ hours to monitor a wider spectrum of commercial vehicle traffic, but lack of personnel precludes 24/7 operations. It would be desirable to have a 24/7 presence at least at some of the facilities, and some 24/7 mobile enforcement. The exact details would be determined by the study previously mentioned.
Concurrent with the study, repairs to the existing facilities should be undertaken. An October 2003 Department Study identified approximately $3.5 million in needed repairs. Conditions at the weigh stations vary from substandard to outright safety hazards. Due to age, heavy use, and lack of maintenance, the scales themselves are in poor overall condition.

Fixed weigh stations are less effective if commercial vehicle operators feel they can route around them with impunity, or pass them when closed. Weigh stations are part of a wider monitoring and enforcement network, and to be effective should be complemented by mobile enforcement which is conducted by both OCC and DPS officers. Currently OCC officers do not have portable scales which would allow them to weigh commercial vehicles away from weigh station sites.

Four scales/officer are required to weigh a commercial vehicle away from fixed facilities. We estimate 20 officers need to be so equipped.

Currently Oklahoma has 7 fixed weigh stations with 12 scale platforms (2 locations are bi-directional). Of those scales, only 9 are currently operational. The scales at Hugo require repairs estimated at $90,000. The scale at Woodward was damaged by lightning and has not been repaired because the scale is of inadequate length to weigh standard commercial vehicles, and the location has such short approaches it presents a traffic hazard.

Our preliminary research (pending completion of the study indicated above) indicates Oklahoma weigh station distribution might be allocated as follows:

**Interstate & major corridors**

| existing, | I-35 N @ Kansas border |
| possible relocation | existing scales @ Tonkawa (one each side) are approx 15 miles south of the Kansas border |
| existing, probable relocation | I-35 S @ Texas border |
| relocate from Davis (one each side) | I-40 mid-state, west of El Reno (one each side) |
| increase approach distances | new |
| new | I-40 E @ Arkansas border |
| new | I-40 W @ Texas border |
| new | I-44 NE @ Missouri border |
| new | I-44 SE @ Texas border |
| existing | US 69/US 75 near Colbert (one each side) |
| existing | US 271 near Hugo (one each side) |

**Non-Interstate**

| existing | US 287 @ Boise City (single scale) |
| new | US 271 @ Texas line |
| new | US 54 in Texas County |
| new | US 385 in Cimarron County |
Article #12: Virtual Weigh Station and Remote Monitoring (Presentation):

This presentation, done by the Indiana Department of Revenue, reports the implementation of the virtual weigh station and the benefits and advantages it has over the static weigh station. The system consists of inductive loops, piezo sensors, and load cell sensors to detect the vehicle’s presence, weight, speed, axle spacing and specification. All this data is sent to the WIM Equipment Cabinet on the side of the road processed by the controller unit and then sent to the 900 MHz radio modem that is in the patrol car. The modem can be passed between patrol cars for each to log into it via a laptop. The laptops have software installed to monitor all the information needed by the officer also with a picture of the overweight vehicle. The SWS (Static Weigh Station) costs $15 million each whereas the VWS (Virtual Weigh Station) costs $300 thousand to be installed. Other than its accuracy and more efficiency over the SWS; the VWS helps more efficient deployment of enforcement resources.
Virtual Weigh Stations and Remote Monitoring

Dick Hayworth
CVISN Program Manager

ITS America Annual Meeting
Philadelphia

Monday, May 8, 2000
Problem Statement

- Overweight trucks significantly decrease pavement life
- Current enforcement has little effect on compliance rate
- Trucks bypass open scales or wait until they are closed
- Static weigh stations are not effective for identifying overweight trucks
- Virtual Weigh Stations are believed to be more effective on a manpower basis
Pavement Damage for Class 9 Trucks

\[ ESAL = \left( \frac{\text{Axle}}{18,000} \right)^4 \]

- 100,000-lb Truck = 6.6 ESALs
  - 65,000 cars

- 80,000-lb Truck = 2.5 ESALs
  - 25,000 cars

Source: WIM, pages 18-19

Motor Carrier Services Division
Indiana Department of Revenue

Monday, May 3, 2008
Projected Damage by Overweight Trucks

- Overweight Trucks
- Legal Trucks

- 120,000,000 ESALs
- Design Life (years)
- Project ESALs (millions)
- 11 YEARS

Legend:
- Legal
- Over Tandem
- Over GVW
- Over Axle

Source: WIM, pages 19-22

Monday, May 3, 2008

Indiana Department of Revenue
Static Weigh Station Study

- Violation data collected
- All 8 active Indiana Weigh Stations
- August-September 2003
- Look for ability to identify overweight trucks

Source: WIM, pages 27-28

Motor Carrier Services Division
Indiana Department of Revenue
Static Weigh Stations

- Primarily located on interstates entering the state
- Screens vehicles entering the state for weight and equipment violations
“Intentional” Violators – Over 85,000 Pounds

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Time</th>
<th>Elapsed Time</th>
<th>GVW</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-65 Lowell</td>
<td>8/18/2003</td>
<td>6:40:00</td>
<td>1:55</td>
<td>90260</td>
</tr>
<tr>
<td>I-65 Lowell</td>
<td>8/26/2003</td>
<td>19:06:00</td>
<td>5:36</td>
<td>85040</td>
</tr>
<tr>
<td>I-69 Warren</td>
<td>8/14/2003</td>
<td>8:04:00</td>
<td>2:04</td>
<td>85340</td>
</tr>
<tr>
<td>I-69 Warren</td>
<td>9/18/2003</td>
<td>20:45:00</td>
<td>0:15</td>
<td>86380</td>
</tr>
<tr>
<td>I-69 Warren</td>
<td>9/24/2003</td>
<td>21:00:00</td>
<td>6:00</td>
<td>94220</td>
</tr>
<tr>
<td>I-69 Warren</td>
<td>9/26/2003</td>
<td>14:05:00</td>
<td>1:05</td>
<td>94020</td>
</tr>
<tr>
<td>I-74 MM18</td>
<td>9/12/2003</td>
<td>9:05:00</td>
<td>3:35</td>
<td>85700</td>
</tr>
<tr>
<td>I-94 EB</td>
<td>8/25/2003</td>
<td>16:00:00</td>
<td>9:30</td>
<td>92880</td>
</tr>
<tr>
<td>I-94 EB</td>
<td>8/29/2003</td>
<td>13:19:00</td>
<td>7:19</td>
<td>86160</td>
</tr>
<tr>
<td>I-94 EB</td>
<td>9/15/2003</td>
<td>15:00:00</td>
<td>7:00</td>
<td>89780</td>
</tr>
<tr>
<td>I-94 WB</td>
<td>8/14/2003</td>
<td>11:00:00</td>
<td>8:00</td>
<td>89000</td>
</tr>
<tr>
<td>I-94 WB</td>
<td>9/22/2003</td>
<td>15:00:00</td>
<td>9:30</td>
<td>85800</td>
</tr>
<tr>
<td>I-94 WB</td>
<td>9/24/2003</td>
<td>8:45:00</td>
<td>2:45</td>
<td>89180</td>
</tr>
<tr>
<td>I-94 WB</td>
<td>9/29/2003</td>
<td>9:00:00</td>
<td>6:00</td>
<td>88500</td>
</tr>
</tbody>
</table>

Heaviest vehicle = 94,220 lbs GVW

Source: WIM, pages 26-27, 36
Static Weigh Station Effectiveness

- Open: 3,680 hours
  - Open 31%
  - 7,360 man-hours of enforcement
- Weight violations are 25% - 30% of activity
- “Intentional” Violators
- Weight Violations (GVW > 85,000 lbs)
  - 14 + (12% * 119 with no recorded weight)
  - 25 “Intentional” Violators
  - 1 for every 147 hours open
  - 1 for every 294 enforcement man-hours

Source: WIM, pages 35-36
Motor Carrier Services Division
Indiana Department of Revenue
Overweight Truck Problem

- Are there any overweight trucks?
- Examine I-80/94 outside of Chicago
  - 8-lanes
  - Heavy truck traffic
  - WIM data
### I-80/94 Class 9 WIM Statistics

<table>
<thead>
<tr>
<th>Month</th>
<th>Total</th>
<th>&gt;80k</th>
<th>%</th>
<th>&gt;90k</th>
<th>%</th>
<th>&gt;100k</th>
<th>%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-02</td>
<td>912,868</td>
<td>35,689</td>
<td>3.9%</td>
<td>1,575</td>
<td>0.2%</td>
<td>316</td>
<td>0.03%</td>
<td>140,000</td>
</tr>
<tr>
<td>Jun-02</td>
<td>832,352</td>
<td>36,258</td>
<td>4.2%</td>
<td>1,306</td>
<td>0.2%</td>
<td>265</td>
<td>0.03%</td>
<td>143,000</td>
</tr>
<tr>
<td>Jul-02</td>
<td>848,587</td>
<td>36,694</td>
<td>4.3%</td>
<td>1,392</td>
<td>0.2%</td>
<td>238</td>
<td>0.03%</td>
<td>135,500</td>
</tr>
<tr>
<td>Aug-02</td>
<td>826,752</td>
<td>31,181</td>
<td>3.8%</td>
<td>1,193</td>
<td>0.1%</td>
<td>179</td>
<td>0.02%</td>
<td>142,700</td>
</tr>
<tr>
<td>Sep-02</td>
<td>856,019</td>
<td>24,768</td>
<td>2.9%</td>
<td>1,129</td>
<td>0.1%</td>
<td>229</td>
<td>0.03%</td>
<td>133,500</td>
</tr>
<tr>
<td>Oct-02</td>
<td>975,637</td>
<td>21,925</td>
<td>2.2%</td>
<td>1,230</td>
<td>0.1%</td>
<td>246</td>
<td>0.03%</td>
<td>130,300</td>
</tr>
<tr>
<td>Nov-02</td>
<td>831,839</td>
<td>15,479</td>
<td>1.9%</td>
<td>1,016</td>
<td>0.1%</td>
<td>194</td>
<td>0.02%</td>
<td>130,600</td>
</tr>
<tr>
<td>Dec-02</td>
<td>828,076</td>
<td>12,587</td>
<td>1.5%</td>
<td>1,017</td>
<td>0.1%</td>
<td>179</td>
<td>0.02%</td>
<td>126,000</td>
</tr>
<tr>
<td>Jan-03</td>
<td>915,372</td>
<td>12,285</td>
<td>1.3%</td>
<td>976</td>
<td>0.1%</td>
<td>202</td>
<td>0.02%</td>
<td>137,000</td>
</tr>
<tr>
<td>Feb-03</td>
<td>836,759</td>
<td>12,466</td>
<td>1.5%</td>
<td>875</td>
<td>0.1%</td>
<td>180</td>
<td>0.02%</td>
<td>131,100</td>
</tr>
<tr>
<td>Mar-03</td>
<td>906,600</td>
<td>15,746</td>
<td>1.7%</td>
<td>982</td>
<td>0.1%</td>
<td>204</td>
<td>0.02%</td>
<td>136,200</td>
</tr>
<tr>
<td>Apr-03</td>
<td>889,877</td>
<td>18,017</td>
<td>2.0%</td>
<td>905</td>
<td>0.1%</td>
<td>200</td>
<td>0.02%</td>
<td>127,300</td>
</tr>
</tbody>
</table>

- 28,660 trucks each day
- 37 trucks over 90,000 lbs each day
- 7 trucks over 100,000 lbs each day

*Source: WIM, pages 26-27*
Typical Weigh-in-Motion Site Layout

- Loops – vehicle presence & speed measurement
- Load Cell – weight & speed
- Piezo – speed & axle spacing & classification

Source: VWS, pages 18-26

Indiana Department of Revenue
Weigh-in-Motion Equipment Cabinet

Radio Modem

Omni Antenna

Source: VWS, pages 23, 31-32, 37, 237

Motor Carrier Services Division
Indiana Department of Revenue

Monday, May 3, 2009
VWS In-Vehicle Hardware

- Protective Case holds modem and antenna that can be passed from car to car
- 900 MHz Radio Modem
- MagMount Antenna

Laptop located in police cruiser with software installed
Certified Scales for Enforcement

Source: WWS, pages 6-8
Motor Carrier Services Division
Indiana Department of Revenue
First Pilot Run

- August 10, 2000
- WIM Reading: 112,340 pounds
- Portable Scales: 111,350 pounds
- Load not properly secured
- Legal ~73,280 (short trailer)
Challenges: Where do you weigh and inspect?
Road Runner Video
Road Runner Still

<table>
<thead>
<tr>
<th>License Plate</th>
<th>Type</th>
<th>Violation</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>24213</td>
<td>9</td>
<td>3</td>
<td>82.3</td>
</tr>
<tr>
<td>24224</td>
<td>9</td>
<td>8</td>
<td>81.2</td>
</tr>
<tr>
<td>24280</td>
<td>9</td>
<td>2</td>
<td>124.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>License Plate</th>
<th>Type</th>
<th>Violation</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>24225</td>
<td>9</td>
<td>3</td>
<td>82.3</td>
</tr>
<tr>
<td>24226</td>
<td>9</td>
<td>8</td>
<td>81.2</td>
</tr>
<tr>
<td>24280</td>
<td>9</td>
<td>2</td>
<td>124.5</td>
</tr>
</tbody>
</table>

Source: WWS, pages 34-36

Motor Carrier Services Division

Indiana Department of Revenue
I-80/94 Class 9 WIM Statistics

<table>
<thead>
<tr>
<th>Month</th>
<th>Total</th>
<th>&gt;80k</th>
<th>%</th>
<th>&gt;90k</th>
<th>%</th>
<th>&gt;100k</th>
<th>%</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-02</td>
<td>912,868</td>
<td>35,689</td>
<td>3.9%</td>
<td>1,575</td>
<td>0.2%</td>
<td>316</td>
<td>0.03%</td>
<td>140,000</td>
</tr>
<tr>
<td>Jun-02</td>
<td>832,352</td>
<td>36,258</td>
<td>4.2%</td>
<td>1,306</td>
<td>0.2%</td>
<td>265</td>
<td>0.03%</td>
<td>143,000</td>
</tr>
<tr>
<td>Jul-02</td>
<td>848,587</td>
<td>36,694</td>
<td>4.3%</td>
<td>1,392</td>
<td>0.2%</td>
<td>238</td>
<td>0.03%</td>
<td>135,500</td>
</tr>
<tr>
<td>Aug-02</td>
<td>826,752</td>
<td>31,818</td>
<td>3.8%</td>
<td>1,193</td>
<td>0.1%</td>
<td>179</td>
<td>0.02%</td>
<td>142,700</td>
</tr>
<tr>
<td>Sep-02</td>
<td>856,019</td>
<td>24,768</td>
<td>2.9%</td>
<td>1,129</td>
<td>0.1%</td>
<td>229</td>
<td>0.03%</td>
<td>133,500</td>
</tr>
<tr>
<td>Oct-02</td>
<td>975,837</td>
<td>21,925</td>
<td>2.2%</td>
<td>1,230</td>
<td>0.1%</td>
<td>246</td>
<td>0.03%</td>
<td>130,300</td>
</tr>
<tr>
<td>Nov-02</td>
<td>831,839</td>
<td>15,479</td>
<td>1.9%</td>
<td>1,016</td>
<td>0.1%</td>
<td>194</td>
<td>0.02%</td>
<td>130,600</td>
</tr>
<tr>
<td>Dec-02</td>
<td>828,076</td>
<td>12,587</td>
<td>1.5%</td>
<td>1,017</td>
<td>0.1%</td>
<td>179</td>
<td>0.02%</td>
<td>126,000</td>
</tr>
<tr>
<td>Jan-03</td>
<td>915,372</td>
<td>12,285</td>
<td>1.3%</td>
<td>976</td>
<td>0.1%</td>
<td>202</td>
<td>0.02%</td>
<td>137,000</td>
</tr>
<tr>
<td>Feb-03</td>
<td>836,759</td>
<td>12,466</td>
<td>1.5%</td>
<td>875</td>
<td>0.1%</td>
<td>180</td>
<td>0.02%</td>
<td>131,100</td>
</tr>
<tr>
<td>Mar-03</td>
<td>906,600</td>
<td>15,746</td>
<td>1.7%</td>
<td>982</td>
<td>0.1%</td>
<td>204</td>
<td>0.02%</td>
<td>136,200</td>
</tr>
<tr>
<td>Apr-03</td>
<td>889,877</td>
<td>18,017</td>
<td>2.0%</td>
<td>905</td>
<td>0.1%</td>
<td>200</td>
<td>0.02%</td>
<td>127,300</td>
</tr>
</tbody>
</table>

- 28,660 trucks each day
- 37 trucks over 90,000 lbs each day
- 7 trucks over 100,000 lbs each day
- Static weigh stations only identified 14 trucks over 85,000 lbs over a two month period STATEWIDE

Source: WIM, pages 26-27, 36
Virtual Weigh Station Comparison

- VWS can be implemented at a fraction of the cost
  - Current static station cost = $15 million
  - VWS deployment cost ~ $300K
- 69 man-hours of enforcement
- 13 “Intentional” Violators (GVW > 85,000 lbs)
- 1 “Intentional” Violator for every 5.3 enforcement man-hours
- Therefore:
  - 55 times more effective than static weigh station
  - Cost effective method to save the infrastructure in Indiana
  - 24 X 7 X 52 Truck Traffic Monitoring
  - Efficient deployment of enforcement resources

Source: WIM, page 62
Overweight Permit Analysis

<table>
<thead>
<tr>
<th>Permit Type</th>
<th>Vehicles</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVERWEIGHT</td>
<td>104,573</td>
<td>Generators</td>
</tr>
<tr>
<td>SPECIAL WEIGHT</td>
<td>32,598</td>
<td>Steel Coils</td>
</tr>
<tr>
<td>SUPERLOAD</td>
<td>7,853</td>
<td>Earth Movers</td>
</tr>
<tr>
<td>TOTAL</td>
<td>145,024</td>
<td></td>
</tr>
</tbody>
</table>

- Permitted Highways: 11,176 miles
- Permitted Bridges: 5,246

Source: OS/OW Permit System FY2005
Motor Carrier Services Division
Indiana Department of Revenue
Michigan Trains Compliance Assurance Event

<table>
<thead>
<tr>
<th>Company</th>
<th>WK-1</th>
<th>WK-2</th>
<th>WK-3</th>
<th>WK-4</th>
<th>WK-5</th>
<th>WK-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>18</td>
<td>20</td>
<td>20</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>20</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>25</td>
<td>40</td>
<td>36</td>
<td>36</td>
<td>47</td>
</tr>
<tr>
<td>D</td>
<td>58</td>
<td>67</td>
<td>55</td>
<td>71</td>
<td>146</td>
<td>110</td>
</tr>
<tr>
<td>E</td>
<td>54</td>
<td>50</td>
<td>59</td>
<td>90</td>
<td>76</td>
<td>69</td>
</tr>
<tr>
<td>F</td>
<td>21</td>
<td>17</td>
<td>43</td>
<td>32</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>G</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>H</td>
<td>10</td>
<td>6</td>
<td>13</td>
<td>17</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>I</td>
<td>91</td>
<td>101</td>
<td>134</td>
<td>98</td>
<td>60</td>
<td>67</td>
</tr>
<tr>
<td>J</td>
<td>72</td>
<td>76</td>
<td>99</td>
<td>81</td>
<td>66</td>
<td>71</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>374</td>
<td>398</td>
<td>672</td>
<td>623</td>
<td>486</td>
<td>540</td>
</tr>
</tbody>
</table>

| 2-weeks: | 162 Permits | 1,195 Permits | 1,058 Permits |
| Average:  | 361 Permits  | 645 Permits    | 529 Permits   |

- 53%: More permits the second two week period
- 79%: Increase in permits the second period
- 296: More permits the third two week period
- 39%: Increase in permits the third period

---

**Michigan Trains Permits Purchased by Ten Selected Companies**

- **Weeks:** 1, 2, 3, 4, 5, 6
- **Permit Volume:** 0, 100, 200, 300, 400, 500, 600, 700

---

Monday, May 3, 2008

Motor Carrier Services Division

Indiana Department of Revenue
• Intentional Violators do Risk Assessment
• Half-life of Compliance Assurance Event is two weeks
• The majority of carriers are compliant
• State could be losing as much as $500,000 a year in permit revenue
Current Efforts

- Use existing WIM infrastructure to screen for overweight trucks
- In-Vehicle Wireless Data (not video)
  - ~$2,000-$5,000 per site
  - ~$1,500 per law enforcement vehicle
- Dedicated Inspection Areas are a must
- We believe a weight enforcement may be more effectively performed by randomly using several dozen geographically dispersed WIMs
- Developing a Long Term Strategic Plan for Weigh Stations
- Research and refinement is on-going
- Hope to begin deployment in earnest soon
How Does VWS Solve the Problems?

- Unpredictable enforcement
- Very flexible program
- Dynamic enforcement possible
- Efficient use of enforcement resources
- Highly focused resource allocation
- Improves CVED personnel “Hit rate”
- Minimal infrastructure required
- Promotes compliance rather than punishment
- Compliance rates can be monitored
- Lower cost to operate
Contacts and References

- Dick Hayworth  Motor Carrier Services
- Darcy Bullock  Purdue University
- Guy Boruff  Indiana Department of Transportation
- Marty Kipp  Indiana State Police

- VIRTUAL WEIGH STATION  (VWS)
  June 2002, 295 pages

- QUALITY CONTROL PROCEDURES FOR WEIGH-IN-MOTION DATA  (WIM)
  June 2004, 239 pages
Article #13: Federal Highway Administration Size and Weight Technologies:

This presentation explains the use of E-permitting in the WIM (Weigh-In-Motion) system and how it can make communications happen faster and better. WIM system weighs the CMV (Commercial Motor Vehicle) on a static scale. The I WIM that weighs truck going at speeds up to 80 mph. The virtual weigh station adds remote view over these trucks. Other states are in the process of having virtual weigh stations deployed like Virginian and Vermont whereas other states already have them such as Indian and Kentucky. The federal role is to continue to recommend the use of virtual weigh stations as an effective, efficient and labor friendly tool and to monitor the studies, usage and data analysis of VWS (Virtual Weigh Station). E-permitting allows the permitting agency to wirelessly transfer data to the roadside. There are different levels of e-permitting and till today only one state has level 4 while six are planning to have it. Another technology used in WIM systems is the on-board vehicle weight sensor which monitors air bag pressure and vehicle height to determine the gross weight.
Federal Highway Administration
Size and Weight Technologies
ITS America Conference - May 2006
Session #35

Office of Freight Management and Operations
Mike Onder, Team Leader
Size & Weight, Operations & Technology (SWOT)
Overview

• Weigh-In-Motion
• Virtual Weigh Stations
• E-permitting
• On-board Vehicle Weight Sensors
• Freight Peer to Peer (P2P) Program
Weigh-In-Motion

- Weigh-In Motion (WIM) allows vehicles to be weighed at speeds from 5-80 mph.
- WIM is commonly used for monitoring CMV weights for strategically placed enforcement efforts; and for targeting overweight vehicles for weighing on a static scale.
- Efficiently weighs high numbers of vehicles in an unattended mode.
- There are over 390 CVO installations in North America, including approximately 175 Ramp Systems, 115 Mainline Systems, and 100 additional WIM/AVI sites used for Pre-Clearance.
Virtual Weigh Stations

- Virtual Weigh Stations utilize WIM, remote monitoring systems, and vehicle recognition equipment where there is no physical weigh station.
- Can include use of vehicle transponders, license plate readers, DOT number reading, and/or wireless access to the data and images by roadside enforcement personnel.
- Allows for enforcement on bypass routes and increased enforcement with limited personnel.
Virtual Weigh Station - State Examples

- Indiana:
  - May, 2001: Virtual Weigh Station deployed
    - Several cases where significantly overweight vehicles were identified and impounded
    - Describes concept of using existing equipment to develop a virtual weigh station
- Virginia and Vermont continue to use Weigh In Motion data collection sites to contribute to enforcement strategy
- Kentucky
  - November, 2001: Deployed a Remote Monitoring System (RMS) with camera technology on evasion routes
  - January, 2003: Added Weigh-In-Motion (WIM) to the RMS to create a Virtual Weigh Station
Virtual Weigh Station – Federal Role?

- Federal Role – Office of Freight Management and Operations
  - Monitor State usage, studies, and data analysis of VWS
  - Continue to recommend VWS as an effective, efficient, and labor friendly tool in size and weight enforcement
  - Look for potential collaborative projects with states
- Anything else?
  - Are there any standards that should be considered?
  - Should there be a coordinated national approach to deployment and can the FHWA and FMCSA help on this?
E-permitting

• Electronic permitting (E-permitting) of oversize and/or overweight loads allows for wireless (and paperless) data transfer from the permitting agency to the roadside.

• Electronically attained permits not only improve the efficiency and timeliness of the permitting process, but when used in conjunction with real-time enforcement efforts and bypass systems, also improves timeliness and efficiency of freight mobility.
4 Levels of E-permitting Capability

1) On-line permitting available for drivers
2) Electronic permit data available to roadside enforcement officers
3) Permit data downloaded to State CVIEW database for verification and tracking purposes
4) Permit data sent from State CVIEW to SAFER and/or used for real-time screening of CMVs (Ex. Red light/green light type systems utilizing DSRC)
National E-Permitting Capabilities

- FHWA Surveyed the States, of the 32 who replied:
  - 24 have Level 1 E-permitting in place, and 5 are in the planning process to initiate
  - 21 have Level 2 E-permitting in place, and 3 are in the planning process to initiate
  - 4 have Level 3 E-permitting in place, and 3 are in the planning process to initiate
  - 1 has Level 4 E-permitting in place, and 6 are in the planning process to initiate
- Other government roles on E-Permitting?
Other Technologies - *On-board Vehicle Weight Sensors*

- **How they work:**
  - Engine and transmission ECU’s used to estimate GVW by monitoring torque/speed curves on accelerations.
  - Monitor air bag pressure and vehicle ride height at each axle to determine the gross weight and load distribution of the vehicle.
  - Load cells mounted at the axles and fifth wheel to directly measure vehicle weights.

- **Use and Accuracy:**
  - Commercially available systems have been proven under operational conditions to 0.5% to 1% accuracy.
  - Commercially available systems are also integrated with the truck's own in-dash display and any off-board communications devices.
  - Position and motion sensors may be applied for loads to detect movement of cargo during operation.

- **Government Role on Technology like this?**
Freight Peer to Peer (P2P) Program

- The FHWA’s Freight Peer to Peer Program provides:
  - information sharing between public sector freight transportation professionals and
  - free short-term technical assistance on an as-needed basis regarding freight planning and operations.

- Contact:
  - Phone: 888-FRT 4 YOU
  - Email: FreightPeerExchange@fhwa.dot.gov
  - Online: http://www.ops.fhwa.dot.gov/freight/fpd/p2/index.htm
Current Activities - *What else is needed?*

- Work with FMCSA to develop a national model for States interested in linking E-Permitting to expanded CVISN
- Continue to recommend VWS as an effective, efficient, and labor friendly tool in size and weight enforcement
- Monitor State usage, studies, and data analysis of VWS
- Look for collaboration on VWS
- Conduct International Scan looking at various size and weight technologies
- Provide the opportunity for States to work with other States in setting up size and weight enforcement systems through the Freight Peer-to-Peer Program
- What are other expectations for these subjects on S&W?
**Article #14: ITS America Panel Truck Parking:**

This presentation emphasizes the issue of real-time information on parking availability for truckers to reduce the number severity of CMV crashes and enhance the efficiency of CMV operations. With 8% of the fatal crashes come from truckers getting tired and 16% of the total crashes the implementation of more parking spots across the highways comes in very handy. The purpose of the project is to see how much real-time information can be helpful for the truckers and how much it can reduce the fatal crashes. The project is yet to be deployed pending for funding.
ITS America Panel Session #11: Truck Parking

Philadelphia, PA
May 7, 2006
ITS America Panel Session #11: Truck Parking

• Quon Kwan, FMCSA, Moderator
• Michael Onder, FHWA, Panel Member
• Gary Ritter, VNTSC, Panel Member
• Susan Shaheen, PATH, Panel Member
• Andy Rollert, SpotScout, Panel Member
Why Should You Be Interested in Truck Parking?

  “Fatal Crashes Prompt Concern over Truckers”
  blames lack of truck parking

- *Washington Post*, April 16, 2006,
  “Trucks on the Highway: How to Live with Them”
  urges more truck parking
Agenda

- SmartPark: Real-Time Information on Parking Availability for Truckers
- SAFETEA-LU Section 1305 Truck Parking Grants
- Intelligent Transportation Systems & Truck Parking
- Truck Parking: The Problem & Possible Solution
- SpotScout
Smart Park: Real-Time Information on Parking Availability for Truckers

Quon Kwan
Program Manager
FMCSA
Smart Park: Real-Time Information on Parking Availability for Truckers

Outline
- FMCSA Mission & Goal
- Background
- Purpose
- Steps
Smart Park: Real-Time Information on Parking Availability for Truckers

• Mission:
  To reduce the number and severity of CMV crashes and enhance the efficiency of CMV operations

• Goal:
  Reduce the CMV fatality rate to 1.6 per 100 million CMV miles traveled by 2008
Smart Park: Real-Time Information on Parking Availability for Truckers

Background

- Fatigue accounts for 8.15% of all fatal truck crashes and 16% of all truck crashes
- Lack of safe, available parking contributes to truck driver fatigue

- NTSB in 2000 recommended FMCSA guide on truck parking locations & availability
- FHWA in 2002 recommended ITS deployment to provide parking information
Smart Park: Real-Time Information on Parking Availability for Truckers

**Purposes**

1) Demonstrate technology for providing information on parking availability in real time to truckers on the road

2) To determine if drivers change their behavior as a result of the information

3) To design/assess business model for self-sustaining operation of the technology
Smart Park: Real-Time Information on Parking Availability for Truckers

Steps

- Tasked Volpe with white paper, “ITS & Truck Parking” in November 2004
- Issued a Broad Agency Announcement (BAA) for proposals in June 2005
- Replaced BAA with a GovWorks Pre-Solicitation in December 2005
- Sent Solicitation to Qualified bidders in January 2006
- Evaluated proposals in March 2006
- Award is pending with respect to issues to be resolved with FHWA
Smart Park: Real-Time Information on Parking Availability for Truckers

Quon Kwan
quon.kwan@dot.gov
(202) 385-2389

Technology Division
Federal Motor Carrier Safety Administration
400 Virginia Ave., SW, Suite 600
Washington, DC 20024

TTY Access: (800) 877-8339
Article #15: Onboard Driver Monitoring and Feedback for Commercial Motor Vehicle Safety:

This presentation describes the causes of car crashes, the process they go thru and the ways of avoidance used. Some of the crashes result from lack of attention on the road, fatigue, and speeding. These causes can be monitored, as suggested by California Path Company and even give real-time feedback for drivers to help them in cases like speeding, seatbelt usage, and drowsiness. With a survey conducted the percentage of incidents increases by 20% with an increase of 2% in at-risk drivers. Deployment of such a project is yet to come with California Path trying to design it.
Onboard Driver Monitoring and Feedback for Commercial Motor Vehicle Safety

Concept of Operations

California PATH
Christopher Nowakowski
On-Board Driver Monitoring System:
Concept of Operations

1. What *driver behaviors* (and subsequently vehicle parameters) should be monitored?

2. How should OBM *feedback* be given to the driver?

3. What are the *measures of success* for an OBM System?
What *Driver Behaviors* Should Be Monitored?

1. What behaviors relate to safety?
   - Reviewed prior research
     - Interviews with management and/or drivers
     - Crash statistics
     - Interim Results of the Large Truck Crash Causation Study
   - Results - list of crash types and insights to causes

2. Performed a reverse FMEA to reach behaviors
   - Effect - crash type or critical event
   - Mode - most common critical reasons
   - Failure - behaviors that might be monitored
What Has Prior Research Found?

1. Most Common Effects (Critical Events - Crash Types)
   - Lane Departure
   - Intersection Crossing Path
   - Rear-End

2. Most Common Failure Mode (Critical Reason)
   - Driver Recognition Errors (inattention/distraction)
   - Driver Decision Errors
   - Non-Performance (sleep, legal drugs, medical)
   - Poor Performance (loss of control)
### Working Back to Behavioral Failures
(Example for Lane Departures)

<table>
<thead>
<tr>
<th>Effect (Crash Scenario)</th>
<th>Mode (Critical Reason)</th>
<th>Possible Behavioral Failure</th>
</tr>
</thead>
</table>
| Single Vehicle Ran-Off-The-Road | - Recognition Error  
- Decision Error  
- Non-Performance  
- Poor Performance | - Eyes-Off-Road  
- Curve Overspeed  
- Sleep (Eyes)  
- Lane Keeping  
- Speeding |
| Overtaking |                         |                             |
| Lane Change Or Merge |                         |                             |
### Resulting Behaviors That Could Be Monitored

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Speed</td>
<td>Speed vs.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Following Distance</td>
<td>Following Distance vs.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Attention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hard Braking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Lane Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Lane Changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Recording Incidents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fatigue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Hours of Service</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Intersection Behaviors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Travel Speed
- Tail-End Conditions
- Weather Conditions
- Night-Time Visibilities
How Should *Feedback* Be Given to the Driver?

1. Reviewed Prior Research (Surveys/Focus Groups), but there was little consensus on:
   - Real-time vs. delayed
   - Auditory vs. visual
   - Positive vs. negative
   - Frequency of feedback

2. Developed a Concept and Guidelines for when to give Real-Time OBM Feedback to the Driver
Where Does OBM Feedback Fit into the Scheme of Driver Assistance?

Figure adapted from NHTSA IVHS Plan (1992)
When Should Real-Time OBM Feedback Be Given?

1. Non-specific and non-urgent threat
   - Increased crash risk
   - Increased crash severity risk

2. Persistent condition

3. A condition that the driver can correct

4. Providing feedback will not make the situation worse or more dangerous
Real-Time Feedback Examples

- Good Candidates for Real-Time Feedback
  - Speed Related
  - Following Distance
  - Seat Belt Usage
  - Drowsy Driving

- Bad Candidates for Real-Time Feedback
  - High g Incidents - Hard Braking
What Are the **Measures of Success** for an OBM System?

1. Reduction in Crashes
2. Reduction in Crash Severity (Costs)
   - Crashes are rare events
   - Crashes are often complex - multiple factors
   - Long time horizon to see reliable effects
   - Currently, there is no direct link between many of the proposed behaviors to be monitored and actual crashes
     - Speed - Yes
     - Lane Keeping - No
What Are the Measures of Success for an OBM System?

3. Objective Classification of At-Risk Drivers
   - Small percentage of drivers
   - 5% of drivers -> 20% of incidents (Hanowski, 2000)
   - 7% of drivers -> 54% of incidents (Dingus, 2001)
   - Can the system identify these drivers before crashes

4. At-Risk Drivers -> Average Drivers
   - Can OBM & feedback improve the at-risk drivers
Implement on PATH Freightliner Trucks:
Silver truck committed to this project

California PATH
Questions?
**Article #16: Kentucky Weigh Station Deployment:**

This presentation describes the Radiation Detection with Spectroscopy part of the Integrated Safety and Security Enforcement System. This is one of the Kentucky deployment plans done with the coordination of Kentucky transportation Cabinet and Kentucky Vehicle Enforcement. Each truck is to pass the Radiation Portal Monitor that monitors the Neutron and Gamma radiations coming out from the truck. The pips cameras are used to capture the license plate of the truck with optical character recognition which will make it easy for database entry or query. The radiations are then tested using handheld radiation detectors. If radiation is detected and it’s not consistent with DOT (Department of Transportation), NORM, or Manifest then a call to KYER fusion center is initiated; otherwise the truck is free to go.
Kentucky Weigh Station Deployment

Deputy Commissioner David Jackson
Kentucky Transportation Cabinet
Chronology of Kentucky Deployment

- 2005 Laurel County Northbound Deployed with DOT Funding
- 2006 Kenton, Boone & Simpson County deployments planned for installation, funded by DHS & DOT
- 2006-07 KDHS & DOT proposed funding for 2 mobile units and 2 additional fixed facilities
- 2006-07 planning for installation of virtual weigh stations.
- 2006-07 – funding proposed for KVE for aerial surveillance
Progress To Date

• Working with DNDO in SETCP or South East Transportation Corridor Pilot, with 8 other Southeastern states & DC
• Provided initial training to KVE officers at Laurel Co
• Working with ORNL on Reach back, Data Integration and ConOps
ISSES Capabilities

Integrated Safety and Security Enforcement System

- Radiation Detection with Spectroscopy
- Thermal Imaging
- License Plate Recognition
- USDOT Image capture
- Automatic Vehicle Identification
- Vehicle classification and counter
- Digital video capture

Tie-ins to existing systems
- WIM Weigh in Motion
- Static Scale
- Transponder
## Detection & Interdiction Challenges?

<table>
<thead>
<tr>
<th></th>
<th>Weigh station</th>
<th>Suspicious bypass</th>
<th>Traffic chokepoints super exit’s, rest area’s</th>
<th>Mobile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commercial Motor Carrier</strong></td>
<td>🟢 ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td><strong>Private Rental Trucks</strong></td>
<td></td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td><strong>Work Utility Vehicles</strong></td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td><strong>Non-USIT Regulated Commercial</strong></td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td><strong>Personal Autos</strong></td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
</tbody>
</table>
Suggested Pilot Corridor that Leverages existing Rad/Nuc Deployments
Kentucky Deployment Plans

- Pre-Clearance Sorting
- Virtual Weigh Station
- Suspicious Bypass
- Weigh Station
- Traffic chokepoints, Super Exit’s, Rest Area’s
- Truck Stop
- Mobile
License plate cameras with Optical Character Recognition (OCR) technology - Used to collect images of the front license plate on trucks entering the static scales. The OCR technology is important to allow easy database entry or inquiry.
Radiation Detection

Radiation Portal Monitor - Radiation portal monitors can include Neutron and Gamma detection. Most of these systems are not designed to identify the radioactive isotopes. However, they can give Counts Per Seconds usually graphed by location on the vehicle.
Handheld Radiation Detectors - This handheld detector can give counts per second as well as give indication of Gamma and/or Neutron activity. Many handheld radiation detectors give indication if the personnel should move back away from the source of radiation. A handheld unit should be able to identify the radioactive isotope with indication of confidence level.
Radiation Awareness and Equipment User Training conducted by Vendors and ORNL
Kentucky Proposed Safety Driven Weigh Station Response Protocol

DRAFT Portal Alert Truck Flow Chart

- Portal Alarm?
  - YES
    - Non Routine Gamma Alarm?
      - YES
        - Instruct driver to pull over into parking area
      - NO
        - Neutron Alarm?
          - YES
            - Re-measure: instruct driver to drive back through portal monitors
          - NO
            - Investigate Source Driver/Cab/Carrier
              - YES
                - Exterior survey with RID/Manifest check
              - NO
                - Dose consistent with DOT, NORM or Manifest?
                  - YES
                  - NO
- NO
  - Release Truck

- Start Investigation in accordance with SOP
  - IF
    - Investigation Clarifies Source?
      - YES
      - Move truck to isolation area
      - NO
      - Call KTER Fusion Center
Invitation

Integrated Safety and Security Enforcement System

![Horse and foal](image1.png)
![Hilly landscape](image2.png)
![Waterfall](image3.png)
![Horse race](image4.png)
Article #17: ITSA Annual Meeting Truck Parking Facilities:

This presentation is a quick description of requesting funds for projects concerning long-term parking problems found in the States. The US Department of Transportation is seeking a pilot program to address the shortage of long-term parking for commercial motor vehicles on the National Highway System. The project includes implementing more rest zones on highways, also opening existing facilities to CMV (Commercial Motor Vehicles) parking. The project is to be applied in all states in need after proving its importance and getting the funding for it.
Section 1305 SAFETEA-LU

• Truck Parking Facilities
  - In cooperation with appropriate State, regional, and local governments, the Secretary shall establish a pilot program to address the shortage of long-term parking for commercial motor vehicles on the National Highway System.
Purpose

• Directs the Secretary to establish a pilot program to address the shortage of long-term parking for commercial motor vehicles on the National Highway System.

• FHWA defines “long-term parking” as the ability to park for up to 8 consecutive hours.
Eligible Projects

• Promoting the availability of parking through ITS technologies
• Construction of safety rest zones
• Constructing CMV parking adjacent to travel plaza and truck stops
• Opening existing facilities (scales, inspection facilities, etc) to CMV parking
Eligible Projects (con’t)

- Making capital improvements to seasonal facilities for year round use
- Improving the geometric design of interchanges on the NHS to improve access
Priorities

• Demonstration of a severe parking shortage
• Consultation with affected State and local governments, community groups, private providers of CMV parking, and motorist and trucking organizations
• Demonstration of positive effects on safety, traffic congestion, air quality
Funding

- $6.25 million for FYs 2006-2009
- $5.35 million for FY 2006 after recession
- Federal share of project can be between 80-100%, depending on project
Who is eligible?

- States, MPO’s and local governments
- All funding requests must come from, and be administered by, the State
- Projects cannot compete with private parking facilities
Application/Selection Process

- Federal Register Notice contains proposal format/elements
- FHWA will review proposals based on grant application scoring criteria
- Selections will be made, all applicants will be notified in writing
- Funds distributed
Questions?
Article #18: Truck Parking the Problem & Possible Solution:

This presentation describes the problem of fewer parking spots for trucks in the US and especially in California. This problem causes drivers to either park illegally which might be a danger for motorcycles in night, or cause accident by tired drivers. 8% of fatal truck collisions are fatigue related and the shortage of parking spaces is increasing tremendously. The ITS (Intelligent Transportation System) is trying to implement systems that can inform truck drivers with pre-trip and en-route information they can park safely. The use of remote systems is thought of but not applied yet which can be very helpful providing the driver with real-time information. The benefits of this project will be in reducing accident levels, reducing driver frustration and turnover, and reducing air pollution.
Truck Parking: The Problem & Possible Solution

Susan Shaheen, Ph.D.
Honda Distinguished Scholar
PATH Program Leader, UC Berkeley
ITS America Annual Meeting, Session 11
May 7, 2006
Overview

• State of National Truck Parking
• California Perspective
• Reasons for Illegal Parking
• Recommended Solutions
• Lessons Learned from Transit Smart Parking
• Challenges to Smart Truck Parking
• Advantages to Smart Truck Parking
State of National Truck Parking

• Parking shortages endanger the National Highway System.
  – 8% of fatal truck collisions fatigue-related
  – Lack of truck parking major contributor to fatigue
  – Illegally parked trucks obscure sight distance of motorists.
• Many State DOTs are experiencing a heavy demand for truck parking.

<table>
<thead>
<tr>
<th>Type of Parking Facility</th>
<th>Percent of States Reporting Parking Shortages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Rest Areas</td>
<td>71%</td>
</tr>
<tr>
<td>Private Truck Stops</td>
<td>16%</td>
</tr>
<tr>
<td>Both Private and Public</td>
<td>24%</td>
</tr>
</tbody>
</table>
National Truck Parking Problem: California Perspective

- California ranks high in parking shortage.
  - 1st in overall (private and public) parking shortage
  - 8th highest Public Rest Area space shortage
  - 2nd highest Private Truck Stop Shortage

- By 2020 California’s shortage of parking spaces is expected to increase.
  - 53% for public rest spaces
  - 100% for private truck stop parking spaces

- CHP noted 198 locations where trucks parked illegally.
Not sure that this is the best slide to illustrate the truck parking shortage problems. Perhaps, combine with other data to illustrate magnitude and distribution across the U.S.

Caroline Rodier, 4/20/2006
## Truckers’ Parking Decisions

<table>
<thead>
<tr>
<th>Reasons for Illegal Parking</th>
<th>Percent Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>No empty spaces at nearby facilities</td>
<td>94%</td>
</tr>
<tr>
<td>No nearby parking facilities</td>
<td>83%</td>
</tr>
<tr>
<td>Time limits at nearby facilities are too short</td>
<td>50%</td>
</tr>
<tr>
<td>Empty spaces available but access is blocked</td>
<td>50%</td>
</tr>
<tr>
<td>Convenient access to road</td>
<td>33%</td>
</tr>
<tr>
<td>Drivers less likely to be bothered by strangers</td>
<td>33%</td>
</tr>
<tr>
<td>Difficult to drive in parking lots</td>
<td>18%</td>
</tr>
<tr>
<td>Better lighting on ramp/shoulder</td>
<td>4%</td>
</tr>
</tbody>
</table>
## Smart Truck Parking: Recommended Near-Term Solutions

<table>
<thead>
<tr>
<th>Improvement Strategies</th>
<th>Combined Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use ITS to expand amount of information available to truckers</td>
<td>4.00</td>
</tr>
<tr>
<td>Expand existing rest areas for truck parking by providing more truck spaces</td>
<td>3.58</td>
</tr>
<tr>
<td>Permit the use of weigh stations for parking</td>
<td>3.27</td>
</tr>
<tr>
<td>Establish federal assistance program targeted at truck parking</td>
<td>3.13</td>
</tr>
<tr>
<td>Encourage the development of public-private partnerships</td>
<td>3.08</td>
</tr>
<tr>
<td>Build new rest areas for autos, trucks, and RVs</td>
<td>2.76</td>
</tr>
<tr>
<td>Permit the use of federal-aid funds to maintain public rest areas</td>
<td>2.17</td>
</tr>
<tr>
<td>Build new rest areas for trucks only</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Lessons Learned from City-Based Smart Parking Signage

- 70-80% travelers are aware of signs, but 20-24% actually use them.
- Visitors use it more than commuters who rely on experiential knowledge.
- Awareness grows quickly over first 3 months.
- Effective messages:
  - Target the information needs, decision points & knowledge levels of the market segment
  - Are conspicuous, consistently credible & reinforced.
Lessons Learned from Transit Smart Parking

- Systems in Europe & Japan typically provide motorists with pre-trip or en-route information about parking availability at transit stations.
- Pre-trip & en-route information shown to positively influence the decision to use park-and-ride lots & transit.
- The first U.S. system launched in the San Francisco Bay Area in 2004 & provided both pre-trip & en-route planning via:
  - Two highway CMSs displaying real-time parking information
  - A reservation system that allowed travelers to check availability & reserve spaces en-route by mobile phone or in advance by Internet or telephone.
Reservation System

Microsoft

Intel

Reservation Availability/Heuristics Module

User Information

Parking Inventory

Parking Enforcement

Inventory Data Table

Reservations Module

Sensor Counting Module

Daily Drive-In

Advance Reservations

Parking Availability

BART PARKING 29 SPOTS

2 Signs on Route 24
Real-time Info
Spots available

www.BART.gov

www.ParkingCarmar.com/BART

voiceIVR

"User # 1018"
This needs to be enlarged to make a bit more readable and also maybe change background color if it helps.

Caroline Rodier, 4/20/2006
Smart Truck Parking in U.S.

- Currently, static signs & trucker maps are major sources of parking information for truck drivers.
- Smart truck parking that provides real-time information about available parking in public rest areas & private truck stops have not been implemented in the U.S.
- However, many regions are researching the impact & importance of such systems.
Smart Truck Parking: Challenges

- Large trucks use multiple lot spaces.
- Real-time information lag
- Best methods to disseminate information:
  - Radio broadcasting (most truckers prefer)
  - Visual display
  - CMS
  - Mobile phone
- Messages that target key trucker needs
Smart Truck Parking: Advantages

• Previous research indicates key truck driver attributes may result in high system use rates:
  – High turnover among truck drivers
  – Truckers do little advanced route planning
  – Thus, truck drivers parking knowledge may be similar to the visitors who frequently used city-based systems.

• Effective systems, may provide a number of benefits:
  – Reduced accident levels
  – Reduced driver frustration and turnover
  – Increased security
  – Reduced air pollution.
**Article #19: States’ Successful Practices Weigh-in-Motion Handbook:**

The States’ Successful Practices Weigh-in-Motion Handbook provides an overview of weigh-in-motion (WIM) technology, systems, sites, and states’ “Successful Practices” using WIM systems. The states selected for each WIM system discussed in this Handbook are: California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. Weigh in Motion is major tool used to collect data which is not only used in the Overweight Enforcement process, it plays a very important role in traffic monitoring in a way to improve highway planning and design. In Summary, The uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues.

The American Society for testing and Materials (ASTM) has classified WIM Stations into four Types according to their application, where table 3.2 shows related performance and user requirements for each type of system. The cost of monitoring 100 established sites using both piezoelectric sensors and bending plate scales is estimated to be $612000 for which includes pavement rehabilitation and initial equipment purchases, while The annual cost was estimated to be $2,100,500 which includes pavement rehabilitation and other site maintenance, sensor replacement, electronics replacement, calibration costs, office costs, and travel and per diem costs. The section talks about three types of WIM systems Bending Plate, Piezoelectric Sensors and Load Cells.
The Dynamic behavior of the vehicle and the accuracy of the estimate of the static weight made affect the WIM system performance, which are factors of the geometric design and pavement condition of the roadway and the overall site location. Thus many considerations should be taken when selecting the WIM site:
Geometric Design:

Horizontal curvature: Horizontal Radius should greater than 1740 meters (5700 feet) for a distance of 46 meters (150 feet) before and after.

Roadway Grade: cannot exceed 2% for 46 meters before and after while for Type IV it should not exceed 1% for 91 meter.

Gross Slope: cannot exceed 2% for 46 meter while for type IV it cannot exceed 1%.

Lane Width: 4.3 meters for a distance of 46 meters before and after.

Pavement Condition: Should be both stable and smooth, since road roughness increase will increase vehicle bounce what leads into variation in the vertical load imposed by the moving axle and the instantaneous axle load, resulting in an inaccurate WIM system.

Site location: the site should be located with specific qualities:

Availability of access to power and phone.

Adequate location for controller cabinet.

Adequate Drainage (no flooding and existing of drainage facilities)

Traffic conditions:

Stop and go traffic is minimized

Slow moving traffic is minimized

Lane changing is minimized

Passing on two lane roads is minimized
States’ Successful Practices
Weigh-in-Motion Handbook

NOTICE

December 1997
This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the contractor, which is responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Department of Transportation.

This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the objectives of this document.
The purpose of the State's Successful Practices Weigh-in-Motion Handbook is to provide practical advice for users of weigh-in-motion (WIM) technology, systems, sites, and states. "Successful Practices" using WIM systems. The states selected for each WIM system discussed in this Handbook are: California for bonding plate, Missouri for piezoelectric sensors, and Oregon for load cell. The Handbook covers several areas including quality assurance, site maintenance, troubleshooting, site characteristics, and WIM system description, installation, and calibration. Throughout the Handbook, several "Tricks of the Trade" are highlighted to reinforce some of the successful practices being used.
### SI (Modern Metric) Conversion Factors

#### Approximate Conversions to SI Units

<table>
<thead>
<tr>
<th>Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LENGTH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in</td>
<td>inches</td>
<td>2.54</td>
<td>millimeters</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>yd</td>
<td>yards</td>
<td>0.9144</td>
<td>meters</td>
</tr>
<tr>
<td>mi</td>
<td>miles</td>
<td>1.6093</td>
<td>kilometers</td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in²</td>
<td>square inches</td>
<td>6.452</td>
<td>square millimeters</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
<td>0.0929</td>
<td>square meters</td>
</tr>
<tr>
<td>yd²</td>
<td>square yards</td>
<td>0.8361</td>
<td>square meters</td>
</tr>
<tr>
<td>ac</td>
<td>acres</td>
<td>4046.9</td>
<td>hectares</td>
</tr>
<tr>
<td>sq mi</td>
<td>square miles</td>
<td>2.59</td>
<td>hectares</td>
</tr>
<tr>
<td><strong>VOLUME</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fl oz</td>
<td>fluid ounces</td>
<td>29.57</td>
<td>milliliters</td>
</tr>
<tr>
<td>gal</td>
<td>gallons</td>
<td>3.785</td>
<td>liters</td>
</tr>
<tr>
<td>hL</td>
<td>cubic hectoliters</td>
<td>0.001</td>
<td>cubic meters</td>
</tr>
<tr>
<td>L</td>
<td>cubic liters</td>
<td>0.7854</td>
<td>cubic meters</td>
</tr>
</tbody>
</table>

**NOTE:** Volume greater than 1000 L should be shown in m³.

#### Approximate Conversions from SI Units

<table>
<thead>
<tr>
<th>Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LENGTH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>millimeters</td>
<td>0.039</td>
<td>inches</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
<td>3.28</td>
<td>feet</td>
</tr>
<tr>
<td>yd</td>
<td>yards</td>
<td>1.09</td>
<td>meters</td>
</tr>
<tr>
<td>km</td>
<td>kilometers</td>
<td>0.621</td>
<td>miles</td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm²</td>
<td>square millimeters</td>
<td>0.0001</td>
<td>square inches</td>
</tr>
<tr>
<td>m²</td>
<td>square meters</td>
<td>10.764</td>
<td>square feet</td>
</tr>
<tr>
<td>yd²</td>
<td>square yards</td>
<td>0.836</td>
<td>square meters</td>
</tr>
<tr>
<td>ha</td>
<td>hectares</td>
<td>2.47</td>
<td>acres</td>
</tr>
<tr>
<td>km²</td>
<td>square kilometers</td>
<td>0.386</td>
<td>square miles</td>
</tr>
<tr>
<td><strong>VOLUME</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mL</td>
<td>milliliters</td>
<td>0.034</td>
<td>fluid ounces</td>
</tr>
<tr>
<td>L</td>
<td>liters</td>
<td>1.02</td>
<td>quarts</td>
</tr>
<tr>
<td>m³</td>
<td>cubic meters</td>
<td>35.32</td>
<td>cubic feet</td>
</tr>
<tr>
<td>yd³</td>
<td>cubic yards</td>
<td>1.307</td>
<td>cubic meters</td>
</tr>
<tr>
<td><strong>MASS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>grams</td>
<td>0.035</td>
<td>ounces</td>
</tr>
<tr>
<td>kg</td>
<td>kilograms</td>
<td>2.205</td>
<td>pounds</td>
</tr>
<tr>
<td>Mg</td>
<td>megagrams</td>
<td>1.103</td>
<td>short tons (2000 lb)</td>
</tr>
</tbody>
</table>

**NOTE:** Mass greater than 1000 kg should be shown in Mg.

#### Temperature (exact)

<table>
<thead>
<tr>
<th>°F</th>
<th>Fahrenheit</th>
<th>5°F = 0°C</th>
<th>Celcius temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>Celcius</td>
<td>0°C = 32°F</td>
<td>Fahrenheit temperature</td>
</tr>
</tbody>
</table>

#### Illumination

<table>
<thead>
<tr>
<th>Lx</th>
<th>foot-candles</th>
<th>1 lx</th>
<th>foot-candles</th>
</tr>
</thead>
</table>

#### Pressure

<table>
<thead>
<tr>
<th>N/m²</th>
<th>newtons per square meter</th>
<th>1 N/m²</th>
<th>Pascals</th>
</tr>
</thead>
</table>

#### Force and Pressure or Stress

| lbf | pounds | 4.45 | newtons |
| lb/ft² | pounds per square foot | 6.89 | kilopascals |
| kPa | kilopascals | 0.145 | newtons per square meter |

---

* SI is the symbol for the International System of Units. Appearances. (Revised September 1993)
STATES’ SUCCESSFUL PRACTICES
WEIGH-IN-MOTION HANDBOOK

prepared for
FEDERAL HIGHWAY ADMINISTRATION

prepared by
Center for Transportation Research and Education
Iowa State University

with
Major Contributions
by
Arkansas State Highway and Transportation Department
California Department of Transportation
Minnesota Department of Transportation
Missouri Department of Transportation
Oregon Department of Transportation

December 15, 1997
Table of Contents

I. ACKNOWLEDGMENTS .............................................................. vii

II. LIST OF FIGURES ................................................................. ix

III. LIST OF TABLES ................................................................. xi

IV. LIST OF "TRICKS OF THE TRADE" ........................................ xiii

SECTION 1. PURPOSE OF THE HANDBOOK ..................................... 1-1

1.1 ESTABLISH SYSTEM REQUIREMENTS .................................... 1-2
1.2 BUDGET FOR THE RESOURCES NECESSARY TO SUPPORT SITE DESIGN LIFE AND ACCURACY REQUIREMENTS ......................... 1-2
1.3 DEVELOP AND MAINTAIN A QUALITY ASSURANCE PROGRAM .......... 1-2
1.4 ESTABLISH WEIGH-IN-MOTION EQUIPMENT WARRANTY ................. 1-2
1.5 MANAGE SYSTEM INSTALLATION ........................................... 1-2
1.6 CONDUCT PREVENTATIVE AND CORRECTIVE MAINTENANCE ........... 1-2

SECTION 2. TRAFFIC MONITORING ............................................... 2-1

SECTION 3. WEIGH-IN-MOTION SYSTEM DISCUSSION ........................... 3-1

3.1 ESTABLISH SYSTEM REQUIREMENTS .................................... 3-3
3.2 ECONOMIC ANALYSIS ......................................................... 3-3
3.3 BENDING PLATE ................................................................. 3-7
  3.3.1 Sensor ................................................................. 3-7
  3.3.2 Site Processor .......................................................... 3-9
  3.3.3 Remote Communication Modem ...................................... 3-9
  3.3.4 Operating Software .................................................... 3-9
  3.3.5 Data Output Format ..................................................... 3-10
3.4 PIEZOELECTRIC SENSORS .................................................... 3-10
  3.4.1 Sensor ................................................................. 3-10
  3.4.2 Site Processor .......................................................... 3-11
  3.4.3 Remote Communication Modem ...................................... 3-12
  3.4.4 Operating Software .................................................... 3-12
  3.4.5 Data Output Format ..................................................... 3-13
3.5 LOAD CELL ................................................................. 3-13
  3.5.1 Sensor ................................................................. 3-13
  3.5.2 Site Processor .......................................................... 3-13
  3.5.3 Remote Communication Modem ...................................... 3-14
  3.5.4 Operating Software .................................................... 3-15
  3.5.5 Data Output Format ..................................................... 3-15
SECTION 7. WEIGH-IN-MOTION ACCURACY AND QUALITY ASSURANCE RELATED TO PROBLEMS OCCURRING AT THE WIM SITE ............... 7-1
7.1 LONG TERM PAVEMENT PERFORMANCE PROCEDURE ............... 7-1
7.2 VEHICLE TRAVEL INFORMATION SYSTEM SOFTWARE ............... 7-1
7.3 CALTRANS SUCCESSFUL PRACTICE: QUALITY ASSURANCE PROGRAM ................................................................. 7-2
  7.3.1 “Knowledge of Site Characteristics” Review ................. 7-6
  7.3.2 “Real Time” Review ............................................. 7-8
  7.3.3 First Level Data Review - Summary Report ................. 7-12
  7.3.4 First Level Data Review - Individual Truck Report .......... 7-21
  7.3.5 Second Level Data Review ..................................... 7-28
SECTION 8. SITE MAINTENANCE ............................................. 8-1
  8.1 CORRECTIVE MAINTENANCE ........................................ 8-1
  8.2 PREVENTATIVE MAINTENANCE ...................................... 8-1
    8.2.1 Weigh-in-Motion Sensor Operation ......................... 8-3
    8.2.2 Loop Operation ............................................... 8-3
    8.2.3 Weigh-in-Motion Electronics and Equipment Functions .... 8-3
    8.2.4 System Maintenance and Cleaning ........................ 8-3
    8.2.5 Visual Inspection of Site ................................... 8-3
    8.2.6 Software Maintenance ........................................ 8-3
SECTION 9. SYSTEM TROUBLE-SHOOTING .................................. 9-1
  9.1 LOGICAL TROUBLE-SHOOTING PROCESS ............................ 9-1
  9.2 REQUIRED RESOURCES ............................................ 9-1

REFERENCE LIST

APPENDICES

APPENDIX 1 Relevant State Documents
California Procurement Documents
California Maintenance Contract

APPENDIX 2 Long Term Pavement Performance
Instructions for Cost Estimate Spreadsheet
I. ACKNOWLEDGMENTS

The Center for Transportation Research and Education at Iowa State University would like to acknowledge the following people for their major contributions and sharing their “Successful Practices” and “Tricks of the Trade”: 

Rich Quinley 
California Department of Transportation 
Mail Stop 36
1120 N Street
Sacramento, CA 95814
rquinley@trmx3.dot.ca.gov 

Curtis Dahlin 
Minnesota Department of Transportation 
395 John Ireland Boulevard 
Mail Stop 450
St. Paul, MN 55155
(612) 296-6846 

Allan Heckman 
Missouri Department of Transportation 
P.O. Box 210 
2103 Missouri Boulevard 
Jefferson City, MO 65102
heckma@mail.mobot.state.mo.us 

Kenneth Evert 
Oregon Department of Transportation 
Motor Carrier Branch 
550 Capitol St. NE
Salem, OR 97310-1380
ken.evert@state.or.us
## II. LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 3.1</td>
<td>Example of Bending Plate System Layout (Adapted from International Road Dynamics graphic)</td>
<td>3-8</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Example of Piezoelectric System Layout (Adapted from International Road Dynamics graphic)</td>
<td>3-11</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Example of Load Cell System Layout (Adapted from International Road Dynamics graphic)</td>
<td>3-14</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Use of Profilograph to Measure Road Roughness (Oregon DOT)</td>
<td>4-4</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Installed Bending Plate Scale (California DOT)</td>
<td>5-6</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Positioning and Painting of Sensor Templates (Missouri DOT)</td>
<td>5-8</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Pavement Grinding (Oregon DOT)</td>
<td>5-10</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Installed Load Cell Scale (Oregon DOT)</td>
<td>5-13</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>Sample WIM Calibration Worksheet (California DOT)</td>
<td>6-3</td>
</tr>
<tr>
<td>Figure 6.2</td>
<td>Sample Gross Weight Percent Error by Vehicle Speed Graph (California DOT)</td>
<td>6-5</td>
</tr>
<tr>
<td>Figure 7.1</td>
<td>&quot;Knowledge of Site Characteristics&quot; Review Flowchart (California DOT)</td>
<td>7-7</td>
</tr>
<tr>
<td>Figure 7.2</td>
<td>&quot;Real Time&quot; Review Flowchart (California DOT)</td>
<td>7-10</td>
</tr>
<tr>
<td>Figure 7.3</td>
<td>&quot;Real Time&quot; Review Example (California DOT)</td>
<td>7-11</td>
</tr>
<tr>
<td>Figure 7.4</td>
<td>First Level Data Review - Summary Report Flowchart (California DOT)</td>
<td>7-15</td>
</tr>
<tr>
<td>Figure 7.5</td>
<td>Distribution of Vehicle Classification by Hour of Day (California DOT)</td>
<td>7-16</td>
</tr>
<tr>
<td>Figure 7.6</td>
<td>Distribution of Classification and Speed Counts by Lane (California DOT)</td>
<td>7-17</td>
</tr>
<tr>
<td>Figure 7.7</td>
<td>Distribution of Speed by Vehicle Classification (California DOT)</td>
<td>7-18</td>
</tr>
<tr>
<td>Figure 7.8</td>
<td>Distribution of Vehicle Classification by Hour of Day (California DOT)</td>
<td>7-19</td>
</tr>
<tr>
<td>Figure 7.9</td>
<td>Distribution of Vehicle Counts by Hour of Day by Lane (California DOT)</td>
<td>7-20</td>
</tr>
<tr>
<td>Figure 7.10</td>
<td>First Level Data Review - Individual Truck Report Flowchart (California DOT)</td>
<td>7-24</td>
</tr>
<tr>
<td>Figure 7.11</td>
<td>Distribution of Weight Violations and Invalid Measurements for Vehicle Classes 4-15 (California DOT)</td>
<td>7-25</td>
</tr>
<tr>
<td>Figure 7.12</td>
<td>Distribution of Truck Record Data by Lane (California DOT)</td>
<td>7-26</td>
</tr>
<tr>
<td>Figure 7.13</td>
<td>Sample Log Sheet (California DOT)</td>
<td>7-27</td>
</tr>
<tr>
<td>Figure 7.14</td>
<td>Second Level Data Review Flowchart (California DOT)</td>
<td>7-31</td>
</tr>
<tr>
<td>Figure 7.15</td>
<td>Distribution of Gross Weight by Lane (California DOT)</td>
<td>7-32</td>
</tr>
<tr>
<td>Figure 7.16</td>
<td>Distribution of Gross Weight by Lane (California DOT)</td>
<td>7-33</td>
</tr>
<tr>
<td>Figure 7.17</td>
<td>Distribution of Average Weights and Spacings by Speed (California DOT)</td>
<td>7-34</td>
</tr>
<tr>
<td>Figure 7.18</td>
<td>Distribution of Average Weights and Spacings by Speed (California DOT)</td>
<td>7-35</td>
</tr>
</tbody>
</table>
III. LIST OF TABLES

Table 1.1 General Guiding Principles Checklist ........................................... 1-1
Table 3.1 WIM System Principles Checklist .................................................... 3-1
Table 3.2 ASTM WIM System Classification (ASTM Standard E 1318-94) .......... 3-2
Table 3.3 Functional Performance Requirements for WIM Systems (ASTM Standard E 1318-94) ......................................................... 3-3
Table 3.4 Cost Comparison of WIM Systems (Taylor and Bergan, IRD) ............ 3-4
Table 3.5 Example of Weigh-in-Motion Costs (LTPP, Halenbeck) .................. 3-5
Table 3.6 Summary of Example Weigh-in-Motion Costs LTPP, Halenbeck) ....... 3-7
Table 4.1 WIM Site Principles Checklist ......................................................... 4-1
Table 4.2 ASTM Standard (E 1318-94) Geometric Design Requirements ........ 4-2
Table 5.1 Installation Principles Checklist ..................................................... 5-2
Table 5.2 Bending Plate Installation Checklist (International Road Dynamics) ... 5-4
Table 5.3 Piezoelectric Sensor Installation Checklist (International Road Dynamics) 5-7
Table 5.4 Load Cell Installation Checklist (International Road Dynamics) ....... 5-11
Table 6.1 System Calibration Principles Checklist .......................................... 6-1
Table 6.2 Caltrans Functional Requirements (California DOT) ......................... 6-6
Table 6.3 Example Automatic Recalibration Values (Minnesota DOT) ............... 6-7
Table 6.4 Example of Recalibration Procedure (Minnesota DOT) ................. 6-8
Table 6.5 Minnesota Department of Transportation Adjustment Factors .......... 6-9
Table 6.6 Example of Recalibration Results (Minnesota DOT) ....................... 6-9
Table 7.1 Quality Assurance Principles Checklist .......................................... 7-3
Table 7.2 California Classification Scheme (California DOT) ......................... 7-5
Table 8.1 Caltrans Successful Practice: Field Maintenance Checklist (California DOT) 8-2
Table 9.1 Trouble-Shooting Principles Checklist ............................................. 9-1
IV. LIST OF "TRICKS OF THE TRADE"

"Tricks of the Trade" are written in italics throughout the document. The pencil to the left is used to further emphasize their location. The "Tricks of the Trade" are numbered and titled for listing purposes.

4.1 WIM Site Selection (California DOT) .................................................. 4-1
4.2 Axle Weight Transfer and Roadway Grade (California DOT) .......................... 4-3
4.3 Pavement Condition (California DOT) .................................................. 4-4
5.1 Installation (California DOT) .............................................................. 5-1
5.2 Sensor Test (California DOT) .............................................................. 5-2
5.3 Frame Installation (California DOT) .................................................. 5-3
5.4 Conduit and Drain (California DOT) ................................................... 5-5
5.5 Leveling (California DOT) .............................................................. 5-5
5.6 Lead Wires (California DOT) ............................................................ 5-5
5.7 Slot Condition (International Road Dynamics) ........................................... 5-8
5.8 Knowledge of Epoxy Properties (Arkansas State Highway and Transportation Department) .................................................. 5-9
6.1 Practical Calibration (California DOT) ................................................ 6-2
6.2 Data Analyst (California DOT) .......................................................... 6-6
7.1 Knowledge (California DOT) ............................................................ 7-2
1. PURPOSE OF THE HANDBOOK

The purpose of the States' Successful Practices Weigh-in-Motion Handbook is to provide an overview of weigh-in-motion (WIM) technology, systems, sites, and states' "Successful Practices" using WIM systems. WIM is described as "the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle" in the American Society for Testing and Materials (ASTM) Standard Specification E 1318-94 (1). States with successful WIM systems were selected using information from the Long Term Pavement Performance (LTPP) Program. The states selected for each WIM system discussed in this Handbook are: California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. The discussion will not be limited to these three states, where applicable successful practices and procedures from other states will be introduced.

The purpose will be accomplished by discussing the principles behind WIM usage and documenting "Tricks of the Trade" for installation and operation of WIM systems. The principles of WIM usage are developed from the successful practices of states using the various WIM technologies. The "Tricks of the Trade" have been developed by state experts and vendors when working with WIM systems and sites. They deal with important aspects of accuracy, quality assurance, sites, installation, and calibration. The Handbook attempts to discuss successful practices that state experts have found over the years to work well.

States have found that the intended use of WIM data determines the approach the state should choose in developing the WIM data collection site and the resources required to maintain the site over the expected "site design life." The following general guiding principle checklist has been developed by state experts that are successfully meeting their end users' data requirements. The guiding principles are addressed in greater detail in the later sections of this handbook. The values in the Handbook are given in metric units when possible. The figures and tables that were obtained from outside sources were not converted to metric units.

<table>
<thead>
<tr>
<th>Guiding Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Decide on &quot;site design life&quot; and accuracy necessary to support the end user.</td>
</tr>
<tr>
<td>1.2 Budget the resources necessary to support the selected &quot;site design life&quot; and accuracy requirements.</td>
</tr>
<tr>
<td>1.3 Develop and maintain a thorough quality assurance program.</td>
</tr>
<tr>
<td>1.4 Purchase the WIM equipment with a warranty.</td>
</tr>
<tr>
<td>1.5 Manage the equipment installation.</td>
</tr>
<tr>
<td>1.6 Conduct preventative and corrective maintenance on the site.</td>
</tr>
</tbody>
</table>
1.1 ESTABLISH SYSTEM REQUIREMENTS

States have found that the intended use of the WIM data should determine the approach the state chooses in developing the WIM data collection "site design life." The state should decide on the number of years that the WIM site will collect data. The established "site design life" and intended use of the data should influence decisions concerning the type of equipment, location and condition of the site, installation of equipment, and analyses performed on the collected data.

1.2 BUDGET FOR THE RESOURCES NECESSARY TO SUPPORT SITE DESIGN LIFE AND ACCURACY REQUIREMENTS

The intended use of the WIM data determines the resources required to maintain the site over the expected "site design life." For a longer "site design life" additional financial and staff resources will be needed to maintain and replace the WIM equipment. The required financial and staff resources increase as the required accuracy level increases. Additional analysis and quality assurance is needed for higher levels of accuracy.

1.3 DEVELOP AND MAINTAIN A QUALITY ASSURANCE PROGRAM

An adequate quality assurance procedure should be developed and implemented to ensure that the gathered data are valid. The extent of this procedure should be based on the intended use of the data and the required accuracy level.

1.4 ESTABLISH WEIGH-IN-MOTION EQUIPMENT WARRANTY

The WIM equipment should have a warranty period that is specified by the state that should be reasonable in regards to the equipment and its intended use. For example, a five year warranty on weighpads may be deemed reasonable.

1.5 MANAGE SYSTEM INSTALLATION

The installation process should be monitored to ensure that the installation requirements are met. This process should be overseen by a state official and a vendor representative, ensuring that both the state's and vendor's requirements are met during the installation process.

1.6 CONDUCT PREVENTIVE AND CORRECTIVE MAINTENANCE

A thorough preventive and corrective maintenance program should be established for the site to help to ensure that the expected "site design life" is attained.

1-2
2. TRAFFIC MONITORING

States conduct traffic monitoring for many reasons, including (1) highway planning and design; and (2) motor vehicle enforcement. Weigh-in-Motion (WIM) is a major tool used to collect traffic data.

WIM equipment provides highway planners and designers with traffic volume and classification data by time of day and day of week. In addition, WIM equipment also provides planners and designers with equivalent single axle loadings (ESAL) that heavy vehicles place on pavements. Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities. In summary, the uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues.

The intended use of WIM data should determine the approach the state chooses in developing the WIM data collection site and the resources required to maintain the site over the expected site design life. The following sections present specific successful practices, principles, and “Tricks of the Trade” that states have used to successfully meet an end user’s data, accuracy, quality, and site design life objectives.
3. WEIGH-IN-MOTION SYSTEM DISCUSSION

This section will discuss three types of weigh-in-motion (WIM) systems: bending plate, piezoelectric sensors, and load cell. Information will be presented for each of the WIM technologies. This information comes from either the states that use the systems or the vendors that provide the systems. Table 3.1 shows the WIM system principles that should be considered when selecting a system.

<table>
<thead>
<tr>
<th>WIM System Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Clearly define the required site design life and accuracy performance level.</td>
</tr>
<tr>
<td>3.2 Devote the necessary financial and technical resources to reaching the chosen site design life and performance level.</td>
</tr>
<tr>
<td>3.3 Consider the following aspects of WIM systems when making the selection.</td>
</tr>
<tr>
<td>3.3.1 Sensor type</td>
</tr>
<tr>
<td>3.3.2 Site processor</td>
</tr>
<tr>
<td>3.3.3 Remote Communication Modem</td>
</tr>
<tr>
<td>3.3.4 Operating Software</td>
</tr>
<tr>
<td>3.3.5 Data Output format</td>
</tr>
</tbody>
</table>

The American Society for Testing and Materials (ASTM) "Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method" (ASTM Designation: E 1318-94) classifies WIM systems as Type I, II, III, or IV according to their application and gives related performance and user requirements for each type of system (1). The Standard lists user requirements that should be met to ensure that the WIM system functions properly. The four systems have different speed ranges, data gathering capabilities, and intended applications. Table 3.2 shows the information for the four types of systems. Table 3.3 shows functional performance requirements for WIM systems.
### Table 3.2
ASTM WIM System Classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed Range</strong></td>
<td>16 - 113 km/h (10 - 70 mph)</td>
<td>16 - 113 km/h (10 - 70 mph)</td>
<td>24 - 80 km/h (15 - 50 mph)</td>
<td>24 - 80 km/h (15 - 50 mph)</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>traffic data collection</td>
<td>traffic data collection</td>
<td>weight enforcement station</td>
<td>weight enforcement station</td>
</tr>
<tr>
<td><strong>Number of Lanes</strong></td>
<td>up to four</td>
<td>up to four</td>
<td>up to two</td>
<td>up to two</td>
</tr>
<tr>
<td><strong>Bending Plate</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Piezoelectric Sensor</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Load Cell</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Wheel Load</strong></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Axle Load</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Axle-Group Load</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Gross Vehicle Weight</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Center-to-Center Axle Spacing</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Vehicle Class</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Site Identification Code</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Lane and Direction of Travel</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Date and Time of Passage</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Sequential Vehicle Record Number</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wheelbase (front to rear axle)</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Equivalent Single-Axle Load</strong></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Violation Code</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
### Table 3.3
Functional Performance Requirements for WIM Systems

<table>
<thead>
<tr>
<th>Function</th>
<th>Tolerance for 95% Probability of Conformity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type I</td>
</tr>
<tr>
<td>Wheel Load</td>
<td>± 25%</td>
</tr>
<tr>
<td>Axle Load</td>
<td>± 20%</td>
</tr>
<tr>
<td>Axle-Group Load</td>
<td>± 15%</td>
</tr>
<tr>
<td>Gross Vehicle Weight</td>
<td>± 10%</td>
</tr>
<tr>
<td>Speed</td>
<td>= 2 km/h (1 mph)</td>
</tr>
<tr>
<td>Axle Spacing</td>
<td>= 150 mm (0.5 ft)</td>
</tr>
</tbody>
</table>

*Lower values are not normally a concern in enforcement*

### 3.1 ESTABLISH SYSTEM REQUIREMENTS

The first step in choosing a WIM system is to clearly define the requirements expected from the system and the staff resources necessary to monitor and maintain the system. The “site design life” and the accuracy level are important requirements to consider when selecting WIM equipment. The cost of the system has been shown to directly relate to the overall performance obtained using that system, as shown in the following section.

### 3.2 ECONOMIC ANALYSIS

According to research by Taylor and Bergan, each WIM system provides a different level of accuracy at different system and maintenance costs (2). Table 3.4 shows the economic analysis produced by Taylor. The cost of the system includes the Estimated Initial Cost per Lane and Maintenance. The performance of the systems is given as a percent error on gross vehicle weight (GVW) estimation at highway speeds under ideal, ASTM site conditions. The Estimated Initial Cost per Lane includes the equipment and installation costs. The Estimated Average Cost per Lane is based on a 12-year life plan and includes maintenance. The report did not specify the interest rate that was used in the calculations. According to Caltrans, maintenance can be subdivided into three areas: (1) power and communication, (2) structural, and (3) WIM system. The power and communication area includes the WIM power and phone lines. The structural area includes the roadway pavement and scale frames. A service contract with the vendor covers the maintenance for the WIM system.
Table 3.4

Cost Comparison of WIM Systems

<table>
<thead>
<tr>
<th>WIM System</th>
<th>Performance (Percent error on GVV at highway speeds)</th>
<th>Estimated Initial Cost per Lane (Equipment and Installation)</th>
<th>Estimated Average Cost per Lane (12-year life span including maintenance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezoelectric Sensor</td>
<td>$10%</td>
<td>$9,500</td>
<td>$4,224</td>
</tr>
<tr>
<td>Bending Plate Scale</td>
<td>$5%</td>
<td>$18,900</td>
<td>$4,990</td>
</tr>
<tr>
<td>Double Bending Plate Scale</td>
<td>$3.5%</td>
<td>$35,700</td>
<td>$7,709</td>
</tr>
<tr>
<td>Deep Pit Load Cell</td>
<td>$3%</td>
<td>$52,500</td>
<td>$7,206</td>
</tr>
</tbody>
</table>

Tables 3.5 and 3.6 show an example of a spreadsheet developed for LTPP to estimate the cost of purchasing, installing, operating, and maintaining WIM equipment (7). This example shows the cost of monitoring 100 established sites using both piezoelectric sensors and bending plate scales. The scales are installed on roadways made of both asphalt concrete pavement (ACP) and portland concrete cement (PCC) pavement. The spreadsheet allows for scale replacement, electronics replacement, pavement rehabilitation, calibration, and the necessary office and maintenance staff. The initial cost for this example is $612,000 which includes pavement rehabilitation and initial equipment purchases. The annual cost for this example $2,100,500 which includes pavement rehabilitation and other site maintenance, sensor replacement, electronics replacement, calibration costs, office costs, and travel and per diem costs. The directions for use of this spreadsheet are given in Appendix 2. Table 3.6 is a summary of the example shown in Table 3.5.
<table>
<thead>
<tr>
<th>ITEM</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Sites</td>
<td></td>
</tr>
<tr>
<td>Number of sites monitored</td>
<td>100</td>
</tr>
<tr>
<td>Number needing new scales</td>
<td>12</td>
</tr>
<tr>
<td>Number needing pavement rehab</td>
<td>10</td>
</tr>
<tr>
<td>Percent of initial rehabs that are ACP</td>
<td>50%</td>
</tr>
<tr>
<td>Percent of sites that are ACP</td>
<td>50%</td>
</tr>
<tr>
<td>Percent Bending Plates at existing sites</td>
<td>50%</td>
</tr>
<tr>
<td>Pavement Rehabilitation Cost</td>
<td></td>
</tr>
<tr>
<td>Initial Rehabilitation</td>
<td>$300,000</td>
</tr>
<tr>
<td>ACP rehabilitation</td>
<td>$30,000</td>
</tr>
<tr>
<td>PCC rehabilitation</td>
<td>$30,000</td>
</tr>
<tr>
<td>Equipment Costs</td>
<td></td>
</tr>
<tr>
<td>Initial Equipment Cost</td>
<td>$312,000</td>
</tr>
<tr>
<td>Piezo WDM scale</td>
<td>$10,000</td>
</tr>
<tr>
<td>Annual Sensor Replacement Cost</td>
<td>$82,500</td>
</tr>
<tr>
<td>Piezo WDM scale installation</td>
<td>$10,000</td>
</tr>
<tr>
<td>Annual Electronics Replacement</td>
<td>$75,000</td>
</tr>
<tr>
<td>Piezo sensor cost</td>
<td>$1,500</td>
</tr>
<tr>
<td>Number of piezo sensors per site</td>
<td>2</td>
</tr>
<tr>
<td>Bending plate cost</td>
<td>$12,000</td>
</tr>
<tr>
<td>Bending plate installation</td>
<td>$20,000</td>
</tr>
<tr>
<td>Cost of replacement plates</td>
<td>$3,500</td>
</tr>
<tr>
<td>Number of plates per site</td>
<td>2</td>
</tr>
<tr>
<td>Office computer</td>
<td>$8,000</td>
</tr>
<tr>
<td>Computer needed per site</td>
<td>0.12</td>
</tr>
<tr>
<td>Cost of office software</td>
<td>$15,000</td>
</tr>
<tr>
<td>Percent of new sites using bending plates</td>
<td>50%</td>
</tr>
</tbody>
</table>
Table 3.5 (Continued)
Example of Weigh-in-Motion Costs

<table>
<thead>
<tr>
<th>ITEM</th>
<th>VALUE</th>
<th>ITEM</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Maintenance</td>
<td></td>
<td>Equipment Cost Rehab Sections</td>
<td>$3,000</td>
</tr>
<tr>
<td>Percent of bending plates failing per year</td>
<td>15%</td>
<td>Annual Pavement Rehab</td>
<td>$225,000</td>
</tr>
<tr>
<td>Percent of piezos failing per year</td>
<td>20%</td>
<td>Annual non-rehab Maintenance</td>
<td>$250,000</td>
</tr>
<tr>
<td>Percent of ACP sites needing rehab per year</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of PCC sites needing rehab per year</td>
<td>5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent field electronics needing replacement</td>
<td>15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of field electronics replacement</td>
<td>$5,000</td>
<td>Annual Electronics Replacement</td>
<td>$75,000</td>
</tr>
<tr>
<td>Calibration</td>
<td></td>
<td>Calibration costs</td>
<td>$1,100,000</td>
</tr>
<tr>
<td>Calibration trips per year</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent next to static scales</td>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost per calibration (static scales)</td>
<td>$3,800</td>
<td>Total Calibration Costs</td>
<td>$475,000</td>
</tr>
<tr>
<td>Cost per sst. calibration session</td>
<td>$5,000</td>
<td></td>
<td>$625,000</td>
</tr>
<tr>
<td>Type of alternative method</td>
<td>two vehicles of known weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent with max. calibration trips per year</td>
<td>50%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staffing</td>
<td></td>
<td>Office Costs</td>
<td>$115,000</td>
</tr>
<tr>
<td>Office FTE needed per site</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telephones dollars per site</td>
<td>$350</td>
<td>Total Travel and per diem Costs</td>
<td>$250,000</td>
</tr>
<tr>
<td>Dollar cost of FTE per year</td>
<td>$40,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field FTE per year</td>
<td>4.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dollar cost of field FTE</td>
<td>$50,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel and per diem Costs</td>
<td></td>
<td>Total Travel and per diem Costs</td>
<td>$250,000</td>
</tr>
<tr>
<td>Dollars per year</td>
<td>$500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.6  
Summary of Example Weigh-in-Motion Costs

<table>
<thead>
<tr>
<th>Initial Costs</th>
<th>Annual Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Rehabilitation</td>
<td>Pavement Rehabilitation</td>
</tr>
<tr>
<td>$300,000</td>
<td>$228,000</td>
</tr>
<tr>
<td>Initial Equipment Costs</td>
<td>Other Site Maintenance</td>
</tr>
<tr>
<td>$311,000</td>
<td>$250,000</td>
</tr>
<tr>
<td>Total Initial Cost</td>
<td>Sensor Replacement</td>
</tr>
<tr>
<td>$611,000</td>
<td>$82,500</td>
</tr>
<tr>
<td></td>
<td>Electronics Replacement</td>
</tr>
<tr>
<td></td>
<td>$75,000</td>
</tr>
<tr>
<td></td>
<td>Calibration Costs</td>
</tr>
<tr>
<td></td>
<td>$1,100,000</td>
</tr>
<tr>
<td></td>
<td>Office Costs</td>
</tr>
<tr>
<td></td>
<td>$115,000</td>
</tr>
<tr>
<td></td>
<td>Travel and Per Diem</td>
</tr>
<tr>
<td></td>
<td>$250,000</td>
</tr>
<tr>
<td></td>
<td>Total Annual Costs</td>
</tr>
<tr>
<td></td>
<td>$2,100,500</td>
</tr>
</tbody>
</table>

3.3 BENDING PLATE

Bending Plate WIM systems utilize plates with strain gauges bonded to the underside. As a vehicle passes over the bending plate, the system records the strain measured by the strain gauge and calculates the dynamic load. The static load is estimated using the measured dynamic load and calibration parameters. The calibration parameters account for the influences factors, such as vehicle speed and pavement/suspension dynamics, have on estimating the static weight. This system is classified as an ASTM Type I, II, III, or IV system depending on the intended use of the device and the number of scales placed in the lane. Several vendors provide bending plate WIM systems.

3.3.1 Sensor

Bending Plate WIM systems consist of either one or two scales. The scale or pair of scales is placed in the travel lane perpendicular to the direction of travel. When two scales are used in a lane, one scale is placed in each wheelpath of the traffic lane so that the left and right wheels can be weighed individually. The pair of scales is placed in the lane either side-by-side or staggered by five meters (16 feet). Bending plate systems with one scale placed in either the left or right wheelpath are usually used in low volume lanes.

There are two types of bending plate systems, permanent and portable. The permanent system is discussed in the following section, including a diagram of a typical system layout. The portable system is not high-speed WIM, and therefore will not be discussed in this report.

3-7
Bending Plate WIM systems consist of at least one scale and two inductive loops. The scales are placed in the travel lane perpendicular to the direction of travel. The inductive loops are placed upstream and downstream from the scales. The upstream loop is used to detect vehicles and alert the system of an approaching vehicle. The vehicle speed, which is used to determine the axle spacing, can be determined by three methods: weighpad to inductive loop, weighpad to axle sensor, and weighpad to weighpad, if the weighpads are staggered. If an axle sensor is used to determine the vehicle speed, it is placed downstream of the weighpad. An example of the layout for a bending plate WIM system is shown in Figure 3.1.
3.3.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. A typical WIM system can process over 15,000 trucks a day and collect at least 30 days of continuous raw data for a four lane installation. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.

3.3.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 1,200 bits per second (bps), but preferably at least 9,600 bps. The amount of data collected at the site and the frequency of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.

3.3.4 Operating Software

WIM software includes three separate software packages; on-site software, communications software, and in-house software. The typical on-site software interprets the signals from the WIM scale and generates the on-site files which include information such as:

1. Site Identification
2. Time and Date of Passage
3. Lane Number
4. Vehicle Sequence Number
5. Vehicle Speed and Classification
6. Weight of all Axles or Axle Groups
7. Code for Invalid Measurement
8. Optional Graphic Configuration
9. Equivalent Single Axle Loading (ESAL) value

The typical communications software allows for changes to be made to the on-site software setup including calibration factors from the in-house computer. The typical in-house software generates hard copy reports as well as ASCII files. The software allows reports to be generated on the collected raw vehicle record files. The typical communications and in-house software allow the user to perform the following tasks:

1. Real time vehicle viewing selectable by lane
2. Resetting of the system clock
3.4.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.
3.4.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 2,400 bps, but preferably at least 9,600 bps. The amount of data collected at the site and the frequency of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.

3.4.4 Operating Software

WIM software includes three separate software packages; on-site software, communications software, and in-house software. The typical on-site software interprets the signals from the WIM scale and generates the on-site files which include information such as:

1. Site Identification
2. Time and Date of Passage
3. Lane Number
4. Vehicle Sequence Number
5. Vehicle Speed and Classification
6. Weight of all Axles or Axle Groups
7. Code for Invalid Measurement
8. Optional Graphic Configuration
9. ESAL value

The typical communications software allows for changes to be made to the on-site software setup including calibration factors from the in-house computer. The typical in-house software generates hard copy reports as well as ASCII files. The software allows reports to be generated on the collected raw vehicle record files. The typical communications and in-house software allow the user to perform the following tasks:

1. Real time vehicle viewing selectable by lane
2. Resetting of the system clock
3. Monitor system memory in terms of storage remaining
4. Setup and initiate the generation of summary reports on data previously collected by the system
5. View generated reports
6. Generate and view error reports including time down, system access, auto-calibration, and improperly completed records
7. Transfer selected raw data files or generated reports from the site system to the office host computer
8. Purge old data files from the system
3.4.5 Data Output Format

The typical in-house software is capable of generating output reports in the FHWA's Traffic Monitoring Guide Card Format. The in-house software is also capable of generating daily, weekly, monthly, or continuous summary reports in hourly increments based on vehicle speed, classification, ESAL, and weight summaries on a lane by lane or directional basis. The typical in-house software can also generate reports on errors, auto-calibration, site history, calibration history, and overweight vehicles. The auto-calibration report is an important report for piezoelectric WIM systems.

3.5 LOAD CELL

Load Cell WIM systems utilize a single load cell with two scales to detect an axle and weigh both the right and left side of the axle simultaneously. As a vehicle passes over the load cell, the system records the weights measured by each scale and sums them to obtain the axle weight.

3.5.1 Sensor

The typical Load Cell WIM systems consist of a single load cell placed across the traffic lane. The single load cell has two in-line scales that operate independently. Off-scale detectors are integrated into the scale assembly to sense any vehicles off the weighing surface. This system is classified as an ASTM Type I, II, III, or IV system depending on the site design.

The typical system consists of the load cell and at least one inductive loop and one axle sensor. The load cell is placed in the travel lane perpendicular to the direction of travel. The inductive loop is placed upstream of the load cell to detect vehicles and alert the system of an approaching vehicle. If a second inductive loop is used, it is placed downstream of the load cell to determine axle spacings, which is used to determine the vehicle speed. The axle sensor is placed downstream of the load cell to determine axle spacings and vehicle speed. An example of the layout for a load cell WIM system is shown in Figure 3.3 on the following page.

3.5.2 Site Processor

Processing units are used to sort and analyze the information obtained by the roadway sensors. The on-site processor can be provided by either the state or the vendor. Caltrans evaluated both options and determined that the vendor-provided processor is preferable as long as it is compatible with the state-provided in-house computer. The vendor-provided on-site processor eliminates the issue of compatibility between the sensors and the state-provided processor.
3.5.3 Remote Communication Modem

The modem used to collect data to monitor the system needs to be operable on a standard telephone line and capable of at least 1,200 bps, but preferably at least 9,600 bps. The amount of data collected at the site and the frequency of downloading should be considered when selecting the telephone line and modem. In general, the download process will be quicker as the quality of the selected phone line and modem increases. The remote communication can be done using either telephone lines or cellular technology.
History and operational feedback

- historical and operational feedback
- software is an essential component of the system's performance.
- feedback received from users and system administrators should be analyzed and incorporated into the system's software.
- System administrators should be encouraged to provide feedback on the system's performance.
- The system's software should be designed to be user-friendly and easy to use.
- Regular updates and patches should be provided to the system's software to address any issues or bugs.
- The system's software should be thoroughly tested before release.
- The system's software should be regularly monitored and updated to ensure it remains effective.
- The system's software should be designed with security in mind.
- The system's software should be designed to be scalable and able to handle increases in workload.
- The system's software should be designed to be maintainable and easy to update.

3.4.2 Data Output Format

8. Print old data from the system
7. Import selected records from the system to the office
6. Generate new reports including the data collected by
5. Generate reports from previously collected data
4. Import data from external sources into the system
3. Generate summary reports on data collected by
2. Generate reports from the system
1. Read existing databases and extract data

The system's communication software allows for changes to be made to the software.
4. SITE DISCUSSION

According to the American Society for Testing and Materials (ASTM) standard entitled Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Methods (ASTM Designation E 1318-94), WIM users must provide and maintain an adequate operating environment for the system to perform properly (1). Several factors that influence the performance of a WIM system are in the geometric design and pavement condition of the roadway and the overall site location. These factors influence the dynamic behavior of the vehicle and thus influence the accuracy of the estimate of the static weight made by the WIM system (4). ASTM Standard, Section 6 has guidelines to be followed when evaluating a possible location for a WIM site. Table 4.1 shows the WIM site principles that should be considered when selecting a location for a WIM system.

4.1 WIM Site Selection

"The quality of the WIM data is dependent upon the quality of the site selected."

... Caltrans.

<table>
<thead>
<tr>
<th>WIM Site Principles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Select the site based on the required site design life and accuracy performance level.</td>
</tr>
<tr>
<td>4.2</td>
<td>Evaluate the geometric design of the location on the following qualities.</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Determine if the horizontal curvature is acceptable.</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Determine if the roadway grade is acceptable.</td>
</tr>
<tr>
<td>4.2.3</td>
<td>Determine if the cross slope is acceptable.</td>
</tr>
<tr>
<td>4.2.4</td>
<td>Determine if the lane is wide enough and marked properly.</td>
</tr>
<tr>
<td>4.3</td>
<td>Determine if the pavement is adequate or if the pavement should be replaced.</td>
</tr>
<tr>
<td>4.4</td>
<td>Evaluate the site location on the following qualities.</td>
</tr>
<tr>
<td>4.4.1</td>
<td>Determine the availability of access to power and phone.</td>
</tr>
<tr>
<td>4.4.2</td>
<td>Determine if there is an adequate location for the controller cabinet.</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Determine if the site provides adequate drainage.</td>
</tr>
<tr>
<td>4.4.4</td>
<td>Determine the traffic condition at the site.</td>
</tr>
</tbody>
</table>
4.1 SITE SELECTION

The site selected for a WIM system should be based on meeting the required "site design life" and accuracy necessary to support the user. In order to meet these requirements, the geometric design, pavement condition, and general characteristics of a potential site should be considered. Selecting an adequate site for the WIM location is a very important part of meeting the established WIM system requirements.

4.2 GEOMETRIC DESIGN

The geometric design of a roadway is an important factor that provides a foundation for using dynamic load measurements to estimate static loads accurately. This is due to the influence longitudinal and transverse offsets have on the behavior of a vehicle. The ASTM Standard sets guidelines for the horizontal curvature, the longitudinal gradient, the cross (lateral) slope, and the width of the paved roadway lane. The guidelines are set for each type (Type I, Type II, Type III, and Type IV) of WIM system installation. Table 4.2 shows the ASTM Standard geometric design requirements for each type of system.

Table 4.2
ASTM Standard (E 1318-94) Geometric Design Requirements

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal Curvature</strong></td>
<td>radius ≥1740m</td>
<td>radius ≥1740m</td>
<td>radius ≥1740m</td>
<td>radius ≥1740m</td>
</tr>
<tr>
<td></td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
</tr>
<tr>
<td><strong>Roadway Grade</strong></td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 1%</td>
</tr>
<tr>
<td></td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
</tr>
<tr>
<td><strong>Cross Slope (lateral)</strong></td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 1%</td>
</tr>
<tr>
<td></td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
</tr>
<tr>
<td><strong>Lane Width</strong></td>
<td>3 to 4.5m</td>
<td>3 to 4.5m</td>
<td>3 to 4.5m</td>
<td>3 to 4.5m</td>
</tr>
<tr>
<td></td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
<td>46m before/after</td>
</tr>
</tbody>
</table>

4.2.1 Horizontal Curvature

The maximum allowable horizontal curvature for the roadway is identical for all four types of WIM system installations. The roadway has to have a horizontal radius of not less than 1740 meters (5,700 feet) for a distance of 45 meters (150 feet) before and after the WIM sensor. The radius is measured at the centerline of the lane in which the sensor is installed.

4.2.2 Roadway Grade

4-2
The maximum allowable roadway grade is the same for Type I, Type II, and Type III WIM systems. For these systems the roadway grade can not exceed two percent for a distance of 46 meters (150) feet before and after the sensor. For a Type IV system, the roadway grade can not exceed one percent for the 91 meter (300 foot) distance. No documentation was found for the minimum allowable amount of longitudinal waves in the roadway approaching the sensor.

4.2 Axle Weight Transfer and Roadway Grade

"The major data problem effected by installing a WIM system on a grade, say anything in excess of one percent, is the weight transfer from the steer axle to the drive axle of the loaded truck." — Caltrans.

4.2.3 Cross Slope

The maximum allowable cross (lateral) slope of the road surface is the same for the first three types of WIM systems. For these systems the cross slope cannot exceed two percent for a distance of 46 meters (150 feet) before and after the sensor. The road surface 46 meters (150 feet) before and after a Type IV system cannot have a cross slope in excess of one percent.

4.2.4 Lane Width

A guideline for the width of the paved roadway lane is the same for the four types of systems. For 46 meters (150 feet) before and after the sensor the width needs to be between 3 and 4.5 meters (10 and 14 feet) depending on scale width. For Types III and IV the lane must be marked with a solid white line, 100 to 150 millimeters (4 to 6 inches) thick, running parallel to the lane. Additionally, one meter (three feet) of clear space must be provided on each side of the WIM sensor lane when the system is used on a ramp.

4.3 PAVEMENT CONDITION

The roadway pavement condition is important in the reduction of vehicle bounce. According to Deakin, "Vehicle bounce, resulting in variations in the vertical load imposed by a moving axle, increases with road roughness, leading to greater variations in the instantaneous axle loads (5)."

The guideline set forth in the ASTM Standard E 1318-94 states that for a distance of 46 meters (150 feet) before and after the sensor the roadway surface "shall be maintained in a condition such that a 130 millimeter (6 inch) diameter circular plate 3 millimeters (0.125 inches) thick cannot be passed beneath a 6 meter (20 foot) long straightedge (I)." The standard also states that a foundation must be provided and maintained to accommodate the sensors. The Oregon Department of Transportation uses a profilograph to measure the pavement roughness, shown in Figure 4.1 on the following page.
Caltrans' successful practice requires that all WIM systems be installed in Portland cement concrete (PCC) pavement to provide roadway stability, durability, and smoothness throughout the 10 to 15 year expected equipment life. Caltrans guidelines establish that the PCC pavement should be the thickness shown on the construction plans or 300 millimeters (one foot), whichever is greater. If the WIM system is to be used on a roadway that is asphalt concrete (AC) pavement, the AC pavement must be replaced with PCC pavement for a minimum distance of 15 meters (50 feet) before and 7.5 meters (25 feet) after the sensor (6). The base structure at the sensor location follows the established parameters for that roadway. The Draft Long-Term Pavement Performance (LTPP) Program Specification sets a minimum pavement strength using a falling weight deflectometer (FWD) test. Using an applied load of 4,080 kilograms (9,000 pounds), the pavement deflection must be between 0.305 and 0.457 millimeters (0.012 and 0.018 inches) and the area of the deflection basin must be 17400 square millimeters (27 square inches) or greater. The Draft LTPP Standard notes that the pavement must be designed to operate near these strength levels throughout the year, even during periods when the pavement structure is weakened by high moisture content or thaw conditions (7).

4.3 Pavement Condition

"If the WIM equipment is not installed in pavement that is both stable and smooth, the estimates of static weight will not be very accurate."... Caltrans.
4.4 SITE LOCATION

The location of a WIM site should be based on more than just the need for truck traffic data (9). The site needs to be located in an area with specific qualities including:

1. Availability of access to power and phone
2. Adequate location for controller cabinet
3. Adequate drainage
4. Traffic conditions

4.4.1 Availability of Access to Power and Phone

The site should have access to an AC power source and telephone utilities. Solar power and cellular phones can be used if utilities are not available. The power source and phone service used at a site is dependent upon the amount of truck data collected at the site. For more active sites Caltrans determined that wired phone service would be more cost effective than cellular (wireless) service.

4.4.2 Adequate Location for Controller Cabinet

The controller cabinet should be located so that it will function throughout the design life of the site. The cabinet needs to be in an area so that:

1. It will not be subjected to runoff during heavy rains or to standing or moving water from irrigation or drainage facilities
2. It cannot be hit by a vehicle leaving the roadway, preferably behind a guardrail
3. It is accessible with a clear line of sight to the sensors
4. It can be serviced without endangering the technician(s)

Items three and four are important because technicians may need to spend time at the controller cabinet during system testing, calibration, and maintenance.

4.4.3 Adequate Drainage

Drainage should be adequate for the controller cabinet, junction boxes, and WIM sensors. The site should not be located in an area subjected to flooding. The water can be directed to the roadside's outside slope or an existing drainage facility.
4.4.4 Traffic Conditions:

WIM systems should be in an area of free traffic flow with good night distances. The traffic conditions should be such that:

1. Stop and go traffic is minimized
2. Slow moving traffic is minimized
3. Lane changing is minimized
4. Passing on two lane roads is minimized
5. SYSTEM INSTALLATION

The American Society for Testing and Materials (ASTM) Standard (E 1318-94) requires that the weigh-in-motion (WIM) equipment be installed and maintained in accordance with the recommendations of the system vendors. This section will discuss techniques and additions that states with successful WIM systems implement during the installation process. The states with successful WIM systems were selected using information from the Long Term Pavement Performance (LTTP) program. The states selected for each WIM systems discussed in this report are California for bending plate, Missouri for piezoelectric sensors, and Oregon for load cell. The discussion will not be limited to these states; successful practices and procedures from other state transportation departments and the LTTP program will also be described. The discussion will cover only the installation procedures for the WIM scales and not the additional inductive loops and axle sensor.

5.1 Installation

"Proper installation is a key element in ensuring the WIM system will function within specifications throughout the site design life."... Caltrans.

The Draft LTTP Specification lists several installation requirements which are in accordance with many of the vendor recommendations. The Draft LTTP requirements are:

1) Installation must be done in good weather, not wet, freezing, or hot conditions
2) The sensors must be flush with the road surface, no more than one millimeter separating the top of the sensor from the road surface
3) The equipment must be protected from water and dust
4) The equipment cabinet must protect the system electronics from temperature, dust, humidity, and insect and rodent infestation
5) The equipment must be protected from lightning and power surges
6) The equipment must be installed so that routine maintenance can occur without disruption of data collection

5.1 OBJECTIVES OF "SUCCESSFUL PRACTICES" INSTALLATIONS

The installation section of the WIM manual is intended to focus attention on techniques or additional steps that states with successful WIM systems implement during the vendor\'s recommended installation process. For each WIM system discussed in this manual, an installation checklist of the required steps is included to show the installation process. The objective of the installation process is to provide a properly functioning WIM site for the established site design life. The WIM site design life should be established by the state. For example, if a state transportation department establishes an expected site design life of 10 to 15 years for bending plate WIM systems, the installation process should be established to provide a 10 to 15 year site design life. To ensure this objective is met, the general installation principles shown in Table 5.1 should be followed.
### Table 5.1
Installation Principles Checklist

<table>
<thead>
<tr>
<th>Installation Principles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2 Overall Process</td>
<td></td>
</tr>
<tr>
<td>5.2.1 A vendor representative should be on-site to ensure vendor requirements are met</td>
<td></td>
</tr>
<tr>
<td>5.2.2 A State representative should be on-site to ensure state requirements are met</td>
<td></td>
</tr>
<tr>
<td>5.2.3 Pre-construction meetings should be held before lane closure.</td>
<td></td>
</tr>
<tr>
<td>5.2.4 All necessary equipment, materials, and WIM components should be on-site before starting the job.</td>
<td></td>
</tr>
<tr>
<td>5.2.5 Complete site plans should be available on-site to ensure proper placement of equipment.</td>
<td></td>
</tr>
<tr>
<td>5.2.6 Installation team needs to make a good estimate of the time required to complete the work and lanes should be opened on schedule to accommodate traffic.</td>
<td></td>
</tr>
<tr>
<td>5.2.7 Junction box and roadside cabinet need to be placed away from water collection areas.</td>
<td></td>
</tr>
<tr>
<td>5.2.8 An accurate set of “as built” plans should be developed for future construction and maintenance work.</td>
<td></td>
</tr>
</tbody>
</table>

### 5.2 WEIGH-IN-MOTION SYSTEM INSTALLATION

During the installation process the principles listed in Table 5.1 need to be followed regardless of the type of WIM system being installed. A representative from both the equipment vendor and the state need to be present during the process to ensure that their requirements are met. A pre-construction meeting or meetings should be held to discuss the installation plan and review the equipment list. All of the necessary equipment, materials, WIM components, and site plans should be on-site and tested before the procedure is started. Checking the equipment and WIM components will save time and money not only during the installation process but also throughout the life of the site. The site must provide proper drainage away from the WIM components. The junction boxes and roadside cabinet must be placed away from water collection areas.

5.2 Sensor Test

"Identifying a 'bad' weighpad or sensor prior to installation will save time and money."...Caltrans.

---

5-2
5.3 BENDING PLATE INSTALLATION PROCESS

The detailed installation procedures for the bending plates and loops are well described in manuals provided by the vendors. This section will highlight areas of the installation process considered important to the successful practice managed by Caltrans. Table 5.2 shows the bending plate installation checklist to aid in the discussion.

5.3.1 Preparing the Road

Road preparation is the initial step in the installation process. In order to reduce the effects of pavement roughness, Caltrans' successful practice requires that the Portland cement concrete (PCC) pavement 46 meters (150 feet) before and 23 meters (75 feet) after the sensor location be ground in accordance with the provisions in Section 42-2, “Grind,” of the Caltrans Specification (6). Grinding specifications require that the distance between the roadway surface and the bottom edge of a straightedge be no more than 3 millimeters (0.01 feet). Asphalt concrete is replaced with PCC for a minimum distance of 15 meters (50 feet) prior to and 7.5 meters (25 feet) after the scale location. The asphalt concrete is ground 7.5 meters (25 feet) before and after the new pavement.

5.3.2 Excavating the Pit Area

The pit area should be marked on the pavement surface using the scale frame as a guide. In addition to cutting the outlines marked on the pavement, lines should be cut inside each outline in a checkerboard style to ease excavation. The concrete pavement must be wet during the cutting process. After the debris has been removed from the pit area, use a vacuum and air compressor to finish the cleaning process. The pit must be clean and dry for the epoxy to reach maximum adhesion, so the use of water to clean the pit area will delay installation.

5.3.3 Frame Installation

Supports are attached to the top of the scale frame to level the frame with the road surface and to make moving the frame easier. The frame is placed in the pit area and anchor holes are started using the frame as a template. The frame is then removed and the anchor holes are drilled to the appropriate dimensions.

5.3 Frame Installation

"At the time that the frame alignment has been finalized for the marking of anchor hole positions, paint the outline of the frame supports on the pavement surface to ensure frame/hole alignment for the epoxy pour."...Caltrans.

5-3
Table 5.2
Bending Plate Installation Checklist

<table>
<thead>
<tr>
<th>Step</th>
<th>Installation Action Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial Test</td>
</tr>
<tr>
<td></td>
<td>a. Resistance test performed before equipment is brought on-site.</td>
</tr>
<tr>
<td>2</td>
<td>Preparing the Road</td>
</tr>
<tr>
<td></td>
<td>a. Pavement prepared following the site specifications, including concrete replacement and grinding.</td>
</tr>
<tr>
<td></td>
<td>b. Saw cutting for pavement components done with care and according to specification.</td>
</tr>
<tr>
<td></td>
<td>c. Concrete removal from scale pit area was done with care to ensure proper pit width and depth.</td>
</tr>
<tr>
<td></td>
<td>d. Anchor holes were drilled with proper alignment, diameter, and depth.</td>
</tr>
<tr>
<td></td>
<td>e. Scale pit area was clean and dry before frame placement.</td>
</tr>
<tr>
<td></td>
<td>f. Proper drainage provided from pit area.</td>
</tr>
<tr>
<td>3</td>
<td>Installing Scale Frames in the Scale Pit</td>
</tr>
<tr>
<td></td>
<td>a. Installed the lead and drainage conduits so that the drainage conduit was lower.</td>
</tr>
<tr>
<td></td>
<td>b. Installed the conduits so that they are not obstructed.</td>
</tr>
<tr>
<td></td>
<td>c. Installed the pull rope in the lead conduit so that it is accessible and free from obstructions, snags, and excessive cable slack.</td>
</tr>
<tr>
<td></td>
<td>d. Sealed the lead and drainage conduits so that epoxy could not enter during epoxy placement.</td>
</tr>
<tr>
<td></td>
<td>e. Scale frames placed so that scales would be flush with road surface.</td>
</tr>
<tr>
<td></td>
<td>f. Epoxy components kept within the manufacturer’s recommended temperature range.</td>
</tr>
<tr>
<td></td>
<td>g. Each scale frame was properly grounded.</td>
</tr>
<tr>
<td></td>
<td>h. Epoxy placed with care to ensure that conduits and scale frames were stable.</td>
</tr>
<tr>
<td>4</td>
<td>Installing Scale Pads in the Scale Frame</td>
</tr>
<tr>
<td></td>
<td>a. Avoided puncturing lead wires when placing scale pads.</td>
</tr>
<tr>
<td></td>
<td>b. Installed the scale pads flush with roadway surface.</td>
</tr>
<tr>
<td></td>
<td>c. Tightened and torqued bolts to vendor specification.</td>
</tr>
<tr>
<td></td>
<td>d. Sealed the system components to prevent possible damage due to moisture and dust.</td>
</tr>
<tr>
<td>5</td>
<td>Final Test</td>
</tr>
<tr>
<td></td>
<td>a. Performed resistance test to ensure lead cables were undamaged.</td>
</tr>
</tbody>
</table>
Install the shoulder conduits for cabling and drainage. The drainage conduit must be lower than the cabling conduit and be sloped a minimum of one percent to ensure water will flow away from the scales. It may also be necessary, depending upon the vendor installation method, to install a conduit where two frames meet in the roadway to facilitate drainage and the pulling of lead-in cables beneath the scale frames. If required by the WIM vendor, install a grounding rod in the shoulder junction box for connection to the scale frame through the cabling conduit.

Typically, mortar "dams" are constructed around the inside of the scale frames to contain the epoxy under the frames. The epoxy can be poured in one of two ways. Either place the frame into the pit area first and then pour the epoxy around the frame or pour the epoxy into the pit area to a pre-determined level and force the frame into the epoxy. In either case cover all holes in the scale frames with duct tape. This is done to prevent the epoxy from entering the frame holes when it is placed in the pit.

5.4 Conduit and Drain
"Ensure that the mortar dams are constructed such that the shoulder conduit and drain are completely encased in epoxy with no voids under the scale frame." ... Caltrans

5.5 Leveling
"When setting the scale frames into the pit, make sure that there is no debris between the bottom of the supports and the top of the pavement surface." ... Caltrans.

Clean the pit area and the scale frames of any excess epoxy by scraping off any material on the scale frames. Finish the cleaning process with a vacuum and an air compressor.

5.3.4 Final Test

Once the scales are in place, they need to be tested to check for possible damage during installation. Resistance checks should be performed on the lead-in cables to check for damage and excitation. The resistance will increase as the length of the lead-in cable increases. The resistance will therefore increase at the roadside cabinet, depending on the distance to the cabinet. A fully installed bending plate scale is shown in Figure 5.1 on the following page. The painted outline of the frame supports can also be seen in this picture.

5.6 Lead Wires
"During the installation process don't pinch the lead wires. Double check to make sure the lead wires are not cut or shorted." ... Caltrans
Figure 5.1 Installed Bending Plate Scale
5.4 PIEZOELECTRIC SENSOR INSTALLATION PROCESS

The detailed installation procedures for piezoelectric sensors and loops are well described in manuals provided by the vendors. This section will highlight areas of the installation process considered important to the successful practice managed by the Missouri Department of Transportation (DOT). Table 5.3 shows the installation checklist for piezoelectric sensor installation.

<table>
<thead>
<tr>
<th>Step</th>
<th>Installation Action Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initial Test</td>
<td></td>
</tr>
<tr>
<td>a. Checked the sensor for dents or abrasions.</td>
<td></td>
</tr>
<tr>
<td>b. Tested the resistance using a multimeter.</td>
<td></td>
</tr>
<tr>
<td>c. Tested the voltage output for a voltage deflection by stepping on the sensor.</td>
<td></td>
</tr>
<tr>
<td>2. Preparing the Road</td>
<td></td>
</tr>
<tr>
<td>a. Pavement prepared according to site specifications, including concrete replacement and grinding.</td>
<td></td>
</tr>
<tr>
<td>b. Sensors placed in accordance with the site layout plan.</td>
<td></td>
</tr>
<tr>
<td>c. Saw cutting for in-pavement components was done with care and according to specifications.</td>
<td></td>
</tr>
<tr>
<td>d. Concrete removal from the slots was done with care to ensure proper hole width and depth.</td>
<td></td>
</tr>
<tr>
<td>e. Slots were clean and dry before sensor placement.</td>
<td></td>
</tr>
<tr>
<td>3. Installing Sensor in the Main Slot</td>
<td></td>
</tr>
<tr>
<td>a. Attached installation brackets to sensor.</td>
<td></td>
</tr>
<tr>
<td>b. Placed part of lead-in cable into lead-in slot and secure with caulking compound.</td>
<td></td>
</tr>
<tr>
<td>c. Filled main slot halfway with epoxy and carefully placed sensor in epoxy to avoid air pockets.</td>
<td></td>
</tr>
<tr>
<td>d. Placed weights on installation brackets to minimize sensor float.</td>
<td></td>
</tr>
<tr>
<td>e. Once the epoxy cured, removed the brackets and finished filling the main slot.</td>
<td></td>
</tr>
<tr>
<td>f. Placed the lead-in cable in the lead-in slot and secured it with loop sealant.</td>
<td></td>
</tr>
<tr>
<td>4. Final Test</td>
<td></td>
</tr>
<tr>
<td>a. Tested the resistance using a multimeter.</td>
<td></td>
</tr>
<tr>
<td>b. Tested the voltage output for a voltage deflection by driving a truck over the sensor.</td>
<td></td>
</tr>
</tbody>
</table>
5.4.1 Initial Test

Prior to installing the sensor in the roadway an initial test of the sensor should be made. This will ensure that the sensor is working properly so that time and money is not wasted installing a defective sensor.

5.4.2 Sensor Layout and Slot Cutting

Once the sensor locations are determined for the site, slotted aluminum templates for the sensors are placed on the roadway according to site layout plans. Florescent orange paint is then sprayed on the templates to mark where the pavement cuts will be made for the sensor slots. Figure 5.2 shows the florescent orange paint being sprayed onto positioned templates (9). Once the cuts have been made the slots need to be cleaned using a wire brush, a vacuum, and an air compressor.

5.7 Slot Condition

"It is important to make sure that the slot is clean and dry to ensure that the epoxy attain maximum adhesion." ....IRD

Figure 5.2 Positioning and Painting of Sensor Templates
5.5 LOAD CELL INSTALLATION PROCESS

The detailed installation procedures for load cell scales are well described in manuals provided by the vendor. This section will highlight areas of the installation process considered important to the successful practice managed by the Oregon DOT. Table 5.4 shows the installation checklist for load cell scale installation.

5.5.1 Initial Test

Prior to installing the scales, resistance checks should be performed on the scale and lead-in cables to check for cable damage, excitation, and proper attachments.

5.5.2 Preparing the Road

Road preparation is the initial step in the installation process. The Oregon DOT attempts to follow the ASTM Standard (E 1318-94) for pavement condition. In order to reduce the effects of pavement roughness, the Oregon DOT requires that the pavement 18 meters (60 feet) before and 12 meters (40 feet) after the sensor location should be ground in accordance with State specifications (II). In addition, the pavement 32 meters (100 feet) before the 18 meters of ground pavement should be milled in accordance with State specifications. If the load cell scale is installed in an asphalt concrete roadway, an 18 to 21 meter (60 to 70 foot) portland cement concrete slab is placed in the roadway before and after the scale location. The concrete is then ground to the State specifications. Pavement grinding is shown in Figure 5.3.

![Figure 5.3](imageurl)
Grinding
Table 5.4
Load Cell Scale Installation Checklist

<table>
<thead>
<tr>
<th>Step</th>
<th>Installation Action Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial Test</td>
</tr>
<tr>
<td>a</td>
<td>Performed resistance checks on the scales and lead-in cables.</td>
</tr>
<tr>
<td>b</td>
<td>Checked lead-in cables for possible damage and proper attachment.</td>
</tr>
<tr>
<td>2</td>
<td>Preparing the Road</td>
</tr>
<tr>
<td>a</td>
<td>Pavement prepared in accordance with the site specifications, including concrete replacement and grinding.</td>
</tr>
<tr>
<td>b</td>
<td>Saw cutting for in-pavement components done with care and according to specification.</td>
</tr>
<tr>
<td>c</td>
<td>Concrete removal from scale pit area was done with care to ensure proper hole width and depth.</td>
</tr>
<tr>
<td>d</td>
<td>Scale pit area was clean and dry before frame placement.</td>
</tr>
<tr>
<td>e</td>
<td>Proper drainage provided from pit area.</td>
</tr>
<tr>
<td>3</td>
<td>Preparing the Pit to Receive the Scale Frame:</td>
</tr>
<tr>
<td>a</td>
<td>Rebar matting prepared in accordance with site specifications.</td>
</tr>
<tr>
<td>b</td>
<td>Dowels placed according to site specifications, only used for concrete roads.</td>
</tr>
<tr>
<td>d</td>
<td>Preparing the Scale Frames:</td>
</tr>
<tr>
<td>a</td>
<td>J-bars installed in accordance with the site specifications.</td>
</tr>
<tr>
<td>b</td>
<td>Jackscrews installed in accordance with the site specifications.</td>
</tr>
<tr>
<td>c</td>
<td>Leveling legs installed in accordance with the site specifications.</td>
</tr>
<tr>
<td>5</td>
<td>Installing Scale Frames into the Scale Pit</td>
</tr>
<tr>
<td>a</td>
<td>Insert scale frames so that J-bars fit in rebar matting and connected scale frames.</td>
</tr>
<tr>
<td>b</td>
<td>Cabling conduit connected between the scale areas.</td>
</tr>
<tr>
<td>c</td>
<td>Drainage conduit installed lower than cabling conduit and at a minimum of one percent slope.</td>
</tr>
<tr>
<td>d</td>
<td>Covered all bearing pads and conduit openings so that concrete would not enter during placement.</td>
</tr>
<tr>
<td>e</td>
<td>Grounded the scale frames.</td>
</tr>
<tr>
<td>f</td>
<td>Leveled the scale frames with the road surface and adjusted for lateral twisting.</td>
</tr>
<tr>
<td>g</td>
<td>Secured the scale frame with the jackscrews.</td>
</tr>
<tr>
<td>h</td>
<td>Poured concrete into scale pit area through the frame up to the bottom of the frame and vibrated concrete.</td>
</tr>
<tr>
<td>i</td>
<td>Poured concrete between frame and pit edge up to the road surface, but do not vibrate.</td>
</tr>
<tr>
<td>j</td>
<td>Finished concrete in accordance to site specifications and allowed 18- to 24-hour curing time.</td>
</tr>
</tbody>
</table>
### Table 5.4 (Continued)
**Load Cell Scale Installation Checklist**

<table>
<thead>
<tr>
<th>Step</th>
<th>Installation Action Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Cleaning up the Frame Installation</td>
</tr>
<tr>
<td></td>
<td>a) Cleaned the scale pit area and scale frame of any spilled concrete.</td>
</tr>
<tr>
<td></td>
<td>b) Uncovered bearing pads and conduit openings.</td>
</tr>
<tr>
<td></td>
<td>c) Grinded drainage conduit flange with bottom of scale frames.</td>
</tr>
<tr>
<td>7</td>
<td>Preparing the Single Load Cell Scale Pads</td>
</tr>
<tr>
<td></td>
<td>a) Carefully removed the temporary shipping plates, load cell hatch, load cell and protective plates from the scales.</td>
</tr>
<tr>
<td></td>
<td>b) Removed the threaded shipping plugs from the pre-load spring holes.</td>
</tr>
<tr>
<td></td>
<td>c) Greased all o-rings and bearing pads with a multi-purpose, non-corrosive grease.</td>
</tr>
<tr>
<td>8</td>
<td>Installing the Single Load Cell Scale Pads into the Frame</td>
</tr>
<tr>
<td></td>
<td>a) Carefully lowered the scale pads into the frame in a level position.</td>
</tr>
<tr>
<td></td>
<td>b) Properly positioned the scale pads with the rounded corners out.</td>
</tr>
<tr>
<td></td>
<td>c) Secured the scales with bolts tightened and torqued to vendor specifications.</td>
</tr>
<tr>
<td></td>
<td>d) Avoided pinching wires when installing the scale pads and load cells.</td>
</tr>
<tr>
<td></td>
<td>e) Poured miflins into the load cell cavity.</td>
</tr>
<tr>
<td></td>
<td>f) Inserted the load cell into the load cell cavity.</td>
</tr>
<tr>
<td></td>
<td>g) Greased the top o-ring.</td>
</tr>
<tr>
<td></td>
<td>h) Replaced and secured the load cell hatch cover and tightened and torqued it to vendor specifications.</td>
</tr>
<tr>
<td>9</td>
<td>Testing the Operation of the Load Cell</td>
</tr>
<tr>
<td></td>
<td>a) Connected the load cell to a 10-volt DC source for testing.</td>
</tr>
<tr>
<td></td>
<td>b) Measured the output and added 2 to 5 mV to obtain a target reading for pre-load springs.</td>
</tr>
<tr>
<td></td>
<td>c) Tightened the pre-load springs in accordance with vendor specifications to target reading.</td>
</tr>
<tr>
<td></td>
<td>d) Installed sealing plugs on pre-load springs.</td>
</tr>
<tr>
<td></td>
<td>e) Installed coast plugs on all bolt holes.</td>
</tr>
<tr>
<td>10</td>
<td>Final Test</td>
</tr>
<tr>
<td></td>
<td>a) Checked the output voltage of the load cell for compliance with site specifications.</td>
</tr>
<tr>
<td></td>
<td>b) Resistance check made on the off-scale sensor and lead-in cables.</td>
</tr>
</tbody>
</table>
5.5.3 Installing the Load Cell Scale

The Oregon DOT contracts the WIM site preparation and equipment installation to a prime contractor. An Oregon DOT inspector is on site to ensure that the state's specifications are met (11). A fully installed load cell scale is shown in Figure 5.4. Since this load cell is located on a ramp that can be closed to traffic, the roadside cabinet is not as protected as it would be on a traffic lane.

![Figure 5.4 Installed Load Cell Scale](image)

Figure 5.4 Installed Load Cell Scale
6. SYSTEM CALIBRATION

Calibration is used to ensure that the estimation of the static weight produced by the weigh-in-motion (WIM) system is as close to the static weight as possible. A system is calibrated to offset the effects of site conditions such as pavement temperature, vehicle speed, and pavement conditions. These factors can influence the weight estimated by the system. Calibration may be done by comparing the estimation from the WIM system to the actual static weight of a number of different types of trucks. The American Society for Testing and Materials (ASTM) Standard Specification E 1318-94 concerning highway WIM systems lists the ASTM recommendations for the calibration procedure, which includes the acceptance and initial calibration processes (I). Table 6.1 shows the system calibration principles that should be considered.

Table 6.1
System Calibration Principles Checklist

<table>
<thead>
<tr>
<th>System Calibration Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Follow a set initial calibration procedure.</td>
</tr>
<tr>
<td>6.2 Perform two-part calibration procedure; acceptance and testing.</td>
</tr>
<tr>
<td>6.2.1 Perform acceptance testing.</td>
</tr>
<tr>
<td>6.2.1.1 Perform a system component operations check.</td>
</tr>
<tr>
<td>6.2.1.2 Perform an initial calibration.</td>
</tr>
<tr>
<td>6.2.1.3 Perform a 72-hour continuous operation check.</td>
</tr>
<tr>
<td>6.2.2 Perform fine tuning or recalibration when the outcome of the quality assurance data analysis indicates recalibration is necessary.</td>
</tr>
<tr>
<td>6.3 Automatic recalibration</td>
</tr>
</tbody>
</table>

6.1 CALIBRATION PROCEDURE

A calibration procedure should be established and followed to ensure that the WIM system performs properly during the site design life. This procedure includes the acceptance testing and recalibration (fine tuning) processes.

6.2 CALTRANS SUCCESSFUL PRACTICE: CALIBRATION PROCEDURE FOR BENDING PLATE WEIGH-IN-MOTION

Caltrans has established a calibration procedure for bending plate WIM systems during their 10-plus years of experience collecting WIM data (15). The procedure is divided into two parts, acceptance testing and fine tuning. The acceptance testing is done after installation and must be completed before the system is brought on-line. The fine tuning or recalibration is done...
throughout the design life of the site.

6.2.1 Acceptance Testing

The acceptance testing is done in three stages: the system component operation check, the initial calibration process, and the 72-hour continuous operation check. Once the acceptance testing is completed on the system, it can be brought on-line and data can be collected and used.

6.2.1.1 System Component Operation

The first stage is to ensure that the components of the WIM system are working properly. The roadway sensors should be sending signals to the on-site controller and the on-site controller should be converting those signals into useable data. This is done through observation at the on-site controller using the “real time” review capabilities of the system.

If the reported vehicles do not match the observed vehicles, or if some of the recorded data for speed and axle counts seem inconsistent, there may be a problem with a system component. Inconsistent readings can also be caused by irregular traffic conditions. If the inconsistent readings are caused by irregular traffic conditions, the types of error readings and the observed traffic conditions should be recorded in the “site database,” as discussed in Section 7.

6.2.1.2 Initial Calibration

The initial calibration is performed after the component check is completed. Caltrans specifies that the WIM vendor is responsible for calibrating the WIM system and Caltrans is responsible for conducting the accuracy performance test. Caltrans works with the vendor during the initial calibration and uses the final test truck runs for the accuracy performance test. If problems occur during the final test runs, Caltrans executes the accuracy performance test with its own test truck.

6.1 Practical Calibration

"It is neither practical nor effective to attempt static weighing of a large sample of random vehicles from the traffic stream to calibrate a WIM system." ... Caltrans

The WIM vendor provides and uses only one test truck to calibrate the system. This differs from the ASTM Standard’s minimum recommendation of 13 test vehicles. The test vehicle is normally a five-axle tractor-semitrailer equipped with air suspension for both tandem axle groups, since this vehicle is the predominant truck used on the California’s highway system. The test truck’s axle groups are statically weighed and the axle spacings as well as the overall length are measured. These measurements as well as other information are recorded on a worksheet shown in Figure 6.1.
### Figure 6.1 Sample WIM Calibration Worksheet

<table>
<thead>
<tr>
<th>WIM CALIBRATION TEST VEHICLE</th>
<th>WIM TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASS/DESCRIPTION</td>
<td>DC-RTE-IN</td>
</tr>
<tr>
<td>WR. UNIT LIC.</td>
<td></td>
</tr>
<tr>
<td>TRLD. 1 LIC.</td>
<td></td>
</tr>
<tr>
<td>TRLD. 2 LIC.</td>
<td></td>
</tr>
<tr>
<td>AXLE SPACING:</td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td></td>
</tr>
<tr>
<td>3-4</td>
<td></td>
</tr>
<tr>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td>5-6</td>
<td></td>
</tr>
<tr>
<td>OVERALL LENGTH:</td>
<td></td>
</tr>
<tr>
<td>STATIC WEIGHTS:</td>
<td>RUN 1 DATE</td>
</tr>
<tr>
<td>AXLE/AXLE/AXLE</td>
<td>/ /</td>
</tr>
<tr>
<td>GROSS WEIGHT</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OWNER</th>
<th>PHONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVER</td>
<td></td>
</tr>
<tr>
<td>NOTES</td>
<td>DT : DATE :</td>
</tr>
</tbody>
</table>

---

293
The initial calibration procedure takes four steps; the last three utilize a test vehicle. The four steps are discussed in the following sections.

6.2.1.2.1 Step 1

The WIM weight, axle spacing, and overall vehicle length settings are roughly adjusted using typical trucks in the traffic stream. This step is done before the test truck is on-site.

6.2.1.2.2 Step 2

The test vehicle makes several runs in each lane equipped with WIM to check the weight and axle spacing factors. The initial weight factor settings need to be set prior to Step 3 so that the estimated weight is within five percent of the actual weight. The axle spacing factor should be corrected at this time since the axle spacing is used to validate the speed readings. Because WIM estimates may be speed dependent, speed accuracy is an important part of the calibration procedure.

6.2.1.2.3 Step 3

The test truck is driven over the WIM sensors in each lane a minimum of three times at 8 kph (5 mph) increments typically between 72 and 105 kph (45 and 65 mph). The range of speeds for which runs are made should include the range of speeds at which trucks in the traffic operate determined from the traffic characteristics. The gross weight percent error is calculated for each speed run, by dividing the difference between the actual and estimated weights by the actual weight. This information is plotted on a “Gross Weight Percent Error by Vehicle Speed” graph for each traffic lane. An example of this graph is shown in Figure 5.2, which was obtained from the conference proceedings and was not converted to metric units. If the plots are inconsistent for any of the speeds, additional runs should be made. The graphs are used to record pavement effects on vehicle dynamics.

These graphs are analyzed to adjust the WIM weight factors. The weight factor can be adjusted for three different speed “points.” The high and low speed “points” should be such that most of the trucks on the roadway fall in that range. The middle speed “point” is typically the midpoint but may be raised or lowered to provide for a best fit. The weight factors for different speeds are adjusted using the speed plots from the graphs.
Figure 6.2 Sample Gross Weight Percent Error by Vehicle Speed Graph

6.2.1.2.4 Step 4

The test truck makes two additional runs at each speed after the weight factors have been adjusted. These runs are used to determine if the WIM system is operating at an accuracy level that meets Caltrans' functional requirements for weight, axle spacing, vehicle length, and vehicle speed. The values for the functional requirements are shown in Table 6.2. The initial and final test truck runs can also indicate a WIM system problem such as a defective weigh pad. If the requirements are not met or a problem is detected, Caltrans uses its own test truck to determine the problem, which can be in the WIM system or the pavement condition.
Table 6.2
Caltrans Functional Requirements

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Weight</td>
<td>± 5 percent</td>
<td>5 percent</td>
</tr>
<tr>
<td>Single Axle</td>
<td>± 5 percent</td>
<td>6 percent</td>
</tr>
<tr>
<td>Tandem Axle</td>
<td>± 5 percent</td>
<td>6 percent</td>
</tr>
<tr>
<td>Gross Weight</td>
<td>± 5 percent</td>
<td>5 percent</td>
</tr>
<tr>
<td>Axle Spacing</td>
<td>± 150 mm (6 in)</td>
<td>300 mm (12 in)</td>
</tr>
<tr>
<td>Vehicle Length</td>
<td>± 300 mm (12 in)</td>
<td>460 mm (18 in)</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>± 1.6 kph (1 mph)</td>
<td>3.2 kph (2 mph)</td>
</tr>
</tbody>
</table>

6.2.1.3 Seventy-Two-Hour Continuous Operation

During the third stage of the acceptance test the WIM system is monitored for a 72-hour period. The data produced during this period is reviewed using the First Level Data Review and the Second Level Data Review discussed in Section 7. Once it is determined that the system components are working on a continuous basis within the required specifications, the system is accepted and placed on-line.

6.2.2 Fine Tuning or Recalibration

Fine tuning or recalibrating takes place throughout the design life of a WIM site. The parameters are adjusted when problems are identified during the Quality Assurance Procedure discussed in Section 7.

6.2 Data Analysis

"It is very important that the data analyst be knowledgeable of the site characteristics, the traffic characteristics, the trucks' operating characteristics, and the WIM System's vehicle passage processing in order to properly validate the data and "fine tune" the WIM system's calibration. As much documentation as possible should be accumulated during on-site system testing." ... Caltrans.

6-8
### Example: Automatic Recalibration Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Product of Class 5 Values Required</td>
<td>2.6</td>
</tr>
<tr>
<td>Percentage of Hours to Be Recalibrated</td>
<td>2.5%</td>
</tr>
<tr>
<td>Percent Decrease Allowed From Darekar Weight</td>
<td>10,000 (3,1,700)</td>
</tr>
<tr>
<td>9,300 (4,3,700)</td>
<td>8,000 (3,800)</td>
</tr>
<tr>
<td>Decrease From Darekar Weight (if any)</td>
<td>Cross Valve Weight (darekar)</td>
</tr>
</tbody>
</table>

#### Table 6.6

The performance of the automatic recalibration process is evaluated by the Eqs. 6.6. The automatic recalibration process is used to correct the inaccuracies in the system. The system is not perfect, and its performance is evaluated by the performance index (PI). The PI is calculated during the process, and it is used to evaluate the performance of the system. If the PI is below a certain threshold, the system is recalibrated. Otherwise, the system continues to operate as usual. The system is considered to be performing well if the PI is below the threshold.
the method used to calculate the calibration correction factor is shown in Table 6.4. This factor is computed averaging the correction percentages for each of the GVW groups. As shown in the example, the correction percentage for the GVW range of greater than 31,750 kg (70,000 pounds) is determined by multiplying the percent deviated from the desired FAWs, 4.8, and the adjustment factor, 90.0 percent, to obtain 4.32 percent. This figure is subtracted from 1.00 to obtain a correction factor, 0.957. The adjustment factor used in this equation is found on a Minnesota DOT adjustment factor table shown in Table 6.5. This table gives adjustment factors based on the number of trucks weighed in each GVW group.

Table 6.4
Example of Recalibration Procedure

<table>
<thead>
<tr>
<th>Gross Vehicle Weight Range [pounds (kg)]</th>
<th>Desired From Axle Weight [pounds (kg)]</th>
<th>Percent Deviation from Desired From Axle Weight</th>
<th>Number of Vehicles Weighed</th>
<th>Adjustment Factor Percentage</th>
<th>Percent Deviation Times Adjustment Factor</th>
<th>Correction Factor 1 - (9% Dev. * Adj. Fac.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 32,000 (14,500)</td>
<td>8,500 (3,850)</td>
<td>-4.7</td>
<td>59</td>
<td>90.0</td>
<td>4.23%</td>
<td>0.958</td>
</tr>
<tr>
<td>32,000 - 70,000 (14,500-31,750)</td>
<td>9,300 (4,200)</td>
<td>-4.3</td>
<td>111</td>
<td>95.0</td>
<td>4.09%</td>
<td>0.959</td>
</tr>
<tr>
<td>&gt; 70,000 (31,750)</td>
<td>10,400 (4,700)</td>
<td>-4.8</td>
<td>79</td>
<td>90.0</td>
<td>4.32%</td>
<td>0.957</td>
</tr>
<tr>
<td>Calibration Correction Factor (Average of Correction Factors)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.958</td>
</tr>
</tbody>
</table>

The calibration correction factor is multiplied by the sensor weight factor to obtain a new sensor weight factor. The sensor weight factor is the base calibration factor used by a WIM system. Once the recalibration is made, the program will begin recording data for the next recalibration procedure. This will continue until the recalibration option is turned off. The program keeps a record of the previous 10 recalibrations. An example of the recalibration results is shown in Table 6.6.
### Table 6.5
Minnesota DOT Adjustment Factors

<table>
<thead>
<tr>
<th>Number of 5-Axle Semis Weighed</th>
<th>Adjustment Factor Percentage</th>
<th>Number of 5-Axle Semis Weighed</th>
<th>Adjustment Factor Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>45 - 49</td>
<td>80.0</td>
</tr>
<tr>
<td>1</td>
<td>20.0</td>
<td>50 - 54</td>
<td>80.0</td>
</tr>
<tr>
<td>2</td>
<td>20.0</td>
<td>55 - 59</td>
<td>90.0</td>
</tr>
<tr>
<td>3</td>
<td>20.0</td>
<td>60 - 64</td>
<td>90.0</td>
</tr>
<tr>
<td>4</td>
<td>20.0</td>
<td>65 - 69</td>
<td>90.0</td>
</tr>
<tr>
<td>5 - 9</td>
<td>30.0</td>
<td>70 - 74</td>
<td>90.0</td>
</tr>
<tr>
<td>10 - 14</td>
<td>50.0</td>
<td>75 - 79</td>
<td>90.0</td>
</tr>
<tr>
<td>15 - 19</td>
<td>50.0</td>
<td>80 - 84</td>
<td>90.0</td>
</tr>
<tr>
<td>20 - 24</td>
<td>60.0</td>
<td>85 - 89</td>
<td>90.0</td>
</tr>
<tr>
<td>25 - 29</td>
<td>70.0</td>
<td>90 - 94</td>
<td>90.0</td>
</tr>
<tr>
<td>30 - 34</td>
<td>70.0</td>
<td>95 - 99</td>
<td>90.0</td>
</tr>
<tr>
<td>35 - 39</td>
<td>70.0</td>
<td>100</td>
<td>95.0</td>
</tr>
<tr>
<td>40 - 44</td>
<td>80.0</td>
<td>&gt; 100</td>
<td>95.0</td>
</tr>
</tbody>
</table>

### Table 6.6
Example of Recalibration Results

<table>
<thead>
<tr>
<th>Lane</th>
<th>Date</th>
<th>Time</th>
<th>15:00.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Fri. Mar. 29, 1991</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gross Vehicle Weight Range [pounds (kg)]</th>
<th>Number of Vehicles Weighed</th>
<th>Average Recorded Weight [pounds (kg)]</th>
<th>Percent Deviation from Desired Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 32,000 (14,500)</td>
<td>59</td>
<td>8,900 (4,000)</td>
<td>+ 4.7</td>
</tr>
<tr>
<td>32,000 - 70,000 (14,500-31,750)</td>
<td>111</td>
<td>9,700 (4,400)</td>
<td>+ 4.3</td>
</tr>
<tr>
<td>&gt; 70,000 (31,750)</td>
<td>79</td>
<td>10,900 (4,950)</td>
<td>+ 4.8</td>
</tr>
</tbody>
</table>

Calibration Factor: 0.959  
Sensor Weight Factor: 15.22

6-11
7. WEIGH-IN-MOTION ACCURACY AND QUALITY ASSURANCE RELATED TO PROBLEMS OCCURRING AT THE WIM SITE

Although weigh-in-motion (WIM) systems can provide massive amounts of valuable data in a relatively efficient manner, the data must be checked for accuracy. This accuracy check is a WIM user’s quality assurance (QA) program. A QA program adds confidence to the validity of the WIM data and alerts the data analyst to problems occurring at the WIM site. The purpose of a QA procedure is to help WIM users check data for accuracy and precision. A QA procedure conducted regularly will point out problems at the WIM site and help maintain the system throughout the site’s design life. The need for quality assurance prompted the development of software programs that could be used to validate data and point to problems occurring at the WIM site. These programs include the Long Term Pavement Performance (LTPP) QA software, the Vehicle Travel Information System (VTRIS) and individual state software.

7.1 LONG TERM PAVEMENT PERFORMANCE PROCEDURE

This section is a brief description of the LTPP QA program. State agencies can use these same tests to help identify potential errors in any WIM data, whether or not it is intended for submission to the LTPP program, as long as those data are in a record format the LTPP QA Software can read (7). The LTPP QA Software automates these checks through a series of Statistical Analysis Software (SAS) programs. The SAS programs produce a number of output reports and graphs that require interpretation. Essentially, the LTPP software summarizes a data set in a series of simple graphs that can be used to identify “unusual occurrences” in the submitted traffic data. These “unusual occurrences” are examined to determine whether they are actually invalid data or rather the result of unusual traffic patterns or site malfunctions.

All graphs produced by the LTPP software are lane- and direction specific. The software creates graphs for all lanes and directions for which data are submitted. The software automatically performs the following analyses and comparisons:

1. Gross Vehicle Weight Analysis
2. 7-Card Versus 4-Card Volume Comparison
3. 4- and 7-Card Vehicle Class Distribution Comparison
4. Cluster Analysis

7.2 VEHICLE TRAVEL INFORMATION SYSTEM SOFTWARE

The VTRIS software replaces the Truck Weight Software and uses the standards, formats, and methods specified by the Traffic Monitoring Guide (TMG), 1995 edition (15). VTRIS is a recommended, but not required, method to submit data to the Federal Highway Administration (FHWA) in a uniform format. The software validates, summarizes, and generates reports on vehicle travel characteristics by lane and by direction in the TMG format.
The VTRIS software develops and maintains a permanent database of the WIM data. The data are validated by VTRIS before inclusion into the VTRIS maintained database. The validation process can be adjusted for each station’s site characteristics and user defined parameters for axle spacings and axle weights. Errors detected by the software can be viewed to determine the type of error and whether or not to include the record in the database. The software also converts the WIM data to metric units, thus complying with the FHWA Metric Conversion Plan.

7.3 CALTRANS SUCCESSFUL PRACTICE: QUALITY ASSURANCE PROGRAM

While the LTPP and VTRIS quality assurance software are available to states upon request, individual states may prefer to develop their own QA program that better fits their specifications. These states can work either independently or with a vendor to produce a QA process and reports. The advantages of a state’s personalized QA process lie in the ability of the state to meet its specific requirements.

The QA procedure developed by the California Department of Transportation (Caltrans) is discussed in the manual as a “successful practice” due in part to the 10-plus years experience they have using WIM data (16). During those learning years the state developed and used a QA procedure for validating data from the WIM systems they have installed. Although their procedure bears several similarities to the procedure used for the LTPP program, it is distinctly different in many respects. Therefore, it is a good example of an individual state’s QA procedure formed separately from the LTPP program. Table 7.1 on the following page is a checklist of the quality assurance principles.

7.1 Knowledge

"To properly diagnose, interpret, and validate data from a WIM System, the analyst must have knowledge of 1) the site’s physical characteristics, 2) traffic and truck behavior, and 3) the WIM System’s vehicle passage processing." ... Caltrans.

The Caltrans QA process applies to bending plate systems and consists of four parts. Part 1 is called the “Knowledge of Site Characteristics” Review. Part 2 is called “Real Time” Review. Part 3 is called the First Level Data Review. Part 4 is called the Second Level Data Review.

The actual Data Validation process itself is preceded by two separate, non-validation processes, the “Knowledge of Site Characteristics” Review and the “Real Time” Review, which supplement the data validation process. The “Knowledge of Site Characteristics” Review generates a “site database” based on the physical and traffic characteristics of the site. The “site database” is used and updated throughout the QA procedure to help explain any data anomalies that may occur. The “Real Time” Review performs a spot check of the site’s performance. Four flowcharts, including descriptions of the main process events, are provided to aid in the discussion of the QA process developed and used by Caltrans.

7-2
<table>
<thead>
<tr>
<th>Quality Assurance Principles</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>Develop and maintain a thorough and scheduled data analysis program.</td>
</tr>
<tr>
<td>7.3</td>
<td>Fix any site problems the data analysis program reveals.</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Develop, maintain, and record a permanent &quot;site database.&quot;</td>
</tr>
<tr>
<td>7.3.1.2</td>
<td>Record the site’s physical characteristics.</td>
</tr>
<tr>
<td>7.3.1.3</td>
<td>Record the traffic and truck behavior.</td>
</tr>
<tr>
<td>7.3.1.4</td>
<td>Record the WIM system’s vehicle processing.</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Conduct a &quot;Real Time&quot; Review.</td>
</tr>
<tr>
<td>7.3.2.1</td>
<td>Review of &quot;snapshot&quot; of the site’s performance via telemetry.</td>
</tr>
<tr>
<td>7.3.2.2</td>
<td>Review the files for proper date, time, and sizes.</td>
</tr>
<tr>
<td>7.3.2.5</td>
<td>Review the &quot;real time&quot; data for proper axle weights and spacings.</td>
</tr>
<tr>
<td>7.3.2.6</td>
<td>Identify and repair any system component problems.</td>
</tr>
<tr>
<td>7.3.2.7</td>
<td>Identify and adjust any calibration parameter problems.</td>
</tr>
<tr>
<td>7.3.3</td>
<td>Conduct a First Level Data Review - Summary Report.</td>
</tr>
<tr>
<td>7.3.3.2</td>
<td>Identify any loop or loop processing problems.</td>
</tr>
<tr>
<td>7.3.3.2</td>
<td>Identify any erratic weighpad behavior causing &quot;ghost axles&quot; or missed axles.</td>
</tr>
<tr>
<td>7.3.3.3</td>
<td>Identify any time periods in which the WIM system is not reporting data.</td>
</tr>
<tr>
<td>7.3.4</td>
<td>Conduct a First Level Data Review - Individual Truck Report.</td>
</tr>
<tr>
<td>7.3.4.2</td>
<td>Identify any system equipment malfunctions.</td>
</tr>
<tr>
<td>7.3.4.2</td>
<td>Identify any atypical traffic patterns.</td>
</tr>
<tr>
<td>7.3.4.2</td>
<td>Identify any atypical truck operating characteristics.</td>
</tr>
<tr>
<td>7.3.5</td>
<td>Conduct a Second Level Data Review.</td>
</tr>
<tr>
<td>7.3.5.2</td>
<td>Identify and correct any problems with the calibration parameters.</td>
</tr>
<tr>
<td>7.3.5.3</td>
<td>Identify and correct any problems with the weighpads.</td>
</tr>
</tbody>
</table>
The Caltrans Data Validation process consists of two levels of review. The First Level Data Review is intended to identify:

1. The extent of loop or loop processing problems
2. Any erratic weighpad behavior causing "ghost axles" or missed axles
3. Missing data from a particular lane(s) and the suspected causes

The First Level Data Review includes two steps. Step 1 consists of reviewing the First Level Data Review - Summary Report presenting daily classification and speed summary data. Step 2 consists of reviewing the First Level Data Review - Individual Truck Report presenting individual truck records. The contents and general formats of the reports provided by the vendor's application software are as required by Caltrans' specifications.

The Second Level Data Review is intended to identify and correct any site calibration problems, including:

1. Wheel weights
2. Axle Spacings (affected by speed)
3. Vehicle overall lengths

The Second Level Data Review consists of reviewing reports generated by Caltrans' WIM system analysis program utilizing known relationships of Class 9 and Class 11 trucks and comparing the report data with the known truck operating characteristics for each WIM site.

One of the modifications Caltrans implemented in the FHWA vehicle classification system is the addition of two vehicle classifications. This change brings the total number of vehicle classifications to 15 instead of the 13 classifications recognized by FHWA. The change to the vehicle classifications are described as follows:

1. Class 9 is a five-axle tractor-semi trailer
2. Class 14 is a five-axle truck trailer
3. Class 15 is for vehicles not meeting the axle configurations and/or weights set for classifications 1 through 14 and vehicles unclassified due to system error

The California 15 Class Scheme is converted to the FHWA 13 Class Scheme when the data are submitted to FHWA. The California classification scheme for Classes 3 through 15 only is shown in Table 7.2 for English units and Table 7.2 (a) for metric units. Class 1, motorcycles, and Class 2, passenger cars, are not included in the table since these classes are not relevant to the manual.

The Caltrans QA procedure discussed in this section is for WIM data in general. Slight modifications may need to be made to the QA procedure depending on the type of system installed and the reports generated by each vendor.

7-4
Table 7.2 California Classification Scheme (English)

<table>
<thead>
<tr>
<th>Class</th>
<th>Vehicle Description</th>
<th>No. Axles</th>
<th>Axle Space Between Axle Numbers (in)</th>
<th>Weight (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1-2</td>
<td>2-3</td>
</tr>
<tr>
<td>3</td>
<td>Other (Limous., Van, RV)</td>
<td>2</td>
<td>10-14.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Other w/ 1 axle trailer</td>
<td>3</td>
<td>10-14.5</td>
<td>6.0-25</td>
</tr>
<tr>
<td>3</td>
<td>Other w/ 2 AT</td>
<td>4</td>
<td>10-14.5</td>
<td>6.0-25</td>
</tr>
<tr>
<td>3</td>
<td>Other w/ 3 AT</td>
<td>5</td>
<td>10-14.5</td>
<td>6.0-25</td>
</tr>
<tr>
<td>4</td>
<td>Bus (2-3 miles)</td>
<td>2 - 3</td>
<td>23.1-40</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>5</td>
<td>2 axles with duals</td>
<td>2-4</td>
<td>8.80-23</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3 axle</td>
<td>3</td>
<td>6.10-23</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>7</td>
<td>4 axle</td>
<td>3 or 4</td>
<td>6.10-23</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>8</td>
<td>2SL, 2L</td>
<td>3</td>
<td>6.10-23</td>
<td>11-40</td>
</tr>
<tr>
<td>8</td>
<td>3SL, 3L</td>
<td>4</td>
<td>6.10-23</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>8</td>
<td>2SL42</td>
<td>4</td>
<td>6.10-23</td>
<td>11-44</td>
</tr>
<tr>
<td>9</td>
<td>3SL2, LOG, 32PUP</td>
<td>5</td>
<td>6.10-20</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>10</td>
<td>3SL3, 33</td>
<td>6</td>
<td>6.10-26</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td>11</td>
<td>2SL12</td>
<td>5</td>
<td>6.10-26</td>
<td>11.1-26</td>
</tr>
<tr>
<td>13</td>
<td>2SL23, 2SL2, 3SL3</td>
<td>7</td>
<td>6.1-45.0</td>
<td>3.5-45</td>
</tr>
<tr>
<td>13</td>
<td>3SL23</td>
<td>8</td>
<td>6.1-45.0</td>
<td>3.5-45</td>
</tr>
<tr>
<td>13</td>
<td>Permit</td>
<td>9</td>
<td>6.10-45</td>
<td>3.5-45</td>
</tr>
<tr>
<td>14</td>
<td>2L</td>
<td>5</td>
<td>6.1-230</td>
<td>3.5-6.0</td>
</tr>
</tbody>
</table>

15 Unclassified and Errors - Vehicles not meeting axle configurations see for Classifications 1 thru 14 and "error" vehicles.
<table>
<thead>
<tr>
<th>Class</th>
<th>Vehicle Description</th>
<th>No. Axles</th>
<th>1-2</th>
<th>3-4</th>
<th>5-6</th>
<th>6-7</th>
<th>7-8</th>
<th>8-9</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Other (Limousine, Van, RV)</td>
<td>3-4</td>
<td>3.0-4.4</td>
<td>1.8-7.6</td>
<td>450</td>
<td>5450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Other w/1 axle trailer</td>
<td>3</td>
<td>3.0-4.4</td>
<td>1.8-7.6</td>
<td>450</td>
<td>5450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Other w/2 AT</td>
<td>4</td>
<td>3.0-4.4</td>
<td>1.8-7.6</td>
<td>0.3-3.7</td>
<td>450</td>
<td>5450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Other w/3 AT</td>
<td>5</td>
<td>3.0-4.4</td>
<td>1.8-7.6</td>
<td>0.3-1.1</td>
<td>0.3-1.1</td>
<td>450</td>
<td>5450</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bus (2-3 axles)</td>
<td>2-3</td>
<td>7.0-12.2</td>
<td>1.1-1.8</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2 axles with duals</td>
<td>2</td>
<td>2.7-7.0</td>
<td>1.1-1.8</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3 axle</td>
<td>3</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4 axle</td>
<td>4</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>1.1-4.0</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>251, 2L</td>
<td>3</td>
<td>1.9-7.0</td>
<td>3.4-12.2</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>351, 3L</td>
<td>4</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>1.9-13.4</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>252</td>
<td>4</td>
<td>1.9-7.0</td>
<td>3.4-13.4</td>
<td>1.1-3.7</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>352, LOG, 32PUP</td>
<td>5</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>1.9-14.0</td>
<td>1.1-3.0</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>353, 33</td>
<td>6</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>1.9-14.0</td>
<td>0.03-3.4</td>
<td>0.03-3.4</td>
<td>5450</td>
<td>&gt;</td>
</tr>
<tr>
<td>11</td>
<td>2512</td>
<td>5</td>
<td>1.9-7.0</td>
<td>3.4-7.0</td>
<td>1.9-7.0</td>
<td>3.4-7.0</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3512</td>
<td>6</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>3.4-7.0</td>
<td>1.9-7.3</td>
<td>2.4-7.9</td>
<td>5450</td>
<td>&gt;</td>
</tr>
<tr>
<td>14</td>
<td>32</td>
<td>5</td>
<td>1.9-7.0</td>
<td>1.1-1.8</td>
<td>1.9-7.0</td>
<td>3.4-4.2</td>
<td>5450</td>
<td>&gt;</td>
<td></td>
</tr>
</tbody>
</table>

15 Unclassified and Errors: Vehicles not meeting axle configuration set for Classification 1 thru 14 and "error" vehicles.
7.3.1 "Knowledge of Site Characteristics" Review

For each WIM site, there is an initial stage of preparation that begins at the time of installation, referred to as the Knowledge of Site Characteristics, described by the flowchart in Figure 7.1. The physical and truck traffic characteristics of the WIM site are observed and recorded by the Caltrans site review person during installation, on-site calibration, and acceptance testing of the WIM equipment. This information is placed in a "site database" to be used during the validation and analysis of downloaded data to help explain any data abnormalities. The "site database" is updated as additional information is identified.

7.3.1.1 Purpose

The Knowledge of Site Characteristics is used to develop a "site database" which is used during the validation and analysis of downloaded data to help explain any data abnormalities.

7.3.1.2 Process 1

The success of the Caltrans QA technique is strongly founded upon a base of knowledge about the WIM site's characteristics. The physical and truck traffic characteristics noted during this review include the following:

1. Physical characteristics of a site
   a. Pavement condition and profile
   b. Grade
   c. Traffic flow restrictions
   d. Weather, including wind
2. Truck traffic characteristics of a site
   a. Empty vs. loaded trends
   b. Seasonal variations
   c. Enforcement effects
   d. Unique vehicles
   e. Traffic operating characteristics

7.3.1.3 Process 2

These characteristics are placed in a "site database" to be used during the data validation and analysis process. The "site database" helps in the development of a "site profile" which the reviewer can use to explain data abnormalities. While there are no pre-printed forms for the "site database," it exists as a file of notes, log sheets and pictures to aid the reviewer.

7.3.1.4 Process 3

Throughout the life of a site the "site database" should be reviewed, updated, and expanded whenever atypical traffic or physical site characteristics become apparent.
Figure 7.1 “Knowledge of Site Characteristics” Review Flowchart
7.3.2 "Real Time" Review

In addition to the two levels of data validation, Caltrans also accesses each site by modem and performs a quick spot check of each site’s operation at least twice per month. This process is referred to as a “Real Time” Review and is shown in Figure 7.2. This “Real Time” Review is not actually a validation of data, but it can give an early indication of system problems and identify unusable data.

7.3.2.1 Purpose

The WIM system is monitored in “real time” via telemetry to get a “snapshot” of the site’s performance condition indicators, at that time. This method is also used to review the status of data files accumulated since the last file download.

7.3.2.2 Step 1

The files stored at the site are checked first for proper time, date, and sizes; “real time” traffic is then monitored for proper axle spacing. An example of the data displayed in the “Real Time” review is shown in Figure 7.3. This figure was taken directly from one of Caltrans’ WIM sites and therefore was not converted to metric. The file sizes vary greatly by site dependent upon traffic characteristics and the number of lanes.

Determine if the time, date, or file sizes are incorrect.

7.3.2.3 Step 2

Check the data files’ time and date stamps and sizes so to locate the day and time the site failed.

7.3.2.4 Step 3

If necessary, correct the system’s time and date.

Determine if the axle weights and spacings are correct.

7.3.2.5 Step 4

If the “real time” axle weights or spacings are found to be questionable, the system components (i.e. loop signals, weigh pad signals, etc.) are checked. Problems with the system components may lead to actual physical repairs.

7-9
Determine if the system components are functioning properly.

7.3.2.6  Step 5

If the system components are not functioning properly, identify the equipment problem(s) and initiate corrective maintenance.

7.3.2.7  Step 6

If the “real time” axle weights or spacings are found to be questionable, the calibration parameters are also checked. A problem with calibration may lead to adjustments of the calibration parameters within the system software. These calibration parameters can be for axle weights, axle spacings, and vehicle overall length.

Determine if the calibration parameters are properly set.

7.3.2.8  Step 7

If the calibration parameters are not properly set, make the necessary adjustments.

7.3.2.9  Step 8

If any problem is found throughout the “Real Time” Review, the questionable data are identified for future analysis and appropriateness of use.
Figure 7.2 “Real Time” Review Flowchart
<table>
<thead>
<tr>
<th>Lane</th>
<th>Type</th>
<th>GVW</th>
<th>kips</th>
<th>Length</th>
<th>ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>502</td>
<td>5x2</td>
<td>35.4</td>
<td>12</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>504</td>
<td>5x2</td>
<td>32.4</td>
<td>12</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

Note: The scales are read from the right to the left, units are shown as they are in the field.
7.3.3 First Level Data Review - Summary Report

The procedure for the First Level Data Review - Summary is shown as a flowchart in Figure 7.4. In general, the first level is intended to identify any system equipment malfunctions, missing data, atypical traffic patterns, and atypical truck operating characteristics, by examining the reports shown in Figures 7.5 - 7.9. Included in the figures are examples of the results obtained from analyzing each report. The figures were obtained from Caltrans and were not converted to metric units. The information established for each site in the “site database” provides a foundation for this review.

Caltrans' First Level Data Review - Summary is accomplished by examining reports that are generated using the WIM vendor's application software. The contents and general format of these reports are in accordance with the Caltrans' specifications.

About 14 days of WIM data per month per site are downloaded to a host PC by modem. This is usually enough data to support planning and pavement design analysis, unless a special study or situation arises. The QA procedure is performed on at least seven days of data per month.

7.3.3.1 Purpose

The first process is to review information on the distribution of vehicle classifications by hour of day and the distribution of speeds by vehicle classification. This process is intended to identify:

1. The extent of loop or loop processing problems
2. Any erratic weighpad behavior causing “ghost axles” or missed axles

The second process is to review daily vehicle counts by hour of day by lane to identify any time periods in which the WIM system is not reporting data. This process also identifies the suspected causes of the lack of data. Both processes are done during this data review.

7.3.3.2 Process 1

Figure 7.5 is an example of the classification summary report. Specific counts that should be examined on this report are:

1. Class 1. Abnormally high Class 1 (motorcycle) counts are generally the result of erroneous low speeds and shortened axle spacings caused by loop errors.
2. Class 13. An obvious increase in Class 13 vehicles usually shows a problem of ghost axles being read by the weighpad.
3. Class 15. Unclassified vehicle counts greater than 0.5 percent are generally caused by loop errors.

7-13
7.14

specific grade. A review of the grades given byTerm, 9, is done. The software

7.3.3 Process 2

property

a weighted distribution needs to be performed to determine if the weighted is incorrect

1. Step 3

Similarly, the software should be evaluated by the term, 9, in the standard. The weighted may be 

2. Step 1

Determine if the high course occur all day or separately

Determine if the courses occur all day or separately. If any of the courses are taught in Term, 9, should be tested when the course

3. Step 2

Associate any problems with a specific line

By looking at the course in Term, 9, in this report may quickly

4. Step 3

Determine if the courses for Class 1, Class 13, or Class 15 are high
counts report is used to reveal time periods in which the WIM system is not reporting data for a particular lane.

3 Determine if there are any times of the day when data are not recorded.

4 Determine if the data are missing from all lanes or from a single lane.

If the data are missing from all lanes it is probably due to a system failure such as a power outage. If the missing data are from a single lane it could be due to a lane closure for maintenance or a loop malfunction.

5 Determine if the vehicle counts in the adjacent lanes are higher than normal.

By looking at the lane distributions in the report, it can usually be determined if the lack of traffic data is simply due to traffic being shifted to an adjacent lane, as opposed to a system failure. If the vehicle counts in the adjacent lanes are higher than normal then the data are probably missing due to a lane closure for maintenance or construction. If the vehicle counts in the adjacent lanes are not higher, the missing data are probably due to a loop malfunction.
Figure 7.4 First Level Data Review - Summary Report Flowchart

7-16
Example Data Review:
- The percentage of Class 15 vehicles (1.6 percent) is too high (> 0.7%) for this site and indicates that one or more lanes are experiencing minor loop problems.
- The Class 15 count is acceptable and indicates that there are no gross axle problems.
- The Class 1 count is acceptable and indicates that loop problems are not "shortening" axle spacings.
- The Class 15 hourly distribution indicates that the "error" vehicles are distributed throughout the day and, as such, are probably not due to changes in temperature or moisture.

Figure 7.5
Distribution of Vehicle Classification by Hour of Day
Example Data Review:
- The circled numbers indicate that almost half of the Class 13 "errors" are in lane 1, whereas almost all of the speed "errors" are in lanes 2 and 3.
Example Data Review:
- The table represents all lanes.
- The speed distribution pattern in this report makes it appear that most of the vehicles exceeding 95 MPH are "error" vehicles. Less than half of these errors, however, have resulted in pole spacings such that the vehicles are "unclassified."

Figure 7.7
Distribution of Speed by Vehicle Classification
Example Data Review:
- This report is the same as the report in Figure 7.5, but only for lane 1.
- By reviewing the report, it is apparent that between the hours 1:00 and 1:00 that a loop of the processing of data inputs was malfunctioning. Since counts for all the classifications are erroneous for this time period, the data for this time would be unusable only for vehicle counts purposes.

Figure 7.8
Distribution of Vehicle Classifications By Hour of Day
Example Data Review:
- Data is missing from Lane 4; all other lanes appear to have normal data.
- In reviewing the Lane 3 and Lane 4 distributions, it is apparent that the "0" counts in Lane 4 are not due to traffic shifts in Lane 3. Therefore, the lack of data could be due to a loop malfunction.

Figure 7.9
Distribution of Vehicle Counts by Hour of Day by Lane
7.3.4 First Level Data Review - Individual Truck Report

The procedure for the First Level Data Review - Individual Truck Report is shown in Figure 7.10. In general, this procedure is intended to identify any system equipment malfunctions, missing data, atypical traffic patterns, or atypical truck operating characteristics by examining the reports shown in Figure 7.11 and 7.12. Included in the figures are examples of the results obtained from analyzing each report. The information established for each site in the "site database" provides a foundation for this review.

7.3.4.1 Purpose

The next data review is conducted on the distribution of weight violations and invalid measurements report, displayed in Figure 7.11. This report covers truck information for all lanes. The truck record data should also be checked on a lane-by-lane basis, as displayed in Figure 7.12. The review of these reports is intended to identify:

1. Any classification problems due to a loop or loop processing malfunction
2. A bad weighpad
3. Any obvious calibration problem
4. Truck operation patterns

Any vehicle with a steering axle exceeding 3500 pounds (Classes 4-15) is included in these individual vehicle records.

7.3.4.2 Process

The First Level Data Review - Individual Truck Reports is completed by reviewing the distribution of weight violations and invalid measurements report (Figure 7.11) and the distribution of truck data by lane report (Figure 7.12). In general, these "truck" reports should be studied for a high number of unclassified (Class 15) counts, invalid measurement counts, and percent of overweight vehicles.

\[ \text{Determine if a high number of Class 15 counts are recorded.} \]

For most California WIM sites, an unclassified count not exceeding four percent is acceptable. It is important to note that the unclassified count will generally increase on weekends when many of the more "typical" trucks, conforming to the Vehicle Classification Table in Table 7.2, are not running and a higher number of recreational vehicles ("Heavy" Class 3) are on the road.

7-22
Determine if there is a high number of invalid measurements.

When the difference between the left and right wheel weights of an axle exceed 40 percent, the measurement for that vehicle is classified as invalid. An imbalance that large may be caused by the following:

1. A truck changing lanes or not driving in the middle of the lane
2. Bouncing, usually by empty trailers
3. Empty van trailers in heavy cross winds
4. An extremely bad weighpad calibration factor
5. A malfunctioning weighpad

Determine if the truck traffic characteristics from the "site database" explains the high number of invalid counts.

Caltrans has performed extensive data analyses to determine at which WIM sites bouncing and cross winds cause a high percentage of invalid measurements and to what extent the two factors affect the invalid measurements. Once again the "site database" is useful in determining the cause for the invalid measurements. Caltrans also requires that the WIM on-site software be programmable from the host PC to modify the algorithm that determines invalid measurements. If the extent of invalid measurements is still suspicious after reviewing the site characteristics, a check should be made on the weighpad calibration parameters and, if necessary, the weighpads.

Determine if there is a high percentage of overweight vehicles.

The percent of overweight vehicles may be used as a check of system calibration. However, the percentage of overweights can vary greatly, depending upon the WIM site, the time of year, and the truck traffic characteristics. If the "site database" does not explain the high percentage of overweight trucks a check should be made of the weighpad calibration parameters. Also, the actual percentage of overweight trucks, if the trucks were weighed statically, may be approximately half the WIM-reported overweights. Some reasons for this are as follows:

1. Many trucks travel very close to their maximum legal weight; the slightest overage read of the static weight by the WIM system will result in a violation count.
2. Although a well-calibrated WIM system may produce good average gross weights, plus or minus three percent of the actual average gross weight, a violation count due to a slightly high reading will be recorded.
3. There is generally some weight transfer from the steer axle to the drive axle for most of the heavier trucks, particularly if there is any uphill grade, which could be recorded as a violation due to heavier drive axles.

4. The weight violation look-up tables do not account for certain exceptions, particularly for the steering axle.

It is important to review the total counts and distributions by class shown in the weight violations and invalid measurements report (Figure 7.11). Doing so will provide additional information about the site characteristics, specifically seasonal variations in truck traffic due to agricultural and industrial shipping.

As the analyses of the reports covered under the First Level Data Review - Summary Report (Figures 7.5 - 7.9) and - Individual Truck Report (Figures 7.11 - 7.12) are performed, certain key elements are entered into log sheets along with any annotations deemed necessary. Figure 7.13 is an example of a log sheet prepared during the analysis of the classification and speed summary reports (Figure 7.6). These log sheets serve three basic purposes:

1. They show what data are available and what data have been validated.
2. They show any exceptions to otherwise "valid" data and show any warnings, if appropriate, as to the use of the data for general or specific use.
3. They track trends of site characteristics which may be added to the "site database."

Therefore, the trends may be checked quickly by the reviewer for comparison reasons in future data analysis.

When data are requested, the logs may be used as "guides" for determining whether or not available data are suitable for the intended use. Since data from a particular lane may be questionable or invalid, the log sheets are used to quickly determine what data can be used from that WIM site. Since a portion of the questionable or invalid records may still be used in research, Caltrans rarely discards WIM data.
Figure 7.10 First Level Data Review - Individual Truck Report Flowchart
Example Data Review:
- This review is for all lanes.
- Considering that this is "truck" only data, the 2.3 percent underride and below the allowable 4.0 percent indicates that there is no major problem with classification.
- The eight data points for speed (out of range errors) is below the allowable 0.1 percent and indicates that there are no major loop problems.
- The 4.8 percent of "invalid measurement" truck data is acceptable for an overall review (5.0 percent is the maximum).
- This report shows almost 900 Class 11's, which is twice the average for this site. These additional trucks are seasonal tomato loaders.
- By understanding the way overweight vehicles are recorded, the percent vehicles overweight in this report is considered high and the calibration parameters should be reviewed.
- Since the operating characteristics of the seasonal tomato loaders are well known, these trucks are used to check the WIM systems calibration.

Figure 7.11
Distribution of Weight Violations and Invalid Measurements for Vehicle Classes 4-15
Example Data Review:
- In that only a small percentage of trucks use the inside ("fast") lanes at this site (Lanes 2 and 3 on this report), the malfunctioning loop or weighbridges on one of these lanes might not be evident in reviewing the "combined lanes" report shown in the Figure 7.11.

- It is noted that the invalid percentages for Lanes 2 and 3 are quite high, but these higher percentages are common for the "fast" lanes due to trucks crossing the lane lines to pass.
Figure 7.13 Sample Log Sheet

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Date</th>
<th>Site Name</th>
<th>Fleet</th>
<th>Number</th>
<th>Carbon</th>
<th>Code</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: The table continues with more entries.*
7.3.5 Second Level Data Review

Typically, the Second Level Data Review, shown in Figure 7.14, is performed on one day's accumulation of individual vehicle records data per month per WIM system. If such review causes calibration parameter changes, an immediate follow-up review is normally performed to verify the results of such changes.

The Second Level Data Review reports, shown in Figures 7.15 - 7.18, are generated using the Caltrans WIM System Analysis program. The figures were obtained from Caltrans and were not converted to metric units. This program, written in the C++ programming language, was developed after several years of importing vehicle record data into a database program. This information was then analyzed to determine the relationships between Class 9 and Class 11 trucks as well as the relationships between speed and weight based upon observation at the WIM sites. The program can also provide statistical information on California's Class 14 vehicles.

7.3.5.1 Purpose

The Second Level Data Review is conducted to determine if adjustments are needed in the calibration parameters for the weighpads or the loops. This review may also disclose or lead to the disclosure of equipment idiosyncrasies or malfunctions not noted in the First Level Data Review.

7.3.5.2 Process 1

The review of the distribution of gross weight by lane report, shown in Figures 7.15 and 7.16, allows the analyst to evaluate gross weight relationships. Although the WIM vendor's application software is required to generate gross weight distribution reports, the Caltrans program displays the distributions for each lane in a single report and displays additional statistical data.

The usefulness of this report in analyzing whether or not a WIM system is properly calibrated for weight is dependent upon several site and truck characteristic factors, including:

1. How well the empty and loaded truck weight groups are distributed
2. How consistently the system reports accurate static weight predictions for different types of vehicles
3. The proportionality of the WIM weight accuracies in the lower and higher weight ranges

Determine if the empty and loaded truck weights are properly distributed.
If not, determine if the truck traffic characteristics explain the atypical data.

If the truck traffic characteristics do not explain the atypical data there is probably a problem with a calibration parameter.

7.3.5.3 Process 2

The weight and axle spacings by speed report, Figure 7.17 and 7.18, provides various data and relationships for weight, speed, axle spacings, and vehicle lengths for each lane.

Determine if the Class 9 average tractor tandem axle spacings and the Class 11 average vehicle lengths are accurate.

Checking the accuracy of axle spacings and overall vehicle lengths gives an indication of problems with the calibration parameters for speed and spacing. Caltrans has determined that the Class 9 tractor tandem axle space should average 1.3 meters (4.3 feet) and the average length for a Class 11 vehicle should be approximately 1.5 meters (5 feet) longer than the average wheelbase.

Determine if the left and right average steer axles weights balance for Class 9 and 11 vehicles.

When the report shows different values for the weights reported by the left and right weighpads of each lane, it is an indication of a malfunctioning weighpad or the need to adjust the calibration factor for one or both of the weighpads. The average left and right steer axle weights should be the same.

Determine if the weights over different speeds are consistent.

In reviewing the distribution of average weights by speed, the average gross weights should be consistent for different speed ranges, provided there is a large number of samples and all trucks are able to operate at a "cruising" speed. Any significant differences in the average gross weight through different speed ranges would indicate that the calibration parameters may need adjustment for certain speed ranges. A review of the most recent test truck calibration documentation on speed versus weight might be helpful in analyzing the speed versus weight report.
Certain key elements and comments of the Second Level Data Review process are entered onto a log sheet. A log sheet is a valuable tool in several respects, including:

1. Identifying the effects of calibration parameter changes on the WIM data for weight, axle spacings, and vehicle length
2. Establishing weight trends over a long period of time, including seasonal variations; by collecting site-to-site comparisons the analyst can determine whether any seasonal variations are due to differences in truck operating characteristics (such as hauling heavy produce in the summer) or to the effect of temperature on the weighpads' reporting weight
3. Determining whether or not WIM weights "drift" over a period of time
4. Monitoring any changes in axle spacings or vehicle lengths which may indicate problems with loops.

The log information is added to the "site database," so that the information may be reviewed at a future time.
Figure 7.14 Second Level Data Review Flowchart

7-32
Example Data Review:

- A review of this report allows an analysis of
  evaluate empty and loaded gross weight relationships.

- This report has well defined empty and loaded
distributions for both Class 9 and Class 11 trucks in
both truck lanes (1 and 4).

- Many of the Class 11's in this report are seasonal
tomato trucks which travel empty (26,000 lbs. + or -)
in Lanes 1 and 2 and fully loaded in Lanes 3 and 4.
Being that there is a weigh station between the
tomato fields and the WEM site, counts exceeding
80,000 lbs. should be minimal, as is reflected on this
report.

- Figure 7.16 displays a report of the kind in
this figure, but is more difficult to analyze.

---

**Figure 7.15**
Distribution of Gross Weight by Lane

---

7-33
Example Data Review:

- In Lane 1 of the Class 9 report, the empty distribution is poorly defined, and there are too many trucks exceeding 80,000 lbs.
- In Lane 1 of the Class 11 report, over half of the trucks are short-haul trailer-trucks which travel empty in Lanes 1 and 2 and loaded in Lanes 3 and 4. Although the empty distribution may be a bit tight, the loaded distribution appears to be too heavy.
- In Lane 4 of the Class 9 report, the empty distribution is better defined than in Lane 1, but there are still too many loaded trucks exceeding 80,000 lbs.
- In Lane 4 of the Class 11 report, there are too few empty trucks to make a judgement; the loaded short-haul trucks are well defined in terms of distribution, but too many exceed 80,000 lbs.

What makes this analysis difficult is the high number of trucks exceeding 80,000 lbs. In that much of the truck traffic at this site is short-haul, it is possible that many of the reported truck exceeding 80,000 lbs. are invalid. Another factor to consider is that this was one of California's initial VIM systems and there was no pavement preparation at the site.

Figure 7.16
Distribution of Gross Weight by Lane

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-40,000 lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40,001-80,000 lbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7-34
Example Data Review:

- This report specifically displays Lane 4 data for the same vehicles that were displayed in the Figure 7.15 report.
- The Class 9 action tandem axle space averages 4.3 ft, which indicates that the parameter for determining speed and axle spacings is correct at this site.
- The Class 11 average vehicle length of 661 ft is roughly five feet longer than the average wheelbase: the parameter for determining overall vehicle length is good.
- The left and right average steer axle weights match each other for both Class 9 and 11 trucks and the standard deviations show that 98% of the steer axle weights will be close to the average weights.
- The average weights in the "Vehicle Gross" column are consistent for the different speed ranges for which there are large numbers of samples; the calculation seems to be fine.
- For comparison, note another report of this type in the Figure 7.18.

Figure 7.17
Distribution of Average Weights and Spacings by Speed
Example Data Review:
- Lane 4 of this WIM system is on a long uphill grade and the heavier trucks travel at lower speeds than the lighter trucks. This is an example of the reviewer needing to assess the traffic and truck characteristics for each specific site in order to raise the correct analysis.
- The spacing of the tractor tandem axles reads 4.2, but it should be 4.3. This shows that there may be a problem with the calibration parameters.

Figure 7.18
Distribution of Average Weights and Spacings by Speed
8. SITE MAINTENANCE

In order to ensure that a weigh-in-motion (WIM) system performs throughout the established site design life, states need to perform maintenance at each site. Maintenance can either be corrective or preventive. Corrective maintenance repairs or replaces any malfunctioning equipment or roadway deterioration. Preventive maintenance ensures that the site will function properly by periodically inspecting the system and roadway. This section will discuss both types of maintenance and provide a checklist of items to inspect during a preventive maintenance inspection.

8.1 CORRECTIVE MAINTENANCE

Corrective maintenance is performed after a problem is detected in the system. Problems are detected during the quality assurance (QA) procedures discussed in Section 7 of this handbook. These problems can be corrected in several ways. The first corrective method is to adjust the parameters for axle weights, axle spacings, and vehicle overall length. The next corrective method is to repair or replace faulty equipment detected during the QA procedure. A third corrective method is to repair any problems detected in the roadway which could range from lane rutting before or after the sensor to extensive roadway deterioration.

8.2 PREVENTIVE MAINTENANCE

Preventive maintenance is performed in an attempt to circumvent future equipment and site problems. The California Department of Transportation’s (Caltrans) successful practice includes using the checklist in Table 8.1 to perform site inspections one to two times a year (17). The California Maintenance Checklist provides an adequate way to perform preventive maintenance on a WIM system. The checklist provides a list of items to be inspected and tasks to be completed. Also included on the checklist is a column for notes about the inspected item. After the inspection a maintenance report is written describing the services performed on-site, other observations, and actions recommended.
Table 8.1
Caltrans Successful Practice Field Maintenance Checklist

<table>
<thead>
<tr>
<th>Item</th>
<th>Observation/Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2.1 WIM Sensor Operation</td>
<td></td>
</tr>
<tr>
<td>8.2.1.1 Sensor number and type</td>
<td></td>
</tr>
<tr>
<td>8.2.2 Loop Operation</td>
<td></td>
</tr>
<tr>
<td>8.2.2.3 Loop number</td>
<td></td>
</tr>
<tr>
<td>8.2.3 WIM Electronics and Equipment Functions</td>
<td></td>
</tr>
<tr>
<td>8.2.3.1 Signal Processing (loop, scale, piezo inputs)</td>
<td></td>
</tr>
<tr>
<td>8.2.3.2 Watchdog</td>
<td></td>
</tr>
<tr>
<td>8.2.3.3 Temperature Sensor</td>
<td></td>
</tr>
<tr>
<td>8.2.3.4 Hard drive and floppy drive</td>
<td></td>
</tr>
<tr>
<td>8.2.3.5 Com ports 1 &amp; 2</td>
<td></td>
</tr>
<tr>
<td>8.2.3.6 Uninterruptible power supply</td>
<td></td>
</tr>
<tr>
<td>8.2.3.7 Modem</td>
<td></td>
</tr>
<tr>
<td>8.2.3.8 Cabinet Fan</td>
<td></td>
</tr>
<tr>
<td>8.2.4 System Maintenance and Cleaning</td>
<td></td>
</tr>
<tr>
<td>8.2.4.1 Clean interior and exterior of all components</td>
<td></td>
</tr>
<tr>
<td>8.2.4.2 Remove, clean, and inspect all circuit boards</td>
<td></td>
</tr>
<tr>
<td>8.2.4.3 Maintain all electrical connectors of operation of interface components</td>
<td></td>
</tr>
<tr>
<td>8.2.4.4 Test and verify control and sequence of operation of interface components</td>
<td></td>
</tr>
<tr>
<td>8.2.4.5 Adjust zero point of WIM scale interface cards if necessary</td>
<td></td>
</tr>
<tr>
<td>8.2.4.6 Clean Cabinet</td>
<td></td>
</tr>
<tr>
<td>8.2.5 Visual Inspection of Site</td>
<td></td>
</tr>
<tr>
<td>8.2.5.1 Fines, weighpods, induction loops, and axle sensors</td>
<td></td>
</tr>
<tr>
<td>8.2.5.2 Roadway through WIM system</td>
<td></td>
</tr>
<tr>
<td>8.2.5.3 Potholes adjacent to roadway</td>
<td></td>
</tr>
<tr>
<td>8.2.5.4 Drainage outlet (when drain to side slope)</td>
<td></td>
</tr>
<tr>
<td>8.2.6 Software Maintenance</td>
<td></td>
</tr>
<tr>
<td>8.2.6.1 Upgrade software to latest version</td>
<td></td>
</tr>
</tbody>
</table>
8.2.1 Weigh-in-Motion Sensor Operation

The WIM sensors are inspected to establish operational condition. The sensor number and type are recorded on the checklist form including any observations regarding the equipment.

8.2.2 Loop Operation

The loop detectors at the WIM site are then inspected to establish operational condition. The loop number, loop type, and observations about the equipment are recorded on the checklist form.

8.2.3 Weigh-in-Motion Electronics and Equipment Functions

The WIM electronics and equipment in the roadside cabinet are inspected to establish operational condition. This section of the checklist starts with an evaluation of the signal processing inputs from the loops, scales, and piezo sensors. Once the inputs have been checked the temperature sensor, computer, and the cabinet fan are checked to ensure that the equipment is functioning properly. The hard drive, floppy drive, com ports, uninterruptable power supply (UPS), and modem are checked on the computer. The watchdog, if it is a part of the system, is checked to ensure that it is operational. The watchdog resets the computer to the factory defaults if the system locks up.

8.2.4 System Maintenance and Cleaning

The interior and exterior of all components are cleaned. The circuit boards are cleaned and inspected. The interface components' electrical connectors and sequence of operation are tested and the control is verified. The cabinet is cleaned and the zero point on the WIM scale is adjusted if necessary.

8.2.5 Visual Inspection of Site

Once the system maintenance and cleaning is finished a visual inspection of the site is made. The frames, weighpads, induction loops, and axle sensors are checked for any visible signs of wear and tear on the components. The roadway through the WIM site is inspected for pavement deterioration, rutting, and cracking. The pullboxes and drainage outlets are inspected and, if necessary, cleared of debris.

8.2.6 Software Maintenance

The last step of the checklist is to maintain the computer software by upgrading the software to the latest version.

8-3
9. SYSTEM TROUBLE-SHOOTING

The goal of system trouble-shooting is to ensure that the weigh-in-motion (WIM) system will function properly throughout the site design life. The principle guidelines shown in Table 9.1 should be followed to meet this goal.

Figure 9.1
Trouble-Shooting Principles Checklist

| 9.1 | Follow a logical trouble-shooting process. |
| 9.2 | Devote adequate financial and technical resources to support an efficient and effective trouble-shooting process. |

9.1 LOGICAL TROUBLE-SHOOTING PROCESS

The trouble shooting process begins with site selection and continues throughout the "site design life." One of the main aspects of this process is to follow the guiding principles listed in each section. The process includes failure detection, analysis, and corrective actions.

9.2 REQUIRED RESOURCES

Throughout the "site design life" adequate financial and technical resources need to be devoted to the program. These resources are included for other areas of the WIM operating procedures. Quality Assurance and site maintenance are areas where financial and technical resources are very important.
REFERENCE LIST


APPENDICES
APPENDIX I
RELEVANT STATE DOCUMENTS
CALIFORNIA MAINTENANCE CONTRACT
Example 1
Contract No. 51W357

Article II - Contract Management

Caltrans Contract Manager is Rich Quinley, (916)654-5651.

Article III - Contract Period

This contract shall begin on November 1, 1994, contingent upon approval by the State, and expire on October 31, 1996, unless extended by supplemental agreement.

Article IV - Cost Limitation

A. Total amount of this contract shall not exceed $__________.
B. It is understood and agreed that this total is an estimate and that the State will pay only for those services actually rendered as authorized by the Contract Manager or his/her designee.

Article V - Scope of Work

Scope of work shall be in accordance with Rider A.

Article VI - Rates


On Call Service and Repairs as described in Rider A

1) On call repair work authorized by the State, shall be reimbursed at rates stated in Rider B, Service Rate Schedule and Permanent Price List. Rider B is attached hereto and incorporated by reference.

2) All subcontracted work or other costs not included in Rider B, shall be reimbursed at actual costs.

3) Total costs for on-call repairs shall no exceed $____ for the Contract term.

4) Contractor shall be reimbursed for transportation and subsistence costs for on-call repair work at the rates shown in Rider B.

Article VII - Payment
RIDER A
SCOPE OF WORK

Contractor shall provide labor and materials to perform routine maintenance and on-call repairs for forty (40) existing Caltrans WIM systems at thirty-three (33) locations throughout the State.

A. Routine Equipment Maintenance

1. Contractor shall check each WIM system covered by this contract. Contractor shall schedule maintenance visits conforming to requirements of section C and shall advise State of such schedule prior to commencing service. Service shall include, but not be limited to the following:

   a) visual inspection of frames & weighpads
   b) visual inspection of the roadway in the area
   c) visual inspection of junction box lids
   d) inspection of battery voltage
   e) inspection of humidity indicator on the central unit; replace drying agent if needed
   f) inspect induction loop indicators and frequencies as necessary
   g) inspect and compensate zero-points of weighpads
   h) clean cabinet
   i) provide a written service report to the State for each site within 10 working days after the service has been performed

2. Software Maintenance. Contractor shall provide software updates and technical support services as may be necessary to ensure that all existing WIM systems and the State’s host computer functions as an integrated data collection system.

B. On-Call Services and Repairs

Upon notice by the State that a particular system is malfunctioning, Contractor shall begin on-site repair within five working days of notification, unless State authorizes an extended repair schedule. Contractor shall notify State if lane closures are necessary to perform repair work. Upon such notification, State shall arrange for State forces to set up lane closures and shall notify Contractor as to scheduling of such closures or shall authorize contractor to subcontract for traffic control services. Contractor shall also verbally notify State at a minimum of twenty-four (24) hours in advance as to the schedule of repairs when no lane closure is needed. Contractor shall verbally notify State a maximum of twenty-four (24) hours after completion of repairs.

The Contractor shall provide the State with a written report of the repairs made for each WIM system within ten (10) working days after the completion of the repair work.
### C. WIM Systems covered under this agreement:

<table>
<thead>
<tr>
<th>SITE NO.</th>
<th>SITE DESIGNATION</th>
<th>DIST-CO-RT-PM</th>
<th>NO. Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LODI</td>
<td>10- SJ-005-437</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>REDDING</td>
<td>02-SHA-005-224.9</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>ANTELOPE (WB)</td>
<td>03-SAC-080-17.2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>WHEELER (SB)</td>
<td>06-KER-003-R15.2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>INDIO</td>
<td>11-RIV-010-R59.4</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>NEWHALL (NB)</td>
<td>07- LA-005-446</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>SANTA NELLA</td>
<td>10-MER-005-20.2</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>VENTURA (2)</td>
<td>07- LA-101-37.8</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>FRESNO</td>
<td>06-PRE-099-25.0</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>SONOMA</td>
<td>04-SON-037-2.7</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>VAN NUTS (2)</td>
<td>07- LA-405-42.9</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>SAN MARCOS</td>
<td>11- SD-078-10.7</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>IRVINE (2)</td>
<td>12-ORA-005-25.8</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>HAYWARD (2)</td>
<td>04-ALA-800-14.7</td>
<td>8</td>
</tr>
<tr>
<td>20</td>
<td>LOLETA</td>
<td>01-HUM-101-65.6</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>MOJAVE</td>
<td>09-KER-058-108.1</td>
<td>4</td>
</tr>
<tr>
<td>22</td>
<td>JEFFREY</td>
<td>11-IMP-008-25.8</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>EL CENTRO</td>
<td>11-IMP-008-40.0</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>NAPA</td>
<td>04-NAP-012-2.3</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>NEWBERRY</td>
<td>08-SBD-040-28.9</td>
<td>4</td>
</tr>
<tr>
<td>26</td>
<td>CAMERON</td>
<td>11- SD-008-51.5</td>
<td>4</td>
</tr>
<tr>
<td>27</td>
<td>TRACY</td>
<td>10- SI-005-7.4</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>MT SHASTA</td>
<td>02-SIS-005-11.4</td>
<td>4</td>
</tr>
<tr>
<td>31</td>
<td>WOODSIDE (2)</td>
<td>04- SM-080-55.6</td>
<td>8</td>
</tr>
<tr>
<td>33</td>
<td>BURLINGAME (2)</td>
<td>04- SM-101-17.5</td>
<td>8</td>
</tr>
<tr>
<td>35</td>
<td>PACHECO</td>
<td>04-SCL-152-26.9</td>
<td>4</td>
</tr>
<tr>
<td>36</td>
<td>LOS BANOS</td>
<td>10-MER-152-23.0</td>
<td>4</td>
</tr>
<tr>
<td>37</td>
<td>ELSINORE (2)</td>
<td>08-RIV-015-31.6</td>
<td>8</td>
</tr>
<tr>
<td>39</td>
<td>REDLANDS</td>
<td>08-SBD-030-31.7</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>COACHELLA</td>
<td>11-RIV-086-R15.9</td>
<td>4</td>
</tr>
<tr>
<td>44</td>
<td>BANTA</td>
<td>10- SI-205-9.5</td>
<td>4</td>
</tr>
<tr>
<td>45</td>
<td>CARBONA</td>
<td>10- SI-580-6.4</td>
<td>4</td>
</tr>
<tr>
<td>47</td>
<td>CASTAIC</td>
<td>07- LA-003-56.1</td>
<td>8</td>
</tr>
<tr>
<td>49</td>
<td>AUBURN</td>
<td>03-PLA-049-9.0</td>
<td>4</td>
</tr>
</tbody>
</table>

| SERVICES | COMMENCE | 4 / 95 | 2 / 95 | 4 / 95 | 3 / 95 |

26 Single system sites
8 Dual system sites

Routine Equipment Maintenance shall be performed four times, at approximately six month intervals, for listed Site No.'s 1 through 40. Routine Equipment Maintenance shall be performed three times for the remaining listed sites commencing with the “Services Commence” date.
RIDER B

* Schedule of service classifications, rates, and expense allowances as negotiated
* Listing of equipment and prices
CALIFORNIA MAINTENANCE CONTRACT
Example 2
Article II - Contract Management

Caltrans Contract Manager is Rich Quinley, (916)654-5651.

Article III - Contract Period

This contract shall begin on July 1, 1995, contingent upon approval by the State, and expire on June 30, 1996, unless extended by supplemental agreement.

Article IV - Cost Limitation

A. Total amount of this contract shall not exceed $__________.
B. It is understood and agreed that this total is an estimate and that the State will pay only for those services actually rendered as authorized by the Contract Manager or his/her designee.

Article V - Scope of Work

Scope of work shall be in accordance with Rider A.

Article VI - Rates

Routine maintenance as described in Rider A shall be reimbursed $______ monthly for July 1, 1995 thru June 30, 1996, not to exceed $______ for the contract term.

On Call Service and Repairs as described in Rider A

1) On call repair work authorized by the State, shall be reimbursed at rates stated in Rider B, Rider B is attached hereto and incorporated by reference.

2) All subcontracted work or other costs not included in Rider B, shall be reimbursed at actual costs.

3) Total costs for on-call repairs shall no exceed $______ for the contract term.

4) Contractor shall be reimbursed for transportation and subsistence costs for on-call repair work at the rates shown in Rider B.

Article VII - Payment

A. The State will reimburse the Contractor monthly in arrears as promptly as State fiscal procedures permit upon receipt of itemized invoices in triplicate. Invoices shall reference this contract number and shall be submitted to the Contract Manager at the following address:
RIDER A

SCOPE OF WORK

Contractor shall provide labor and materials to perform routine maintenance and on-call repairs for eleven (11) existing Caltrans Weigh-In-Motion (WIM) systems at eight (8) locations throughout the State.

A. Routine Equipment Maintenance

1. Contractor shall check each WIM system covered by this contract. Contractor shall schedule maintenance visits conforming to requirements of Section C and shall advise Caltrans’ Contract Manager of such schedule prior to commencing.
   Service shall include, but not be limited to the following:
   a. Test response levels, signal levels, and lead cables for:
      - in-road instrumentation
      - WIM scales
      - piezoelectric sensors
   b. Maintain and clean electronics interface and system components:
      - clean interior and exterior of all components; remove, clean and inspect all printed circuit boards
      - maintain all electrical connectors of operation of interface components
      - test and verify control and sequence of operation of interface components; adjust zero point of WIM scale interface card if necessary
   c. Visually inspect condition of:
      - frames, weighpads, induction loops and axle sensors
      - roadway through WIM system
      - pullboxes adjacent to roadway
      - drainage outlet (when drain to side slope)
   d. Clean cabinet
   e. Provide a written report to the State for each WIM system within ten (10) working days after service has been performed.

2. Software Maintenance

   Contractor shall provide software updates and technical support services as may be necessary to ensure that all existing WIM systems and the State’s host computer functions as an integrated data collection system.

B. On-Call Services and Repairs
Upon notice by the State that a particular system is malfunctioning, Contractor shall begin on-site repair within five (5) working days of notification, unless State authorizes an extended repair schedule. Contractor shall notify State if lane closures are necessary to perform repair work. Upon such notification, State shall arrange for State forces to set up lane closures and shall notify Contractor as to scheduling of such closures or shall authorize contractor to subcontract for traffic control services. Contractor shall also verbally notify State at a minimum of twenty-four (24) hours in advance as to the schedule of repairs when no lane closure is needed. Contractor shall verbally notify State a maximum of twenty-four (24) hours after completion of repairs.

The Contractor shall provide the State with a written report of the repairs made for each WIM system within ten (10) working days after the completion of the repair work.

C. Location of WIM systems covered under this agreement:

<table>
<thead>
<tr>
<th>SITE NO.</th>
<th>SITE DESIGNATION</th>
<th>DIST-CO-RT-PM</th>
<th>NO. LAINES</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>MACDOEL</td>
<td>02-SIS-097-34.5</td>
<td>2</td>
</tr>
<tr>
<td>29</td>
<td>ARCO (SB)</td>
<td>03-SAC-005-28.9</td>
<td>3</td>
</tr>
<tr>
<td>41</td>
<td>VACAVILLE (2)</td>
<td>10-SOL-080-30.6</td>
<td>8</td>
</tr>
<tr>
<td>43</td>
<td>CHOLAME</td>
<td>05-SLO-046-44.7</td>
<td>2</td>
</tr>
<tr>
<td>46</td>
<td>GALT</td>
<td>03-SAC-099-6.9</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>ELMIRA</td>
<td>10-SOL-505-2.2</td>
<td>4</td>
</tr>
<tr>
<td>53</td>
<td>NEWPORT (2)</td>
<td>12-ORA-001-22.6</td>
<td>6</td>
</tr>
<tr>
<td>51</td>
<td>WEST SAC (2)</td>
<td>03-YOL-050-0.6</td>
<td>8</td>
</tr>
</tbody>
</table>

5 Single system sites
3 Dual system sites

Routine Equipment Maintenance shall be performed two (2) times, at approximately six (6) month intervals for the above listed WIM systems except for Site No. 51. For Site No. 51, routine maintenance shall be performed one (1) time after November 1995.
APPENDIX 2
LONG TERM PAVEMENT PERFORMANCE
INSTRUCTIONS FOR COST ESTIMATION SPREADSHEET
COST OF WIM EQUIPMENT

Below are instructions for using the spreadsheet file WIMCOST.XLS, which estimates the cost of purchasing, installing, operating, and maintaining WIM equipment.

The spreadsheet is designed for ease of use. At the simplest level, you only need to type in the number of WIM scales that will be purchased and indicate whether the WIM systems will be bending plate or piezo cable based. The spreadsheet will then calculate crude estimates of the cost and staffing required to keep those systems operating at the level expected by LTPP.

The crude estimates initially supplied by the spreadsheet are based on a number of assumed costs and levels of maintenance and operating activity. These assumptions may or may not be realistic for any given state or provincial highway agency (SHA). Consequently, you have the option of changing (and are encouraged to change) the majority of the inputs used in the cost estimation process. You should update the cost and staffing estimates supplied as defaults with the spreadsheet to reflect specific conditions within your SHA and your SHA's experiences. This will provide a more realistic estimate of the staffing and resources needed to install, operate, and maintain the WIM equipment.

STARTING THE WIM RESOURCE ESTIMATION PROCESS

The spreadsheet is stored in a Microsoft Excel 5.0 format.

To open the spreadsheet, start Excel, and open the file WIMCOST.XLS.

Two windows open with the spreadsheet. In the left hand window are the basic data entry requirements. In the right hand window are the total cost estimates calculated by the spreadsheet.

USING THE SPREADSHEET

Basic Input Section

The spreadsheet requires the following inputs:

- the number of WIM sites to be installed, by type of WIM system
- the average number of lanes to be installed at each site
- whether a PC needs to be purchased for the central office operation
- the number of new sites that will need pavement rehabilitation before WIM installation (this is split by type of pavement).

Number of WIM sites to be installed. The number of sites at which WIM devices will be
installed is entered in three different cells, depending on the type of equipment being purchased.

Enter the number of piezo cable systems to be installed in Cell B5.
Enter the number of heading plate systems to be installed in Cell B6.
Enter the number of any other systems being considered in Cell B7.

Piezo cable and bending plate WIM systems have been the most widely adopted technologies in the U.S., so default values are included in the spreadsheet for those systems. If you are intending to use a different technology, you must place the appropriate cost estimates in the lower section of the spreadsheet. (This section is described under the heading “Changing The Basic Assumptions.”) Note also that the piezo cable and bending plate cost estimates should be updated if you have better cost estimates that are more specific to your SHA.

**Average number of lanes to be installed.** For this spreadsheet, a “site” is defined as each set of roadside electronics required. For example, if WIM will be placed on a four-lane, divided highway, this installation could be either a single four-lane site or two two-lane sites. If the median is very large, this location will likely become two separate “sites,” both having two lanes of WIM scales. These two sites will have separate power and telephone connections, as well as separate equipment cabinets and data collection electronics. If the median is not too large, and the cabling from all four lanes of sensors can be hooked to a single cabinet and set of data collection electronics, then this configuration would be considered a single four-lane site.

Enter the average number of lanes of WIM sensors for all sites in the cost estimate in Cell B10 (this number can be a decimal fraction).

**PC purchases for central office operation.**

If your SHA is purchasing WIM for the first time, and/or if your SHA does not have an extra PC that is capable of automatically polling the WIM sites and storing the downloaded data, then place the number of PCs to be purchased in cell B12.

This will cause the spreadsheet to include the cost of this computer(s) in the cost calculation. Note that if your SHA is planning to purchase many WIM systems, more than one PC is usually required to poll, store, process, and report the collected WIM data. A rough estimate (subject to the traffic volumes at the WIM sites, how the sites are operated, and how the collected data are}
retrieved) is that one central PC is required for every eight to twelve WIM sites.

If this is the first WIM installation to be purchased from this vendor, your SHA will also probably have to purchase the required office processing software.

| If this is the case, place a “1” in cell B13. If central office software is not required, place a “2” in cell B13. |

**Number of sites requiring pavement rehabilitation.** The last entries concern the need for pavement rehabilitation at the WIM sites. WIM equipment can only estimate static truck weights accurately if the pavement in which they are installed is smooth, strong, and in good condition. In addition, the life expectancy of the axle sensors is substantially longer if they are placed in pavement that is in good condition. As a result, it is often necessary (and cost effective) to perform some type of pavement maintenance or rehabilitation before sensor installation.

The spreadsheet can consider two types of pavement rehabilitation efforts, asphalt concrete pavements (ACP) and portland cement concrete pavements (PCC). (The actual estimated costs of these treatments are contained in cells B26 and B27, respectively, where you can change them.)

The basic input section requires that you enter the number of new WIM sites that require each type of preliminary pavement rehabilitation.

| If no pavement rehabilitation is required, enter “0” in both cells B15 and B16. Otherwise, enter the number of sites that need ACP rehabilitation in cell B15 and the number that need PCC rehabilitation in cell B16. (Note: the sum of these two cells does not have to equal the total number of new WIM sites.) |

**Results Section**

The spreadsheet outputs (right hand window) include (1) the total initial costs for system purchase and installation and (2) the estimated annual cost and staffing requirements for maintaining the systems purchased. These estimates are shown in bold type. These costs assume that some initial pavement rehabilitation is needed at the WIM sites for the equipment to operate correctly. (See "Site Preparation Costs" for more information on this subject.)

Below these cost calculations are additional estimates of the annual budget for pavement maintenance and rehabilitation needed to keep equipment at the WIM sites operating within ASTM and LTPP specifications. These estimates reflect the fact that your SHA will need to budget for the repair and replacement of WIM systems because those systems will fail as the pavement deteriorates.
The table on the following page includes the input variables that can be changed. Each of these

variables are used in the spreadsheet to model the

scenario. The spreadsheet allows you to experiment with different values for these variables to see how they affect the outcome of the model.

Changing the basic assumptions

The table below shows the input variables used in the spreadsheet model.
<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Cell Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACP rehabilitation cost per lane</td>
<td>B26</td>
</tr>
<tr>
<td>PCC rehabilitation cost per lane</td>
<td>B27</td>
</tr>
<tr>
<td>Basic system cost for a one-lane piezo-cable based WIM site, including installation</td>
<td>B33</td>
</tr>
<tr>
<td>Basic system cost for a one-lane bending plate based WIM site, including installation</td>
<td>B34</td>
</tr>
<tr>
<td>Basic system cost for a one-lane WIM site for some other technology of interest to the SHA, including installation</td>
<td>B35</td>
</tr>
<tr>
<td>Cost reduction factor for multi-lane WIM sites</td>
<td>B37</td>
</tr>
<tr>
<td>Piezo-cable sensor failure rates</td>
<td>B40</td>
</tr>
<tr>
<td>Bending plate sensor failure rates</td>
<td>B41</td>
</tr>
<tr>
<td>Other technology sensor failure rates</td>
<td>B42</td>
</tr>
<tr>
<td>The replacement cost of a piezo-cable sensor (including installation)</td>
<td>B45</td>
</tr>
<tr>
<td>The replacement cost of a bending plate sensor (including installation)</td>
<td>B46</td>
</tr>
<tr>
<td>The replacement cost of a sensor from another technology (including installation)</td>
<td>B47</td>
</tr>
<tr>
<td>The staff time required to replace a piezo-cable sensor (including installation)</td>
<td>C45</td>
</tr>
<tr>
<td>The staff time required to replace a bending plate sensor (including installation)</td>
<td>C46</td>
</tr>
<tr>
<td>The staff time required to replace a sensor from another technology (including installation)</td>
<td>C47</td>
</tr>
<tr>
<td>The number of sensors required per lane for a piezo-cable WIM system</td>
<td>B50</td>
</tr>
<tr>
<td>The number of sensors required per lane for a bending plate WIM system</td>
<td>B51</td>
</tr>
<tr>
<td>The number of sensors required per lane for a WIM system using some other technology</td>
<td>B52</td>
</tr>
<tr>
<td>Input Variable (continued)</td>
<td>Cell Location</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Cost of a single central computer to perform the required office functions (usually a high-end PC)</td>
<td>B55</td>
</tr>
<tr>
<td>Cost of the central office software used by the WIM system vendor to poll the remote WIM sites, store and process the data, and create the necessary reports</td>
<td>B56</td>
</tr>
<tr>
<td>The cost of an FTE of office staff time</td>
<td>B63</td>
</tr>
<tr>
<td>The staff time needed to monitor the operation of, and process data from, a WIM site</td>
<td>C63</td>
</tr>
<tr>
<td>The monthly power cost for a WIM site</td>
<td>B66</td>
</tr>
<tr>
<td>The monthly telecommunications costs for a WIM system</td>
<td>B67</td>
</tr>
<tr>
<td>Expected maintenance expenses per WIM site (but not including expected pavement rehabilitation expenses)</td>
<td>B70</td>
</tr>
<tr>
<td>Expected maintenance staff requirements per WIM site (but not including those needed for pavement rehabilitation expenses)</td>
<td>C70</td>
</tr>
<tr>
<td>The number of calibration trips expected per site per year</td>
<td>B72</td>
</tr>
<tr>
<td>The cost of a single-lane calibration effort when that effort is performed by pulling trucks from the passing traffic stream and weighing them both at the WIM scale and at a nearby static scale</td>
<td>B75</td>
</tr>
<tr>
<td>The staff time needed to perform a single-lane calibration effort when that effort is performed by pulling trucks from the passing traffic stream and weighing them both at the WIM scale and at a nearby static scale</td>
<td>C75</td>
</tr>
<tr>
<td>The cost of a single-lane calibration effort when that effort is performed by bringing two loaded test trucks of known weight to a WIM site and having them pass repeatedly over the scale.</td>
<td>B76</td>
</tr>
<tr>
<td>Input Variable (continued)</td>
<td>Cell Location</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>The cost of a single-lane calibration effort when that effort is performed using a different calibration technique.</td>
<td>B77</td>
</tr>
<tr>
<td>The staff time needed to perform a single-lane calibration effort when that effort is performed using a different calibration technique.</td>
<td>C77</td>
</tr>
<tr>
<td>A cost/staff reduction factor that indicates the cost savings associated with calibrating more than one lane of sensors at a single location</td>
<td>B79</td>
</tr>
<tr>
<td>An indicator of which calibration technique should be used in the cost estimation procedure</td>
<td>B81</td>
</tr>
<tr>
<td>An estimate of the costs required to outfit a maintenance technician so that s/he can diagnose problems with the WIM equipment</td>
<td>B86</td>
</tr>
<tr>
<td>An estimated cost for rehabilitating the pavement at an existing scale site (i.e., once the pavement at a site has deteriorated, the cost to bring that site’s pavement back up to par).</td>
<td>B89</td>
</tr>
<tr>
<td>The percentage of sites that need rehabilitation during any given year.</td>
<td>B90</td>
</tr>
</tbody>
</table>

**Site Preparation Costs:**

As noted above, accurate operation of a WIM system requires that it be placed in strong pavement that is in good condition. Consequently, pavement rehabilitation is often necessary before sensors are installed. The cost of this rehabilitation effort will vary considerably from site to site, depending on the type existing pavement and its condition.

In general, the 200 to 500 feet of pavement immediately surrounding the axle sensors should be in excellent condition (no cracking, no visible rutting). (See the LTPP SPS Traffic Data Collection Protocol for LTPP’s recommended pavement specifications for WIM sites.) To achieve this standard may require anything from grinding the surface of an existing PCC pavement to completely rebuilding it. Consequently, costs can vary considerably from site to site.

Because of the cost of pavement rehabilitation, in many cases WIM equipment is only placed in the road as part of an otherwise planned road construction project. In this way, the pavement rehabilitation effort is paid for from a different funding source and is not considered part of the cost of the WIM system.

Each SHA should determine the true cost of pavement rehabilitation at the proposed site with the help of its own pavement engineering section. This requires that the engineering section know the
proposed WIM system location, the condition of the existing pavement, and the pavement requirements for the WIM system site. The cost value provided by the engineering section should then be entered in the appropriate cell (B26 or B27), expressed as a cost per lane.

Where multiple sites require pavement rehabilitation, you should total these costs and then divide the sum by the total number of lanes to be rehabilitated. This will compute the average cost per lane to be entered into the spreadsheet.

**Hardware System Costs**

The cost of installed WIM systems (excluding pavement rehabilitation) will also vary from SHA to SHA and from contract to contract as a result of differences in vendors, the size of different equipment orders, and the special conditions SHAs place on specific vendors.

The estimates included in cells B33 and B34 are approximate values developed from telephone conversations with various SHA personnel involved with the LTPP program. These estimates may not represent well the costs that any one SHA may encounter. More accurate system costs can be obtained from neighboring SHAs that have recently purchased equipment.

The estimates in cells B33 through B35 include the cost of installation, as well as the costs of installing power, communications, and other site necessities. The cost reduction factor (cell B37) is designed to account for the fact that a multi-lane site requires only one power source, one communications line, and one set of central electronics. In addition, there are economies of scale in the areas of traffic control, equipment use, and other construction related items. This cost reduction factor is applied to the cost of all additional lanes at each site.

**Sensor Failure Rates, Costs Per Sensor, and Sensors Per Lane**

Axle sensors fail for a variety of reasons, including poor installation, pavement failure, sensor fatigue, and faulty sensor design and construction. Sensors tend to fail more quickly under heavy loading and poor environmental conditions. This failure occurs both because of increased fatigue and because pavements tend to deteriorate more quickly under those same conditions.

The "default" sensor failure rates are based on a series of conversations with SHA staff involved with traffic data collection for LTPP. These figures include all kinds of sensor failure and may over-estimate the failure rate of a sensor that is carefully placed in good pavement. (Also note that the failure rate is not linear and can be expected to increase as sensors age. The rate given in this spreadsheet is intended to reflect conditions two or more years from installation to give the SHA a feel for anticipated funding needs.)
If an SHA has experience with specific sensors, more specific failure rates should be substituted for the default rates. Similarly, the replacement costs for sensors listed in the spreadsheet should be overridden whenever possible with more specific values.

The number of sensors listed per site assumes the following sensor configurations: For the piezo cable installation, two 12-foot cables are used along with one 6-foot square loop for vehicle presence detection. For bending plate sites, two 6-foot bending plate scales are placed side by side (one for each wheel path), with 6-foot loops both up- and downstream of the scale.

If the SHA plans on purchasing a WIM system with a different sensor configuration, the number of sensors per lane should be changed accordingly. (Note that the cost of inductive loops is so low in comparison to the other WIM system components that they are not accounted for separately in the spreadsheet.)

**Central Computer Hardware and Software**

An SHA usually has to have at least one large central PC to collect, store, process, and report the WIM data collected in the field. If your SHA is adding to its existing WIM devices, it may not have to add an additional CPU. This can be accounted for in the spreadsheet by entering "0" in cell B12. If a one or more PCs are required, the appropriate number should be entered in cell B12.

The cost of these PCs should be entered B55. In most cases, this CPU should be the fastest Pentium-based machine available, with a 28.8-bit per second modem, a minimum of 1 GB of hard disk storage, and some kind of disk back-up device (e.g., removable optical storage, tape back-up).

In addition to the basic hardware requirement, the CPU will need the central processing software supplied by the WIM system vendor. If your SHA already owns this software and is simply purchasing additional WIM scales, enter a "2" in cell B13. This removes the cost of the software from the spreadsheet calculations. If central software is needed, enter a "1" in cell B13, and enter the actual cost of the software in cell B56.

**Operating Costs:**

Operating costs are divided into four categories: utilities, calibration, maintenance, and office processing.

Utilities primarily include power and telecommunications costs. These costs are entered as average monthly costs per site in cells B66 and B67. Note that if solar power is used at a site, there may be no monthly power cost. Instead, include the cost of the solar panels in the initial system cost (Cells B33, B34, or B35).

WIM system calibration is crucial to obtaining usable information. Most WIM systems have some
kind of “auto-calibration” capability, but work with the traffic data submitted to LTPP has shown that these systems do not always work reliably. Therefore, your SHA should continually monitor the performance of its WIM equipment and periodically perform complete calibration tests.

The “default” in the spreadsheet is that the calibration of each scale will be independently tested and confirmed four times per year. Approximate costs are given for two different calibration methods. The first weighs trucks from the traffic stream at both a static scale and the WIM scale in question. This is an excellent method for calibrating WIM scales, but it is only economically feasible when a static scale is located up- or downstream of the WIM scale.

The second calibration approach for which a cost estimate is included relies on the use of two loaded test trucks (of known weight). These trucks make multiple passes over the scale being calibrated. This method is not as effective as calibrating from the traffic stream, but it is more economically feasible when a static scale is not located near the WIM scale being calibrated.

A number of other calibration techniques are also possible. SHAs selecting one of these techniques should use the category “other techniques” and provide a cost per lane for that technique in cell B77.

When calibration costs are added and/or changed, it is also important to change the staffing requirements listed in Column C. Calibration tends to be staff intensive, regardless of the technique selected, although some techniques are more labor intensive than others.

After specific calibration technique has been selected, make sure to enter a “1,” “2,” or “3” in cell B81 to indicate the appropriate technique. “1” means that your SHA will use the traffic stream and an existing static scale. “2” indicates the use of two test trucks, and “3” indicates the use of an alternative methodology.

Finally, make any necessary changes to the number of calibration efforts per year (cell B72). When a scale is first installed, multiple calibration efforts are required to ensure that it operates accurately throughout the year, as different climatic conditions can change sensor and pavement responses to axle loadings.

Routine maintenance is required for both the site and the equipment at the site. The site maintenance cost estimates are located in cells B70 (funding) and C70 (staff). These estimates do not include major pavement repair, which is covered by the estimates for pavement rehabilitation. They do include electrical repair, repair to the WIM system electronics, and a variety of minor site maintenance tasks.

The last operating expense is for office processing. Although many office tasks have been automated by vendors, the volume of information generated by WIM devices and the need to monitor the calibration and operating condition of these devices to ensure their reliable operation require some fairly substantial office staff time. An estimate of the staff time is given in cell C65. The spreadsheet assumes 0.2 FTE for the very first WIM system purchased and installed. Cell
Major Change: (Unprotecting) to the Spreadsheet

To prevent accidental changes to formulas and default values included in this spreadsheet, the majority of cells in the spreadsheet have been locked. If your SHA determines that it wants to make major revisions to the spreadsheet (as opposed to simply changing the input values), you must "unprotect" the spreadsheet. To do this within Excel, you have to enter a password.

The password for the spreadsheet's protection mechanism is "LTPP."

Questions about this spreadsheet can be directed to Mark Hallenbeck at (206) 543-6261, by fax at (206) 685-0767, or by e-mail at tracmark@u.washington.edu.
C63 contains the marginal staff time required for each additional WIM device. Because some central office tasks only need to be performed once, there is some economy of scale in the operation of multiple WIM devices.

**Other Potential Costs**

If your SHA is just getting into WIM system deployment, some additional “one-time” costs will be incurred to equip your SHA’s maintenance technicians. The items required vary from technology to technology but can include oscilloscopes and volt meters (to measure signal performance) and specialized electronic diagnostic tools. The estimate in the spreadsheet assumes that a vehicle for the maintenance technician is already available through other SHA sources.

**Annual Pavement Rehabilitation Costs**

The last cost included in the spreadsheet is an annual component for pavement rehabilitation. As pavement ages it deteriorates. As the pavement deteriorates, WIM sensor performance deteriorates and sensor life expectancy decreases. In many cases, sensor failure is caused not by the failure of the sensor itself but by the failure of the pavement around the sensor, which causes the sensor to quit operating correctly or results in sensor damage that would not otherwise have occurred.

Therefore, the pavement that contains WIM system sensors must be rehabilitated periodically. When the pavement is repaired or replaced, the WIM sensors almost always have to be replaced. This repair/replacement needs to be budgeted. In many SHAs, sensors are replaced as part of routine pavement maintenance actions (i.e., overlays). The cost of new sensors and installation is simply included in the cost of the new pavement. However, when this occurs, the data collection function is often interrupted from the time the sensor fails to when the pavement is reconstructed or rehabilitated. This time period can be several years.

Regardless of whether the pavement reconstruction pays for the sensor replacement or the WIM system replacement pays for the pavement reconstruction, it is important that the SHA acknowledge the role of pavement reconstruction in the life-cycle cost of the WIM system. Consequently, this spreadsheet includes these costs (Cell B89 lists the average pavement rehabilitation cost per lane for the WIM site, and cell B90 lists the percentage of sites requiring pavement rehabilitation each year). The “Results” section of the spreadsheet lists them separately.
Strategies for Successful Implementation of Virtual Weigh and Compliance Systems in California
Strategies for Successful Implementation of Virtual Weigh and Compliance Systems in California

Amelia Regan, Minyoung Park, Srinivas Nandiraju, Choon-Heon Yang
University of California, Irvine

California PATH Research Report
UCB-ITS-PRR-2006-19

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Final Report for Task Order 3103

October 2006
ISSN 1055-1425
Strategies for Successful Implementation of Virtual Weigh and Compliance Systems in California

Prepared for
The California Department of Transportation
Division of Research and Innovation, MS 83
1227 O St., Sacramento, CA 95814

Prepared by
Dr. Amelia Regan  Associate Professor / Principal Investigator
Minyoung Park  Graduate Student Researcher
Srinivas Nandiraju  Graduate Student Researcher
Choon-Heon Yang  Graduate Student Researcher

Institute of Transportation Studies
University of California
Irvine, CA 92697-3600
http://www.its.uci.edu
1. Introduction

1.1 Background

Freight transportation, particularly by trucks, plays a crucial role in regional and national economy. Trucks account for three-fourths of the value and two-thirds of the weight of freight moved within the United States (BTS, 2005). The ability to efficiently handle truck traffic is essential to the overall economic vitality of the nation.

Fueled by demand for all types of goods mainly due to a population and economic growth, truck traffic has been rapidly increasing in most urban and rural roadways throughout the United States. Transportation statistics expose the growing magnitude of this situation. Since 1970, truck travel in the United States, as measured in vehicle-miles of travel (VMT), has increased by 216%, whereas overall vehicle travel (total VMT) has increased by 137% (BTS, 2001). Forecasts of future freight flows indicate that this growth trend will continue. The volume of domestic freight is projected to increase by 87% between 1998 and 2020, while the volume of international freight is projected to increase by 107% during the same period (FHWA, 2001). This implies additional volume of trucks on the roadway systems in the nation.

Increasing truck traffic poses many challenges for the agencies that construct, operate, and maintain the transportation system. These include:

- Traffic congestion, especially where activities such as loading and unloading and queuing spill truck traffic onto public roadways;
- Safety hazards, especially where heavy trucks are mixed with light-duty vehicles;
- Deterioration of infrastructure, as increasing numbers of heavy vehicles reduce the useful life of pavement;
- Degradation of the environment resulting from increased emissions, particularly of pollutants such as nitrogen oxides (an ozone precursor) and particulate matter associated with diesel truck engines;
- Impediments to economic development, especially in areas where public opposition has arisen to truck intensive development such as truck terminals and intermodal yards;
- Losses in productivity due to congestion, which can delay critical shipments, increase costs, and affect manufacturing schedules or shipping deadlines.

Transportation agencies are increasingly faced with the dilemma of needing to accommodate truck traffic to sustain economic growth and development, while minimizing the negative impacts of increasing truck traffic. The primary mission of commercial vehicle operators by public agencies is the safe and efficient movement of goods. Efficiency is assured when there is minimum interference by the agencies, only to the degree necessary to ensure the safety of the traveling public.

For the movement of goods to function properly, a set of clear guidelines and regulations should be consistently enforced. Regulations cover a large number of parameters that are

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.

The same applies to the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public, and the mutual interests of the parties and the public.
These new compliance technologies come in the form of technologies used to provide fully automated weigh stations, referred to as "virtual weigh stations". Virtual weigh stations may be placed at strategic locations, both on the mainline of roadways and at selected bypass routes, to enable enforcement agencies to plan the optimal use of their resources. Virtual weigh stations would use existing WIM system in combination with Automatic Vehicle Identification (AVI) technologies so that they can monitor and communicate violations in an unattended manner. By automatically detecting attempts of overweight vehicles to bypass weigh stations, deployment of virtual weigh stations will lead to improved enforcement and more efficient utilization of enforcement resources. By removing overweight vehicles from our roadways, this new system ultimately will help public agencies achieve the goals of protecting infrastructure and enhancing safety and air quality while minimizing the delays at weigh stations for inspections.

California Department of Transportation (Caltrans) recently initiated a program aiming at the development of a virtual weigh and compliance system (VWCS) for better commercial vehicle monitoring and weight enforcement. For the successful development of the VWCS, it is first necessary to enhance knowledge baseline associated with the virtual WIM systems. This can be achieved by evaluating the current state of the practice that could aid enforcement agencies in the selection of appropriate operating methods and technologies. As an initial step of the program, Caltrans has teamed up with the Institute of Transportation Studies at the University of California at Irvine to document a synthesis for successful implementation of the virtual weigh and compliance systems.

1.2 Synthesis Objective and Scope

The objective of this synthesis is to document recent efforts and technologies associated with the automated monitoring and enforcement of commercial vehicles and to present the current state of the practice in dealing with overweight vehicle enforcement using advanced WIM technologies. To accomplish this goal, the synthesis identifies:

- Historical background and current state of commercial vehicle enforcement practices,
- Emerging new technologies and methods applicable to upgrade existing commercial vehicle weight enforcement methods,
- Basic concept of the virtual weigh and compliance system considered by the Caltrans,
- Key considerations when implementing the VWCS, and
- Strategies for successful implementation of the VWCS.

The information presented in this synthesis was based on literature survey related to weight enforcement practices and technologies. The literature was collected from a number of sources, including academic journals, government reports, and online materials. These are cited as references in the report.

1.3 Organization of Report

This synthesis is organized to provide better understanding of virtual WIM systems. It begins by reviewing historical background of vehicle weight enforcement using WIM technologies, continues with a discussion of the basic concept and benefits of virtual
mple ofゐり語 training with a sample of English training in the

Plainly, the sentence drops commas with a summary of Chinese learning in the

feasible that the sentence be considered when developing a deployable

When the sentence is deployed, the summary indicates that a feasible and deployable

Section II includes physical deployment and operation of weigh-in-motion systems for
2. Review of Commercial Vehicle Operations and Enforcement

By the American Society of Testing and Materials (ASTM), ‘Weigh-in-Motion (WIM)’ is defined as the process of estimating a moving vehicle’s gross weight and the portion of that weight that is carried by each wheel, axle, or axle group, or combination of these, by measurement and analysis of dynamic vehicle tire force (ASTM, 1994). Consequently, ASTM defines a WIM system as a set of sensors and supporting instruments, which measures the presence of a moving vehicle and the related dynamic tire force at specified locations with respect to time; estimates tire loads, speed, axle spacing, vehicle class according to axle arrangement, and other parameters concerning the vehicle, and processes, displays, and stores this information.

As a weigh enforcement tool, a WIM system could be deployed on the ramp to a weigh station or on the mainline. In either case, based on a preset weight threshold, the WIM system typically sorts arriving trucks prior to entering a weigh station either on the mainline traveling at highway speeds or on off-ramps at reduced speed. Where truck volumes are low, static scales provide sufficient capacity to weigh most trucks passing through the facility. However, many weigh stations experience high volume of truck traffic that they do not have the capacity to weigh all trucks statically. In these cases, trucks that the WIM identifies as near the allowable weight limits are directed to the static scales, while all other trucks are allowed to bypass the weigh station. Such a bypass system has the potential to significantly improve the efficiency of commercial vehicle enforcement agencies that operate weigh stations, as well as the trucking companies that deliver the goods. Even in the event of weigh station closure, weight data could still be collected continuously by the WIM unit if it is deployed on the mainline.

When considering the development of advanced WIM systems, it is important to understand historical background behind the development of existing WIM systems. This section provides a brief overview of the evolution of WIM systems for highway use, including significant changes made in latest version of the industry standard for WIM systems –ASTM 1318-02: Standard Specification for Highway Weigh-in-Motion (WIM) Systems, and its implications for WIM vendors and users. This is followed by reviewing the current state of commercial vehicle enforcement practices in California. Emerging technologies and new methods for weight enforcement are also included in this section.

2.1 Historical Background and Evolution of WIM Systems

The first formal effort to develop a WIM system appeared in literature is an experiment of WIM equipment conducted in 1951 by the U.S. Bureau of Public Roads (BPR) in cooperation with the Virginia State Department of Highways and the Williams Construction Company (Mettler Toledo, 2002). The experiment involved the construction of a pit and slab for the load cells and electrical equipment to test WIM equipment on the Henry G. Shirley Memorial Highway. The experiment near the intersection with U.S. 1 led to the conclusion that a good possibility exists for improving accuracy to the point that weighing trucks in motion will provide data that is as accurate as weighing trucks statically.
Other significant events related to WIM evolution are as follows:

- 1960s: The California Department of Transportation becomes actively involved with weigh-in-motion research.
- 1983: The first National Weigh-in-Motion conference held
- 1987: Long-term Testing of Pavement Program initiated in 1987 as part of the Strategic Highway Research Program
- 1990: The first version of ASTM 1318 Standard Specification for Highway Weigh-in-Motion (WIM) Systems was published.
- 1994: Minor revisions were made to ASTM 1318.
- 1996: The first mainline electronic weight and credential screening system was installed in California.
- 2002: A second version of the ASTM 1318 Standard Specification for Highway Weigh-in-Motion (WIM) Systems was released.

The original edition of ASTM 1318 was published in 1990 in response to the need for a definition of performance standards for various types of WIM systems. Revisions to the standard were made in 1994. Extensive additional research and field experience identified the need for additional revisions, which were released in February, 2002.

Specifications for weigh stations and traffic data collection sites are typically written by State Department of Transportation Engineering Divisions. Weigh-in-Motion installation, performance, and acceptance test criteria are included in these specifications. ASTM 1318 has allowed state highway engineers to reference performance and installation practices that are now familiar to equipment vendors and contractors. Some state specifications call out ASTM 1318 sections, while others incorporate portions of ASTM 1318 into their specifications. ASTM 1318 has also provided a common performance standard from which equipment vendors and contractors can work, helping to prevent a proliferation of different systems supplied to different states.

The growth of the installed WIM base in a variety of environments has provided insight into the needed revisions to ASTM 1318. The major changes in ASTM 1318 released in 2002 and their impacts on WIM vendors and users are summarized in Table 1. The most significant changes have been driven by

- The growth of mainline weight sorting systems, which require that weight enforcement-related WIM systems function at higher speeds.
- Users experiencing inconsistent weight data accuracy stemming from temperature variations, which has compromised the accuracy of collected vehicle weight data.
- The realization that vehicles are not always centered over the weighing platform, and that weight readings from off-center vehicles can have significantly lower accuracy.
- Experience and research indicating that pavement smoothness and durability is critical to long-term accuracy of WIM systems as well as safe operations.
<table>
<thead>
<tr>
<th>Revision to ASTM 1318</th>
<th>Reason</th>
<th>WIM Vendor Impact</th>
<th>WIM User Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in Type III operational speed to 80mph</td>
<td>Growth of mainline weight enforcement WIM</td>
<td>Need to ensure accuracy at higher speeds</td>
<td>More options on placement of WIM equipment</td>
</tr>
<tr>
<td>Suggestion to user to specify that sensor accuracy is met across 20°F to 120°F range</td>
<td>Finding that some sensors lose weighing accuracy at the high and low end of the temperature range</td>
<td>Need to ensure accuracy via data conditioning or other methods</td>
<td>Improved quality of weight data</td>
</tr>
<tr>
<td>Requirement to certify sensor accuracy across width of weighing platform</td>
<td>Experience that some sensors are less accurate for off-center applied loads</td>
<td>Need to design systems to maintain accuracy across width of weighing platform</td>
<td>Improved quality of weight data</td>
</tr>
<tr>
<td>Increase of smooth and level pavement surface to 200 ft in advance of WIM sensor (100 ft beyond sensor)</td>
<td>Experience that greater distance of smooth pavement increases WIM weighing accuracy</td>
<td>None</td>
<td>No net change to smooth pavement length, only WIM repositioning</td>
</tr>
<tr>
<td>Recommendation that WIM system be installed into Portland Cement concrete pavement only</td>
<td>Experience showed improved accuracy and durability when using PCC vs. asphalt</td>
<td>None</td>
<td>Increase in initial construction cost with increase in system life and accuracy</td>
</tr>
<tr>
<td>Increase of minimum road width in advance of and beyond WIM system to 12 ft wide</td>
<td>None</td>
<td>Increase in construction cost</td>
<td></td>
</tr>
<tr>
<td>Increase in maximum allowable cross slope to 3° for Type I, II, and III</td>
<td>None</td>
<td>Decrease in construction cost</td>
<td></td>
</tr>
<tr>
<td>Data communication link between the WIM site and a remote host computer, allowing for remote settings adjustment</td>
<td>Prevalence of sites where operator is not near the WIM system and where users desire to change settings</td>
<td>Hardware and software requirement</td>
<td>Increased WIM functionality</td>
</tr>
<tr>
<td>Addition of vendor Type-Approval Test</td>
<td>Cases where WIM system could not meet accuracy requirements</td>
<td>Need to provide Type-Approval Test compliance</td>
<td>Assurance of WIM system capability</td>
</tr>
<tr>
<td>Acceptance test includes non-centered platform loading</td>
<td>Experience that some sensors are less accurate for off-center applied loads</td>
<td>Need to design systems to maintain accuracy across width of weighing platform</td>
<td>More accurate data under actual range of use conditions</td>
</tr>
<tr>
<td>Acceptance test does not require on-site static weights, but rather pre-weighted vehicles</td>
<td>None</td>
<td>Lower testing cost when no on-site static scales exist</td>
<td></td>
</tr>
</tbody>
</table>

Source: Mettler Toledo, 2002
2.2 Current Commercial Vehicle Enforcement Practice in California

2.2.1 General Requirements for Commercial Vehicle Operations in California

"Commercial vehicle" is defined in California Vehicle Code Section 260 as a motor vehicle of a type used or maintained for the transportation of persons for hire, compensation, or profit or designed, used, or maintained primarily for the transportation of property. Any vanpool or passenger vehicles which are not used for the transportation of persons for hire, compensation, or profit are not included in the definition of commercial vehicles.

To operate commercial vehicles in California, the following documents must be carried and shown to enforcement personnel when requested:

- Drivers license documents and any related certificates.
- Registration documents (cab cards, permits, etc.).
- Proof of insurance.
- Special permits for oversize and overweight loads, if required.
- Hazardous materials shipping papers, if required.
- Fuel tax permits.
- Hours of service records (log book).
- Bills/Invoices etc. showing content and origin of agricultural products, if required.
- Proof of sales tax payment if applicable.

Commercial vehicle operators must comply with many of the applicable requirements listed in Appendix A.

2.2.2 Who must stop at Weigh Stations?

By California State law, any commercial vehicles entering and operating in California must stop for inspection of their size, weight and emissions at commercial vehicle enforcement facilities when signs are displayed requiring the stop. Commercial vehicle enforcement facilities are commonly called weigh stations or truck scales. These facilities are operated by the California Highway Patrol (CHP), not by Caltrans.

California Vehicle Code Section 2813 outlines who must stop at weigh stations and inspection stations as follows:

- **Code 2813**: "Every driver of a commercial vehicle shall stop and submit the vehicle to an inspection of the size, weight, equipment, and smoke emissions of the vehicle at any location where members of the California Highway Patrol are conducting tests and inspections of commercial vehicles and when signs are displayed requiring the stop. Every driver who fails or refuses to stop and submit the vehicle to an inspection when signs are displayed requiring that stop is guilty of a misdemeanor."

Highway pavement life depends upon the weight and frequency of the traffic carried. To illustrate the difference between cars and trucks, a road test sponsored by the American Association of State Highway Officials, established that it takes the passage of
approximately 9,600 cars to equal the pavement damage caused by one legal 80,000 pound truck (CHP, 2001).

Based on a 1991 overweight vehicle fine schedule analysis, it is estimated that overweight vehicle alone increase the state highway system pavement maintenance and rehabilitation costs by $17,000,000 annually. If excessive weights were not controlled by the weigh stations, these figures would be substantially greater. The inspection program through weigh stations can also significantly increase the detection and apprehension of the impaired and fatigued commercial vehicle operator, consequently enhancing commercial vehicle safety.

For these reasons, the weight of commercial vehicles is strictly controlled by public agencies. Table 2 summarizes maximum allowable vehicle weight regulated in California (California Vehicle Code Sections 35550-35558).

Table 2. Maximum Allowable Commercial Vehicle Weight in California

<table>
<thead>
<tr>
<th>Gross Weight</th>
<th>Unit</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Axle</td>
<td>20,000 pounds</td>
</tr>
<tr>
<td></td>
<td>Axle Group:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Less than 8'-6''</td>
<td>34,000 pounds</td>
</tr>
<tr>
<td></td>
<td>- 8'-6'' and more</td>
<td>34,000 – 80,000 pounds</td>
</tr>
</tbody>
</table>

Source: California Department of Transportation, 2005

2.2.3 Facility Classification and Location

Based on primary function, staffing needs, size, location, and physical configuration, five classifications have been established to define the existing facilities for commercial vehicle enforcement (weigh stations): Class “A”, Class “B”, Class “C”, and mini-sites (CHP, 2001). Currently there are 38 facility locations throughout the state with some locations having a facility in each direction of travel. There are a total of 53 facilities: 2 Class “A”, 17 Class “B”, 14 Class “C”, and 20 Class “D.” Additionally, there are 58 mini-sites. A map and list of the existing commercial vehicle enforcement facilities in California are presented in Appendices B and C, respectively.

A. Class “A” and “B” Facilities

Class “A” facilities are located at strategic points of entry into the state, while Class “B” facilities are located along major highway routes. These facilities have independent CHP command identity, and normally operate 24-hours per day, 7-days per week. Class “A” and “B” facilities may be used by other state or local agencies as well as jointly used by bordering state representatives, such as the Air Resources Board, Board of Equalization, Department of Motor Vehicles, California Department of Food and Agriculture, and court clerk. Therefore, administrative office space should be included in the facility
designed to accommodate allied agency use on a permanent of frequent basis. Accommodations and funding should also be included for the installation of the weigh stations.

Class “A” and “B” facilities generally have weigh-in-motion and static scales for the weighing of vehicles and cover areas for the inspection of vehicle equipment. The covered inspection area should be constructed with two or more bays (at least one designed without inspection pits). The number of bays is determined by the average daily truck traffic and projected long-term needs for the location. The facility should have an open storage area for legalizing loads, a parking area, and area to permit the turning of trucks for reweighing. These facilities are designed and staffed for a primary focus on the inspection of vehicle equipment and loads during all hours of operation.

Class “A” and “B” Facilities are intended to be operational 24-hours per day, 7 days per week. CHP staffing generally includes 1 lieutenant, 2 sergeants, 10 to 12 officers, 16-20 Commercial Vehicle Inspection Specialists, 1.5 clerks, and 1 maintenance worker and/or 1 janitor.

The following pictures depict a Class “A” facility and Class “B” facility, respectively.

![Class “A” Facility – Calexico](image1.png)  
![Class “B” Facility - Cottonwood](image2.png)

Figure 1. Pictures of Class “A” and “B” Facilities

B. Class “C” and “D” Facilities

Class “C” facilities are located at strategic points on major highway routes, while Class “D” facilities are located at strategic points on major and secondary highway routes. Operational hours of these facilities are based on such factors as the average daily truck traffic, peak truck traffic hours, and seasonal needs, normally operated up to 24-hours per day, 5 or 7 days per week.
Class "C" facilities should have static scales designed for vehicle weighing, areas for the inspection of vehicle equipment, open storage for legalizing loads, a parking area, and area to permit the turning of trucks for reweighing. Class "D" facilities also have static scales designed for the weighing of vehicles, but may have a limited open areas for the inspection of vehicle equipment. Accommodations and funding should be included for the installation of the mainline bypass system for facilities participated in this program.

Class "C" and "D" facilities are designed and staffed for a primary focus on the inspection of vehicle equipment and loads. The facilities not equipped with a covered inspection area and/or under-track lighting should direct primary focus on vehicle inspection during daylight hours. During periods of darkness or inclement weather this focus would necessarily be redirected toward size, weight, and loading enforcement, as well as toward conducting Commercial Vehicle Safety Alliance Level II inspections of driver qualifications and topside vehicle equipment.

Class "C" and "D" Facilities are generally operational less than 24-hours per day, 5 or 7 days per week. These facilities are not "stand-alone" command facilities, and therefore are not staffed by managerial or supervisory personnel. The facilities are normally staffed with 2 to 6 officers. In addition, Class "C" facility staffing usually includes 1 to 3 commercial vehicle inspection specialists and 0.5 clerk. Class "C" and "D" facilities located in close proximity to Class "A" or "B" facilities become a portion of that command structure. Remaining facilities are under the direct command of the respective Division Special Services Commander and, in those instances where a sergeant has not been specifically assigned to the facility, are supervised by the Division commercial sergeant.

The following figure presents pictures of the Class "C" and "D" facilities.

(a) Class "C" Facility – E/B Antelope  (b) Class "D" Facility – Keene

Figure 1. Pictures of Class "C" and "D" Facilities
C. Mini-Sites

Mini-sites are designed as safe locations for portable scale operations. Mini-sites are strategically located on highways with an above-average volume of commercial vehicle traffic to screen vehicles which may use bypass routes to avoid commercial facilities. There are no above-ground facilities at mini-sites. Mini-sites should be designed to accommodate portable scales and should include an area designed for truck inspections. The sites may be randomly used by either platform scale personnel or Mobile Road Enforcement officers.

Operational equipment for mini-sites is normally transported to the site. Traffic is directed into the site by traffic control signs and appropriate roadway markings. Mini-site locations are under the command of the facility commander or Division Special Services Commander who has supervisory responsibility for the officers using the site. Pit scales are included within the definition of the term “mini-site” since they are simply considered to be an earlier version of the mini-site.

Mini-sites are not staffed facilities. Personnel as well as needed operational equipment are transported to the site during hours of operation. Mini-sites are generally operated by Mobile Road Enforcement officers. Figure 3 illustrates a picture of a mini-site located at Southbound 99 North of Riego Road.

Figure 3. Pictures of Mini-Site Located S/B 99 North of Riego Road
2.2.4 Weigh Station Bypass Program: 'PrePass™'

For the purpose of enhancing the operational efficiency of weigh stations for commercial vehicle weight enforcement, California developed a weigh station bypass system called 'PrePass™' in 1994. The weigh station bypass system is an automated system allowing heavy vehicles that are registered in the program to legally bypass open weigh stations.

The bypass system requires carriers to obtain special transponders used for communication between computers in the weigh stations and the vehicles. If all requirements for weight, size, safety, etc. are met, the driver receives a green signal that allows the vehicle to bypass the weigh station. Otherwise, the driver receives a red signal which requires the vehicle to go through the weigh station. All heavy vehicles that are not registered in PrePass™ are required to pass through weigh stations that are open. The system has been in operation in California since 1994. Currently, there are 36 weigh stations across California deploying the PrePass™ technology (Caltrans, 2005). The location map of the California PrePass™ sites and the list including the location and status of all bypass sites are presented in Appendices D and E, respectively.

The following graphic diagram shows the overview of the PrePass™ system that explains basic operating process of the system.

![Diagram of PrePass™ system](image)

Source: California Department of Transportation, 2005

**Figure 4. Overview of the PrePass™ system**
2.3 Emerging Technologies

The PrePass™ systems have the mainline WIM capability that automatically pre-screen commercial vehicles traveling at highway speeds up to 80 mph. By allowing for static scale to be used for only the most likely violators, the systems facilitate overweight vehicle enforcement activities, being effective especially in the region with high volume of truck traffic. However, the systems are limited to the transponder-equipped vehicles, still required for trucks without transponder to stop at the weigh stations for inspection.

Recent advances in sensor and communication technologies lead to the emergence of advanced WIM technologies that have the potential for further improvement of existing weigh station operations. New technologies involving WIM systems include Automated Vehicle Identification systems. Integration of AVI with WIM technology creates new methods of screening commercial vehicles traveling on the mainline at high speeds in an unattended mode for their conformity to weights, dimensions and other regulations. Newer forms of technology also include a photo WIM system, mainline automated clearance system, and new WIM scale developed by Omni Weight Corporation known as the Safe Load WIM.

2.3.1 Automated Vehicle Identification Systems

Automated vehicle identification (AVI) is the application of sensor technologies to make more informed screening decisions at weigh station for commercial vehicles. It may be described as containing three components, the transducer, a signal processing device, and a data processing device. The transducer detects the passage or presence of a vehicle or its axles. The signal processing device typically converts the transducer output into an electrical signal. The data processing device usually converts the electrical signal to traffic parameters.

A sensor is a key component of any AVI systems. Depending on the installation location, sensors are categorized into two types, intrusive and non-intrusive (Mimbela and Klein, 2000). Intrusive sensors are those that require the installation of the sensor directly onto or into the road surface, including inductive loops, magnetometers, microloop probes, pneumatic road tubes, piezoelectric cables and other WIM sensors. On the other hand, non-intrusive sensors are mounted overhead or on the side of the roadway. The video image processors, microwave radar, active and passive infrared sensors, and ultrasonic sensors fall in this category.

In Table 3, the strengths and weaknesses of the sensors are summarized with respect to installation, parameters measured, performance in inclement weather and variable lighting conditions, and suitability for wireless communication. The types of data typically available from each sensor technology are listed in Table 4, including coverage area, communication bandwidth requirements, and purchase costs. Several technologies are capable of supporting multiple detection zone applications with one or a limited number of units. These devices may be cost effective when larger numbers of detection zones are needed to implement the traffic management strategy.

Inductive loop detectors have been most widely used to monitor traffic flow and control signals because of their relatively low cost, maturity, aesthetics, and policy issues. Some
of the overhead technologies, such as video image processing and multi-zone microwave and infrared sensors, may replace several inductive loops since the higher cost of the aboveground sensors can offset the costs associated with installing and maintaining multiple inductive loops. In addition, most overhead sensors have the advantages over intrusive sensors of being compact and not roadway invasive, thus making installation and maintenance relatively easy.

AVI technologies have already been used to a limited extent in some locations, but it is expected that most WIM systems will eventually be integrated with this new technology. Properly implemented, electronic screening using AVI results in significant improvement of weigh station operations in a cost effective manner.

**Table 3. Strengths and Weaknesses of Sensor Technologies**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive Loop</td>
<td>• Flexible design to satisfy large variety of application</td>
<td>• Installation requires pavement cut</td>
</tr>
<tr>
<td></td>
<td>• Mature, well understood technology</td>
<td>• Decreases pavement life</td>
</tr>
<tr>
<td></td>
<td>• Provides basic traffic parameters (e.g., volume, presence, occupancy,</td>
<td>• Installation and maintenance require lane closure</td>
</tr>
<tr>
<td></td>
<td>speed, headway, and gap)</td>
<td>• Wire loops subject to stresses of traffic and temperature</td>
</tr>
<tr>
<td></td>
<td>• High frequency excitation models provide classification data</td>
<td>• Multiple detectors usually required to instrument a location</td>
</tr>
<tr>
<td>Magnetometer (Two-axis fluxgate Magnetometer)</td>
<td>• Less susceptible than loops to stresses of traffic</td>
<td>• Installation requires pavement cut</td>
</tr>
<tr>
<td></td>
<td>• Some models transmit data over wireless RF link</td>
<td>• Decreases pavement life</td>
</tr>
<tr>
<td>Magnetic (Induction or search coil magnetometer)</td>
<td>• Can be used where loops are not feasible (e.g., bridge decks)</td>
<td>• Installation and maintenance require lane closure</td>
</tr>
<tr>
<td></td>
<td>• Some models installed under roadway without need for pavement cut</td>
<td>• Some models have small detection zones</td>
</tr>
<tr>
<td></td>
<td>• Less susceptible than loops to stresses of traffic</td>
<td>• Installation requires pavement cut or tunneling under roadway</td>
</tr>
<tr>
<td>Microwave Radar</td>
<td>• Generally insensitive to inclement weather</td>
<td>• Cannot detect stopped vehicles</td>
</tr>
<tr>
<td></td>
<td>• Direct measurement of speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Multiple lane operation available</td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>• Active sensor transmits multiple beams for accurate measurement of</td>
<td>• Operation of active sensor may be affected by fog when visibility is less than 20 ft or</td>
</tr>
<tr>
<td></td>
<td>vehicle position, speed, and class</td>
<td>blowing snow is present</td>
</tr>
<tr>
<td></td>
<td>• Multiwave passive sensors measure speed</td>
<td>• Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog</td>
</tr>
<tr>
<td></td>
<td>• Multiple lane operation available</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Strengths and Weaknesses of Sensor Technologies (Continued)

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic</td>
<td>• Multiple lane operation available</td>
<td>• Some environmental conditions such as temperature change and extreme air</td>
</tr>
<tr>
<td></td>
<td></td>
<td>turbulence can affect performance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature compensation is built into some models.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Large pulse repetition periods may degrade occupancy measurement on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>freeways with vehicles traveling at moderate to high speeds.</td>
</tr>
<tr>
<td>Acoustic</td>
<td>• Passive detection</td>
<td>• Cold temperatures have been reported as affecting data accuracy</td>
</tr>
<tr>
<td></td>
<td>• Insensitive to precipitation</td>
<td>• Specific models are not recommended with slow moving vehicles in stop and</td>
</tr>
<tr>
<td></td>
<td>• Multiple lane operation available</td>
<td>go traffic</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>• Monitors multiple lanes and multiple zones/lane</td>
<td>• Inclendent weather, shadows, vehicle projection onto adjacent lanes,</td>
</tr>
<tr>
<td></td>
<td>• Rich array of data available</td>
<td>occlusion, day-to-night transition, vehicle/road contrast, and water,</td>
</tr>
<tr>
<td></td>
<td>• Provides wide-area detection when information gathered at one camera</td>
<td>salt grime, icicles, and cobwebs on camera lens can affect performance.</td>
</tr>
<tr>
<td></td>
<td>location can be linked to another</td>
<td>• Require 50- to 60-ft camera mounting height (in a side-mounting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>configuration) for optimum presence detection and speed measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Some models susceptible to camera motion caused by strong winds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generally cost-effective only if many detection zones are required within</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the field of view of the camera</td>
</tr>
</tbody>
</table>

### Table 4. Traffic Sensor Output Data, Bandwidth, and Cost

<table>
<thead>
<tr>
<th>Technology</th>
<th>Output data</th>
<th>Multiple Lane, Multiple Detection Zone Data</th>
<th>Communication Bandwidth</th>
<th>Sensor Purchase Cost* (Each in 1990 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Presence</td>
<td>Speed</td>
<td>Occupancy</td>
</tr>
<tr>
<td>Inductive Loop</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Magnetometer (Two-axis fluxgate)</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Magnetic (Induction or search coil)</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Microwave radar</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Infrared</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Acoustic array</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>X</td>
<td>X</td>
<td>X²</td>
<td>X</td>
</tr>
</tbody>
</table>

*Note: Installation, maintenance, and repair costs must also be included to arrive at the true cost of a sensor solution as discussed in the text.

Speed can be measured by using two sensors a known distance apart or by known or assuming the length of the detection zone and the vehicle.

With specialized electronics unit containing embedded firmware that classifies vehicles.

From microwave radar sensors that transmit the proper waveform and have appropriate signal processing.

With multi-detection zone passive or active mode infrared sensors.

With active mode infrared sensor.

Models with appropriate beam forming and signal processing.

Depends on whether higher bandwidth raw data, lower bandwidth processed data, or video imagery is transmitted to the traffic management center.

Includes underground sensor and local receiver electronics. Receiver options are available for multiple sensor, multiple lane coverage.

Source: Klein, 2001
2.3.2 Photo WIM Systems

Dramatic improvement in video sensor technology and computing capability leads to the development of photo WIM systems. In fact, the use of video technology in combination with WIM is a concept that has been in existence since the mid-1980's and expanded considerably in recent years. The future potential of this technology is extensive.

As shown in Figure 5, a photo WIM involves the merging of two existing technologies: WIM and photo enforcement. The primary function of photo WIM systems is to detect vehicles that are of interest to the weight enforcement or planning agency, and to capture an image of those vehicles. Photo WIM operates in a similar fashion to photo radar or red light camera systems. Photo WIM systems can be installed in mainline or remote locations in either a permanent or portable application to monitor commercial traffic at a particular location in the road network. WIM sensors are used to measure vehicle weights and dimensions and a camera is used to capture and store a photographic image of the vehicles of interest. If digital images are used, the images can be immediately communicated electronically to a central office for real time deployment of enforcement personnel.

![Diagram of Photo Weight-in-Motion system]


Figure 5. The Overview of Photo Weigh-in-Motion system

Photo WIM can be used to augment permanent weigh station operations by providing images for mainline WIM pre-screening systems, monitoring vehicle compliance to WIM sorted traffic signals and traffic signs, and for monitoring weigh station evasion routes. Photo WIM may also be deployed in conjunction with mobile and remote weight enforcement as a pre-screening system, or as an automated stand alone monitoring system on remote routes. Data collected by photo WIM can provide weight enforcement agencies with a visual record from which to engage in discussions with particular carriers detected as chronic violators, or to assign preferred carrier status. Photo WIM may also
2.3.4 Omni Weight Corporation Safe Load System

New form of WIM scale, known as the Safe Load WIM, has been developed by the Omni Weight Corporation. The Safe Load System is a dynamic scale automated truck weigh station developed under ASTM guidelines as a Type III and IV WIM system. The system has several benefits of saving capital cost in installation by not requiring concrete slabs for the WIM sensors, providing weighing and classification software in one element, and providing a maintenance-free rugged element without load bearing sensors. The system has been installed on the Smart Road in Blacksburg, Virginia, and being monitored by the Virginia Tech Transportation Institute (Katz and Rakha, 2002).
3. The Concept of Virtual Weigh and Compliance Systems

The availability of advanced WIM technologies in conjunction with improved sensor and communication technologies had lead to the development of virtual (unattended) weigh stations. Virtual WIM systems provide enforcement agencies with a cost-effective tool to monitor and enforce truck weights on bypass or secondary routes as well as major highways, and new opportunities for easily accommodating increased truck traffic volumes while significantly reducing the costs of expanding the physical weigh stations.

This section presents the basic concept of virtual weigh and compliance systems considered in California. Key system components and their functions are described. Expected potential benefits of the virtual weigh and compliance systems are discussed along with empirical evidence. Case studies of other states directed toward accommodating advanced WIM technologies are also included in this section.

3.1 Basic Concept of Virtual Weigh and Compliance Systems

Depending on the traffic characteristics and enforcement objectives, in general, a variety of weight enforcement strategies can be considered and WIM systems vary widely in functionality and level of complexity. Weight enforcement options to be applicable for different traffic conditions and enforcement levels include

- Portable Scales
- Virtual Weigh Stations using WIM
- Fixed Facility Weigh Stations with Static Scales
- Fixed Facility Weigh Stations with Ramp WIM
- Fixed Facility Weigh Stations with Mainline WIM

Traditionally, secondary roads and bypass routes have been randomly monitored by mobile enforcement officers. Given the time consuming process of weighing trucks with portable scales, there is a need to pre-screen which trucks should be weighed statically in order to maximize a mobile enforcement officer’s effectiveness. To address the need for low cost, continuous monitoring of lower volume secondary roads or bypass routes, a “virtual weigh station” can be used.

Designed to help provide effective truck weight enforcement on secondary and bypass roads as well as highways, the virtual weigh station is a new method for overweight vehicle enforcement that integrates WIM technology with other technologies including AVI, video sensor, and wireless communication. It operates in an unattended mode, weighs and classifies vehicles, and retains images of weight violators along with their weight data, time and date information.

A weigh-in-motion system is installed across the lanes of a bypass road. As vehicles cross the WIM scale, a photo overview image of the vehicle including license plate of the vehicle, are captured if the vehicle is overweight. Images and weight data are stored for
remote retrieval, or instantly transmitted via a wireless communication network to a laptop computer in a nearby patrol car. Another option is wireless or landline transmission to a weigh station located nearby the bypass road, or to a centralized traffic control center. The weigh station or traffic control center can then dispatch an enforcement officer to intercept the violating vehicle (See Figure 5-(a)).

As shown in Figure 5-(b), the virtual weigh station can be also applied to complement existing fixed WIM sites. It can automatically pre-weigh vehicles and transmit a photo image with the vehicles' weights and/or dimensions to an enforcement officer downstream of the WIM or to a central facility. Based on vehicle information, vehicles suspected of being overweight can be either stopped and weighed using portable scales or can be directed to the nearest fixed facility weigh station with static scales for more accurate weighing, while allowing vehicles in compliance to continue on their way. The use of virtual weigh stations would significantly improve existing bypass systems as in the PrePass™ program by allowing even trucks without transponders to bypass the fixed weigh station if they satisfy enforcement requirements.

Source: Mettler Toledo, 2005

Figure 5. Typical Configuration of Virtual Weigh-in-Motion Systems
3.2 System Components and Function

Designed to realize unattended weight enforcement of overweight trucks, a virtual weigh station consists of a set of components that must perform together for the system to work successfully. These include WIM sensors, video image processing system, wireless communication and portable communication devices, and WIM cabinet. Depending on the applications, additional options can be added, such as an interface to a static scale, message sign and over-height detectors. Key system components and their functions of a virtual WIM system are as follows. These are described in detail in next chapter.

3.2.1 WIM Sensors

A WIM system functions to provide preliminary dynamic weight readings which can be used to pre-clear and automatically sort vehicles. According to enforcement objectives, WIM systems can vary widely in functionality and level of complexity. The most important component of WIM systems is a WIM scale that measures the gross vehicle weight of a vehicle as well as the portion of this weight that is carried by each wheel assembly, axle and axle group on the vehicle. Several types of WIM scales are currently available, including single load cell scales, bending plate scales, and piezoelectric, quartz and fiber optic sensors (portable and permanent). The categories of WIM systems are listed in Table 5 along with the corresponding data each provides. Other components in WIM systems include inductive loop sensors to detect approaching vehicles, electronics to interpret the signals, a computer for data processing and storage, and a computer display screen. At weigh stations, the ultimate goal of the WIM system is to enhance weight enforcement operations by enabling low to high speed dynamic weighing to complement static weighing.

3.2.2 Video Image Processing Systems

Video image processing systems typically consist of one or more cameras, a microprocessor-based computer for digitizing and processing the imagery, and software for interpreting the images and converting them into traffic flow data. As vehicles go across the WIM scale, the systems automatically capture a photo overview image of the vehicle of interest and extract information for commercial vehicle operations. If the vehicle is overweight, the overview image of the vehicle with weight and speed data is stored for remote retrieval, or instantly transmitted via a wireless connection to a laptop computer in a nearby patrol car. Conceptual video image processing for vehicle identification is presented in Figure 6.

![Figure 6. Conceptual Video Image Processing for Vehicle Identification](image-url)

23


3.2.3 Wireless Communication Systems

<table>
<thead>
<tr>
<th>Source: ANSI 1994</th>
</tr>
</thead>
<tbody>
<tr>
<td>**</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
<tr>
<td>X</td>
</tr>
</tbody>
</table>

Table 3: WLAN System Categories, Applications, and Data Types.
3.2.4 Other Components

WIM cabinet is also a key part of virtual weigh station, which includes roadside data acquisition electronics that convert the scale readings to vehicle information.

Optionally, other components can be added, including multiple inductive loops for vehicle tracking, one or more static scales, directional signs, over-height detectors, and automatic vehicle identification equipments.

- Over-height Detector: This identifies heights of vehicles entering the truck weigh station. The detection of over-height vehicles shall take place along with the in-motion weight measurement.

- Static Scale: It provides fully unattended operation of both the WIM and static scale allowing for more efficient personnel use.

- Directional message signs: The system readily identifies overview image of the truck, providing information on the axle weights, gross weights, class, speed, date, time, and any weight violations.

3.3 Expected Benefits of Virtual Weigh and Compliance Systems

Compared to those of static weighing and low-speed WIM installed at a fixed weigh station, the use of virtual WIM systems for monitoring and enforcement of commercial vehicles has a range of advantages for both enforcement agencies and trucking companies. The expected benefits of virtual WIM systems include prevention of overloading, decrease of delays at weigh stations, enhancement of safety and air quality, as well as cost savings.
3.3.1 Prevention of Overloading

In traditional weigh station operations based on static scales, all trucks are required to stop at the weigh stations for visual inspection and/or weighing. At busier routes and/or during peak time periods, it is normal for trucks to fill the stations such that they must close temporarily until the queues diminish. The temporary closure of the stations is necessary to prevent traffic backups onto the highway and to avoid the safety hazards of having immobile vehicles adjacent to vehicles traveling at high speeds. When the stations are closed, some trucks are able to bypass the weighing process even though they may be overweight, causing many problems related to overweight vehicles discussed earlier.

By implementing virtual WIM systems, all trucks can be weighed in an unattended manner. Thus no overweight trucks are allowed to bypass, leading to a decrease in the number of overweight trucks. Table 6 provides empirical evidence that shows a significant decrease in overweight violation rates at high enforcement levels, compared to that of low enforcement levels. A decrease in the number of overweight trucks immediately indicates a reduction in infrastructure damage and deterioration attributed to overweight trucks.

Table 6. Impacts of Enforcement Level on Overweight Violation Rate

<table>
<thead>
<tr>
<th>State</th>
<th>Violation Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At High Enforcement Level</td>
</tr>
<tr>
<td>Virginia</td>
<td>0.5-2.0</td>
</tr>
<tr>
<td>Maryland</td>
<td>1.0</td>
</tr>
<tr>
<td>Arizona</td>
<td>1.5</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>1.0</td>
</tr>
<tr>
<td>Idaho</td>
<td>11.9</td>
</tr>
<tr>
<td>Florida</td>
<td>1.4</td>
</tr>
<tr>
<td>Montana</td>
<td>1.0</td>
</tr>
</tbody>
</table>


3.3.2 Decreasing Delays at Weigh Stations

In traditional weigh station operations, even trucks with legal weights experience unnecessary delays at the weigh stations. It has been documented that on average, each truck experiences a delay of approximately 5 minutes for weight compliance checks (Benekohal et al., 1999). This delay increases with the traffic at the weigh stations, ranging from 8.7 to 137.6 minutes. Such long delays resulting from the inefficient
Advantages appear to lie above the previous environment, which is why virtual WiMAX systems can also help minimize this problem.

Panasonic has demonstrated the reduction of WiMAX systems in a study of 20 (2002). The study showed that the number of virtual WiMAX systems can also help reduce the environmental impact of virtual WiMAX systems. This is achieved by reducing the amount of energy required to process the data. Therefore, virtual WiMAX systems in terms of their environmental impact are better than their counterparts in terms of their potential benefits.

Hence, virtual WiMAX systems can also help reduce the environmental impact of virtual WiMAX systems.

3.3.3 Environmental of Safety and Stability

Environmental of Safety and Stability: The environmental of Safety and Stability can also help reduce the environmental impact of virtual WiMAX systems. This is achieved by reducing the amount of energy required to process the data. Therefore, virtual WiMAX systems in terms of their environmental impact are better than their counterparts in terms of their potential benefits.

A simulation study by Ramig (8651) shows the potential impacts of virtual WiMAX. The simulation study shows that the number of virtual WiMAX systems can also help reduce the environmental impact of virtual WiMAX systems.

Therefore, virtual WiMAX systems can also help reduce the environmental impact of virtual WiMAX systems. This is achieved by reducing the amount of energy required to process the data. Therefore, virtual WiMAX systems in terms of their environmental impact are better than their counterparts in terms of their potential benefits.
emissions and maximize fuel efficiency by limiting the number of idling trucks at weigh stations.

3.3.4 Saving Taxpayers' Money

WIM systems help enforcement agencies easily monitor and keep weights under control in a cost effective way. With virtual WIM systems, enforcement agencies can target violators with less enforcement personnel, leading to the enhanced operational efficiency and safety, infrastructure protection, and less emissions and less delay of trucks. All these benefits mean savings to the taxpayer through better roads, cheaper goods, and more efficient enforcement operations.

3.3.5 Collection of Valuable Data

Virtual WIM systems provide valuable data for future transportation planning and maintenance activities. The WIM systems collect traffic data continuously, even while the weigh stations are closed. Information on peak times, traffic volumes, type of vehicles and weight of vehicles allows transportation planners to improve existing systems and design better future systems. In addition, the data collected from the WIM system can be used for scheduling truck weight enforcement resources and details, both geographically and temporally (i.e., by time of day).

For example, the current WIM systems installed at key locations in California highways provide 24-hour traffic information. The primary information collected from the WIM systems includes axle weights and gross weight, axle spacing, vehicle classification and speed. The information gathered is essential for the pavement studies, highway monitoring and capacity studies, accident rate calculations, and analysis of truck transport practices.
3.4 Case Studies

This section presents case studies of planning activities of other states directed toward accommodating advanced WIM technologies. These examples were selected to indicate the types of activities being undertaken with different technologies in a range of geographic areas across the United States.

3.4.1 Florida’s Weigh Station Bypass Detection System

In Florida, as with many states in the United States, commercial vehicles are required to meet legal requirements for weight and size. As the Virtual Weigh Station (VWS) concept is propagating throughout the United States, Florida Department of Transportation (FDOT) plans to utilize this strategy for screening overweight trucks and the successive apprehension and citation issuance for those violators. Two major activities deserve special attention.

First, FDOT has teamed up with the Center for Advanced Transportation Systems Simulation (CATSS) at the University of Central Florida to deploy an “outdoor” lab to evaluate selected technologies for a virtual weigh station (FDOT, 2004). There is an abundance of vendors marketing technologies and devices to serve the needs fulfilled by virtual weigh stations. However, there is a deficiency of deployment studies that could aid state agencies in the selection of appropriate proven technologies. This lab will serve as a unique facility in the nation, evaluating hardware and software enforcement technologies. Vendors are invited to submit their hardware and software systems for an unbiased evaluation of operational characteristics — not from an indoor lab but rather from an environment that mimics the exact operational characteristics where these systems will be deployed. The evaluation results will be shared with transportation and research agencies. This research project has two additional objectives, namely, the development of a framework for virtual weigh stations and the deployment of a Web-based public database to serve as a reference for available technologies, vendors, and evaluation results.

Second, FDOT is implementing a weigh station bypass detection system designed to detect possible overweight vehicles which exit before the weigh station and re-enter the highway afterwards. Although WIM scales are very accurate for determining the commercial vehicle’s weight, most states including Florida only allow citations to be written based on static scale measurements. The weigh station system works fine as long as the commercial vehicles come through the weigh station. However, there is a high probability in reality that if a commercial vehicle is deliberately running overweight, the driver may decide to take a route that avoids the weigh station. Because of primary and secondary roads, there is usually at least one alternative route around every weigh station. In response to this reality, FDOT initiated a pilot project to develop a weigh station bypass detection system.

The first installation will be near the Punta Gorda weigh station located on I-75 in Charlotte County. This system is designed to screen all commercial vehicles using the exit and entrance ramps before and after the weigh station and to categorize them as
either “potential violator” or “non-violators.” Law enforcement personnel will focus their attention toward potential violators that appears to violate Florida’s weight or dimension requirements or intentionally avoid the weigh station.

The weigh station bypass detection system will be automated, determining commercial vehicle weights using WIM technology. If the commercial vehicle is shown to be overweight, this will trigger optical character recognition (OCR) cameras that will record license plate numbers and capture a digital image of the vehicle. The system will then merge these three pieces of data and send an image, via wireless communication, to an enforcement officer’s patrol car laptop and to the computer located at the Punta Gorda weigh station. The image will consist of a digital photo of the offending commercial vehicle superimposed with WIM data and the license plate number. This system will also have a random component which will be set by law enforcement personnel to randomly flag a commercial vehicle for further review even though none of the other violator criteria is met. License plate numbers of commercial vehicles bypassing the Punta Gorda weigh station will be stored in a database for future use.

Once the system is developed and brought on-line, the system’s database will be integrated into Florida’s Commercial Vehicle Information Exchange Window (CVIEW) system. Florida’s CVIEW will provide Florida’s commercial vehicle regulatory agencies with a single database that contains all information used in the regulation of commercial vehicles operating in Florida. By utilizing existing infrastructure to the greatest extent possible, the system is a very cost-effective method of augmenting the current FDOT weight enforcement efforts. This will greatly enhance the efforts of finding and dealing with unsafe or illegal commercial operators.

3.4.2 Kentucky’s Remote Monitoring System and Virtual Weigh Station

To provide effective roadside enforcement, Kentucky has invested in state-of-the-art enforcement stations, providing a high level of enforcement on the route segment where they are located. However, much of Kentucky’s truck traffic is on routes not monitored by fixed weigh stations. Even on monitored routes, routes for detour are often available to bypass the weigh station. Mobile enforcement has been used to augment fixed weigh stations, but Kentucky Vehicle Enforcement has concerns about its effectiveness because truckers know where the mobile enforcement is set up, and thus they can avoid it. Furthermore, limited staffing restricts the number of routes that can be monitored.

In response to this problem, Kentucky developed a virtual weigh station that combines the Remote Monitoring System (RMS) with a weigh-in-motion system (Crabtree, 2003). To automatically check commercial vehicles’ credentials, taxes, and safety rating, the Remote Monitoring System was first developed and deployed on US-25 in Kenton County, Kentucky. The system uses roadside photo equipments installed for the RMS that capture images of passing trucks and transmit those images to the “Image Review Station” at the Kenton County weigh station. From this image, enforcement personnel can read the USDOT number, enter the number into Kentucky’s observation system, and instantaneously check the motor carrier’s registration, tax status, and safety record.
Later, researchers in Kentucky Transportation Center identified the potential of combining the RMS with a WIM system to create a virtual weigh station. The virtual weigh station consists of an image capture system provided by Computer Recognition Systems (CRS) and a WIM system of Quartz Piezo provided by International Road Dynamics (IRD). All system components were installed in December 2002, providing the same functionality as the fixed weigh stations at lower cost by not requiring continuous staffing, nor continuously monitoring. The system also provides covert enforcement, thus making it more difficult for violators to avoid enforcement.

Based on the data collected from 48 hour enforcement in June 2003, a preliminary evaluation of the system's effectiveness showed that only 34% of total 493 system transactions triggered by trucks was readable for USDOT number. This low efficiency was resulted from some deficiencies of the system, including blurry images, numbers too small to read, poor contrast between numbers and background, location and timing of image capture, and lighting and shadowing. Although some challenges still remain to be solved, the system turns out to be very cost effective. The potential value of virtual weigh station was evaluated for fraction of the cost of a fixed weigh station to be $100K to $130K versus $3-5 million. This implies that approximately 40 virtual weigh stations could be installed at the same cost for a new fixed weigh station. It can also spread enforcement coverage to many routes where fixed station may not be feasible.

3.4.3 Montana's STARS Program

The Montana Department of Transportation (MDT) developed a 10-year WIM plan in 1997, and initiated a virtual weigh station project to develop “State Truck Activity Reporting System (STARS).” The project aimed at improving the efficiency and effectiveness of truck weight enforcement activities performed by the Motor Carrier Services (MCS) Division of MDT, and providing MDT access to improved truck-related data for use in pavement design and planning applications.

STARS consists of an array of WIM and AVI sensors deployed across the Montana highway system that feed data to customized software programs, including system of 26 piezo-based WIM recorders, portable WIM program at 64 sites, comprehensive calibration program, and a software program dealing with the collected data. At each STARS location, WIM hardware installed directly in the traveling lanes of the roadway unobtrusively and automatically collects information on the weight and configuration of the vehicles traveling on that roadway. This data subsequently processed to characterize commercial vehicle operations at the site by vehicle classification and weight. Information of this type is essential to several MDT activities, from vehicle weight enforcement to roadway design and transportation planning.

One of unique features of the STARS is the capability of automatically identifying overweight incidents and dispatching enforcement personnel to individual overweight incidents in real time. To identify these locations, MDT developed a software program, called “Measurement of Enforcement Activity Reporting System (MEARS)” that processes the STARS data specifically to obtain information on commercial vehicle and overweight vehicle activity.
A pilot project to evaluate the effectiveness of Montana's STARS has shown that a significant reduction was seen in the percent of overweight vehicles in the traffic stream (Stephens, et al., 2003). Statewide, throughout the extensive network of highways covered by STARS, the percent of overweight vehicles in the traffic stream dropped by 22 percent. The average amount of overweight on each vehicle was also decreased by 16 percent. The overall reduction in pavement attributable to the STARS program statewide over the year was on the order of magnitude of 6 million ESAL-miles of travel. The cost savings associated with this change in pavement damage was estimated to be approximately $700,000 per year.

3.4.4 Indiana's Photo Virtual Weigh Stations

Virtual weigh station project initiated by Indiana Department of Transportation (INDOT) and Purdue University in 2000 was originally motivated by the need to have more dynamic procedures for catching habitual overweight trucks that bypass port-of-entry fixed scale houses (Nichols, et al., 2003). Originated as Strategic Highway Research Project and Long Term Pavement Performance Project sites, WIM systems were installed at 42 WIM sites to collect continuous vehicle data to be used for research, highway design and planning. Indiana State Police (ISP) wanted a method for using the WIM systems for dynamic weight enforcement efforts.

Using existing WIM equipment, a laptop computer, and wireless communication technology, early concept of the virtual weigh station developed in Indiana was that ISP commercial vehicle enforcement mobile units connect wirelessly to WIM cabinets to see real-time truck weight data. The WIM reading is used to screen vehicles to be pulled over and weighed with certified portable scales. For the virtual weigh station to function, radio equipments were installed in 2 WIM sites, I-65 in Merrillville and US-24 in Fort Wayne, Indiana, and ISP has 4 radio units to use during enforcement efforts.

More recently, a collaborative effort between INDOT, ISP, Mettler Toledo and Purdue, has developed advanced virtual weigh station with image capturing capability. The photo virtual weigh station was installed and is tested on SR-1 in southeast Indiana – 2 lane road with high truck volumes between I-74 and I-275. The objective of the system is to develop a virtual WIM system that can record picture of overweight truck at WIM site and transmit the image to a police cruiser downstream. The Photo WIM system developed in Indiana is at the early stage of development and thus should only be viewed as work in progress. When using WIM data for enforcement, enforcement personnel desire more accuracy than traditionally required for performance monitoring. To create more reliable online reports on various sites for ISP enforcement scheduling purposes, Purdue is conducting large-scale analysis of database from all Indiana WIM sites.

3.4.5 Virtual Weigh Station Project for the GCM Corridor

A virtual weigh station project designed for the Gary-Chicago-Milwaukee (GCM) corridor, one of the busiest commercial vehicle corridors in the United States, provides a good example that shows how multiple agencies cooperatively plan and deploy ITS technologies for commercial vehicle operations and enforcement.
The GCM Corridor is one of four multi-agency ITS coalitions formed as a result of the Internodal Surface Transportation and Efficiency Act of 1991. Officially started in 1993, the GCM Corridor is comprised of all of the major transportation agencies in the 16 county area connecting Gary, Indiana through Chicago, Illinois to Milwaukee, Wisconsin. The GCM Corridor includes the three state departments of transportation, 16 counties, and numerous local agencies, as well as the Federal Highway Administration. The objective of the GCM Corridor Program is to improve the efficiency and effectiveness of the Corridor's transportation infrastructure through the planning, design, deployment, and evaluation of leading edge ITS applications. As part of the GCM Corridor program, a virtual weigh station pilot project was recently initiated by a collaborative effort of the GCM corridor agencies (GCM Corridor, 2004).

The virtual weigh station pilot project involves the deployment of virtual weigh stations (VWS) at three sites, one each in Wisconsin, Illinois and Indiana. The objective of this project is to introduce the use of WIM sensor and communication technologies to the GCM corridor agencies in an effort to encourage greater compliance with truck weight restriction laws. The project calls for the development of a central operating system that would monitor and control multiple sites across the three states. Besides the central dispatch computer, the VWS system also includes high-speed WIM scales, digital camera, communication systems, police-vehicle computers and inspection sites. The computer in the enforcement vehicles will enable enforcement officers to screen large numbers of trucks on multiple routes in order to single out the gross offenders who will then be pulled over and weighed along the roadside using conventional portable static scales. Digital cameras will record images of non-compliant vehicles the moment they are screened for weight to help the enforcement officers identify them several miles downstream. This allows enforcement officials to screen large numbers of vehicles with a minimal impact on the flow of truck traffic.

Depending on the placement of the WIM systems, any roadways in the corridor could be monitored by virtual station enforcement personnel. Since the three states have limited permanent weight enforcement facilities within the GCM corridor, this initiative is seen as a cost-effective solution that can be developed in a reasonably short time.

3.4.6 Bi-National Virtual Weigh Stations for Cross-border Mobility

Rapid growth in trade and commercial truck traffic across the Washington State-British Columbia border has strained border crossing facilities and enforcement agencies. As a result, commercial vehicles are often delayed at the border, and long queues of trucks waiting to cross in either direction are a common sight. It has been estimated that $40 million in business productivity is lost annually due to the border crossing delays (SAIC, 2003). To alleviate these problems, the public and private stakeholders in Washington State and British Columbia established the International Mobility and Trade Center (IMTC) partnership in 1997. The IMTC is a coalition of over 60 U.S. and Canadian business and government entities whose mission is to identify and pursue improvements to cross-border mobility.
The IMTC has supported the development of a network for assimilating and exchanging information between British Columbia and Washington State motor vehicle enforcement agencies to enable bi-national weigh-in-motion information exchange, referred to as “Bi-National Virtual Weigh Station.” With this CVISN-based system, both northbound and southbound trucks operating in the IMTC will be monitored for safe and legal compliance, allowing eligible carriers to bypass IMTC corridor weigh stations on both sides of the border.

Based on statistical weigh station usage data provided by the WSDOT and the ICBC, and focused on five weigh stations along the IMTC corridor, a benefit-cost analysis was conducted to quantify the potential benefits and costs associated with the WIM data sharing system to IMTC stakeholders (SAIC, 2003). The analysis showed that travel time savings for motor carriers associated with bypassing weigh stations are expected to be between $25.6 and $61.7 million over the next 10 years. The corridor bypass time savings occur as driver/vehicle/shipment are screened initially via electronic means or through physical inspection, then are cleared from further inspections along the corridor. This information is then passed electronically to other weigh/inspection sites along the corridor, subject to verification via WIM and AVI transponder technologies.

Additionally, resource savings and safety benefits were also estimated for the enforcement agencies. This would be expected since resource efficiencies to the agencies would be realized through the elimination of “double weigh-ins” of “safe and legal” trucks along the IMTC corridor, allowing additional resources to be focused on non-transponder-equipped trucks, and especially carriers considered “high risk.” Based on this, the safety benefits associated with this operational concept are estimated to be between $21.1 and $50.9 million over the next 10 years.

Overall, the virtual weigh station deployment at the border crossing facilities showed significantly positive benefit-cost ratios ranging from 4.0:1 to 8.5:1, and the benefits of employment of the virtual weigh station operational concept in a bi-national border region range from approximately $35 to $102 million, as moving from low to high ITS scenarios. The estimated payback periods for the weigh station ITS deployments are 2 years for the low and medium ITS scenarios, and 1 year for the high ITS scenario. As this technology is currently just being deployed, it will be interesting to examine how this concept is actually deployed in the field, and if the benefits estimated in this evaluation study can be validated.

The IMTC public-private partnership provides an international model for development of freight border ITS/CVO projects across international borders. The IMTC model involves successful interactions with federal, state, and local governments from two countries to fund and deploy major border ITS solutions for commercial vehicle operations and enforcement activities. The IMTC structure, functions, processes and real-world deployment of advanced WIM technologies can serve as an input or point of discussion to other bi-national stakeholder communities in border regions with significant freight flows such as the United States – Mexican border.
4. Key Considerations in the Development and Deployment of VWCS

Weigh-in-motion systems can be defined as the tools that estimate static loads of the vehicles using dynamic load impact force measurements. Virtual WIM systems are a new set of weight enforcement tools where the mainline weigh-in-scales are used as screening rules. In this exposition, key considerations required in the implementation processes of Virtual Weigh and Compliance Systems (VWCS) will be looked into. The key factors can be categorized depending on the time of implementation.

4.1 Overview of Issues in Development and Deployment of VWCS

Before implementation, the WIM facility location has to be closely surveyed to meet necessary physical requirements for VWCS. Based on this site, the system components required for VWCS will also be specified. An in-depth knowledge of the VWCS systems available commercially has to be known for proper selection. The other essential criterion is the budgetary considerations involving VWCS setup and operating costs. The VWCS system setup has to be planned and an effort must be made to teach the execution aspects to the personnel and other agencies involved in the handling of the system to set up a workable "quality assurance program".

Upon the choice of implementation, tests (dry runs) must be made to look into the data requirements and accuracy of the system. After the implementation of the system, the systems need constant maintenance and personnel for handling the system. After the implementation, an effort must be made to improve the operational efficiency of the system. The information gathered from the weigh stations must be translated into suitable formats for information dissemination and sharing among different agencies involved. The various issues to be considered in the deployment and development of VWCS are summarized in Table 7.

Table 7. Issues in Development and Deployment of VWCS

<table>
<thead>
<tr>
<th>Stages</th>
<th>Issues under consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before implementation</td>
<td>- Physical requirements for WIM facility location</td>
</tr>
<tr>
<td></td>
<td>- Standard specification of system components</td>
</tr>
<tr>
<td></td>
<td>- Costs and personnel requirements</td>
</tr>
<tr>
<td></td>
<td>- Justification and feasibility</td>
</tr>
<tr>
<td>During implementation</td>
<td>- System installation</td>
</tr>
<tr>
<td></td>
<td>- System calibration</td>
</tr>
<tr>
<td></td>
<td>- Data requirements and accuracy</td>
</tr>
<tr>
<td>After implementation</td>
<td>- Operations and maintenance</td>
</tr>
<tr>
<td></td>
<td>- Information collection, Dissemination and sharing</td>
</tr>
<tr>
<td></td>
<td>- Quality assurance program</td>
</tr>
</tbody>
</table>
4.2 Physical Requirements for WIM Facility Location

Although the actual system characteristics of different WIM systems are different, the layout and the considerations that should be made are essentially the same. Generally speaking, cost will most likely be a key concern, but it is also important to carefully study the location that is chosen for the WIM system. The design speed of WIM systems is an important issue in designing the geometric of a WIM facility. In evaluation of the geometric design of the location, horizontal grade, roadway grade, cross slope, lane width must be within acceptable levels. In cases where a long design life for pavements is established, the reliance on the WIM data will most likely be high (McCall and Vodrazka, 1997). Additional considerations for a good site location are availability of access to power and phone, adequate location for the controller cabinet, proper drainage facilities and freeway traffic conditions.

In the preliminary site evaluation, steps need to be taken to find that there are no alternative routes to circumvent the system by overweight trucks. The site chosen should be such that it is not a point of high congestion such that more delays may creep into the highway traffic. Table 8 shows some of the general checklist site selection criteria.

Table 8. WIM Site Selection Criteria

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Objective</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distance from controller unit</td>
<td>Drive time (minutes)</td>
</tr>
<tr>
<td>2</td>
<td>Roadway geometry</td>
<td>Alignment, cross-slope, lane width</td>
</tr>
<tr>
<td>3</td>
<td>Pavement structure</td>
<td>Thickness</td>
</tr>
<tr>
<td>4</td>
<td>Traffic mix</td>
<td>Percent trucks and total volume</td>
</tr>
<tr>
<td>5</td>
<td>Multiple lanes</td>
<td>Number of lanes</td>
</tr>
<tr>
<td>6</td>
<td>Power and communication</td>
<td>Distance to service</td>
</tr>
<tr>
<td>7</td>
<td>Right-of-way</td>
<td>Distance to safe parking</td>
</tr>
<tr>
<td>8</td>
<td>Adjacent space</td>
<td>Park calibration truck</td>
</tr>
<tr>
<td>9</td>
<td>Space for structure</td>
<td>Area for building</td>
</tr>
<tr>
<td>10</td>
<td>Sign bridge structure</td>
<td>For mounting overhead Devices</td>
</tr>
<tr>
<td>11</td>
<td>Roadside pole</td>
<td>For mounting overhead Devices</td>
</tr>
<tr>
<td>12</td>
<td>Lighting</td>
<td>Security and night visibility</td>
</tr>
<tr>
<td>13</td>
<td>Pavement condition</td>
<td>Rutting, cracking, Smoothness</td>
</tr>
<tr>
<td>14</td>
<td>Pavement rehabilitation</td>
<td>Rehabilitation schedule</td>
</tr>
<tr>
<td>15</td>
<td>Circuit time for calibration truck</td>
<td>Cycle time</td>
</tr>
<tr>
<td>16</td>
<td>Sight distance</td>
<td>For clear visibility of traffic</td>
</tr>
<tr>
<td>17</td>
<td>Proximity to highway patrol and enforcement site</td>
<td>For ground truth weights</td>
</tr>
<tr>
<td>18</td>
<td>Access to satellite sites</td>
<td>Distance from primary site</td>
</tr>
<tr>
<td>19</td>
<td>Safety features</td>
<td>Longitudinal direction</td>
</tr>
<tr>
<td>20</td>
<td>Traffic congestion</td>
<td>Free-flow or stop-and-go</td>
</tr>
<tr>
<td>21</td>
<td>Bending plate WIM</td>
<td>Existing, buildable, or not buildable</td>
</tr>
</tbody>
</table>

Source: Middleton, et al., 2004
Other exogenous criteria that must be met for locating a single weigh station, include avoiding environmental impact, minimizing avoidance of the weigh station, avoiding the need to weigh all trucks statically, and minimizing the staffing requirements needed.

The nature of pavement also becomes a critical part of site location as it produces variable bounce causing impact forces thus bringing about variations in the instantaneous axle measurements. The ASTM has designated guidelines in the ASTM standard E 1318-94 for geometric design for different types of weigh in motion sensors and nature of pavement surface as shown in Table 9 (ASTM, 1994).

Table 9. ASTM Standard Geometric Design Requirements

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Curvature</td>
<td>Radius ≥ 1740m 46m before/after</td>
<td>Radius ≥ 1740m 46m before/after</td>
<td>Radius ≥ 1740m 46m before/after</td>
<td>Radius ≥ 1740m 46m before/after</td>
</tr>
<tr>
<td>Roadway Grade</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 1% 46m before/after</td>
</tr>
<tr>
<td>Cross Slope (lateral)</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 2% 46m before/after</td>
<td>≤ 1% 46m before/after</td>
</tr>
<tr>
<td>Lane Width</td>
<td>3 to 4.5m 46m before/after</td>
<td>3 to 4.5m 46m before/after</td>
<td>3 to 4.5m 46m before/after</td>
<td>3 to 4.5m 46m before/after</td>
</tr>
</tbody>
</table>

Source: ASTM, 1994

Another important consideration of the sites is availability of access to power, telephone or other communication utilities. These utilities are dependent on the range of operations and amount of data collected at the weigh station. Power source is essential and any source like AC or solar power can be used. Communication can be done using telephone or cellular wireless, though wireless communications involve more costs. The choice of controller cabinet (CC) depends on the design life of the site. The CC must be protected from elements like runoff from heavy rains, irrigation and drainage facilities. It should be placed such that vehicles leaving the roadway do not hit it and protect the servicing technicians from danger. Care must be taken so as to properly place the CC with good sight distances near the sensors to diminish any possible errors in calibration. Traffic conditions are also critical for WIM station deployment. The site should ensure a smooth flow of traffic. Traffic conditions like stop and go traffic, slow moving, lane changing should be minimized.

4.3 Standard Specification of System Components

The VWCS systems proposed require an integration of AVI and WIM technologies, so that the weight and safety check of commercial vehicles and drivers can be done in real time on highway main lanes under normal traffic speed. Weigh-in-Motion systems generally have four main elements, roadway component, vehicle component, data & communications unit and weight enforcement center. The roadway component includes detectors to check for vehicle presence as well as for vehicle speed, a WIM scale, and an over-height detector. The roadway system also consists of a control assembly, directional
signals, and variable message signs. Finally, for the tracking, a series of inductive loops, one upstream to the WIM detector and one downstream are placed. The computer component consists of a desktop computer, a display, and a printer.

4.3.1 WIM Scales

As shown in Table 5, WIM systems are mainly classified into four different types according to their application and details about their respective functions, performance, and user requirements. The classification mainly depends on the speed of the vehicles, type of application, number of lanes. Some of the existing WIM scales used in real world practices include bending plates, piezoelectric sensors, and load cells.

**Bending Plate System**

Bending plate WIM systems have plates with strain gauges attached to them. These sensors are placed perpendicular to the direction of travel and when a vehicle moves over them the strain gauge readings are used to calculate the dynamic load (McCall and Vodrazka, 1997). The system needs extensive calibration to convert the dynamic load measurements to the required actual static loads. The bending plates systems can either be portable or permanent. The portable systems are useful for high-speed WIM applications and maybe employed at a adjacent WIM stations instead of mainline WIM stations. Depending on the intended usage, a bending plate system can be classified as ASTM Type I, II, III, or IV. The systems consists at least one scale and two inductive loops. An inductive loop placed at the upstream detects the incoming vehicles and sends a signal to the WIM sensor. The axle spacing is determined by vehicle speed is determined by three methods: weighpad to inductive loop, weighpad to axle sensor, and weighpad to weighpad, if the weighpads are staggered. The on-site processor is used to analyze the data emanating form the WIM system.

**Piezoelectric System**

The Piezoelectric sensor as the name specifies uses Piezoelectronic sensors to estimate the static loads. The sensors detect the changes in voltage caused by the pressure exerted by a moving vehicle, and calculate the dynamic load (McCall and Vodrazka, 1997). Similar to the bending plate systems the calibration methods and dynamic load measurements are used to estimate the static loads. The Piezo WIM systems consist of one or more sensors placed on the traffic lane which may or may not be wrapped in an epoxy-filled metal channel, usually made of aluminum. The whole system typically consists of one sensor and at least inductive loop. These are placed perpendicular to the traffic lane. In case of more than one inductive loop, an upstream inductive loop is used to detect the approach of incoming vehicles and the downstream loops to determine the speed of the vehicles. Again, this information can be analyzed from a site processor with operating software and can be saved in a manner so that the information can be downloaded on site or through a computer.

**Load Cell System**

The load cell WIM system consists of a load cell with scales, placed across the traffic lane (McCall and Vodrazka, 1997). The scales are used to detect an axle weigh both the right and left sides at the same time. The sum of the right and left side measurements are
used to determine the weight of the vehicle. The two in-line scales operate independently. Depending on the design of the system, it can be classified as ASTM Type I, II, III, or IV. In addition to the load cell, at least one inductive loop and one axle sensor are fitted to this system. The inductive loops usually placed upstream are used to detect the incoming vehicle. Sometimes a downstream inductive loop is placed to determine the axle spacing to measure the vehicle speed. The axle sensor is placed downstream determines the axle spacing and the velocity of the vehicle. Again, the data is analyzed from the site processor and software and saved in a format available for download.

Figure 8 presents a typical design of WIM scale and other component installation.

![Diagram of WIM scale installation](image)

(a) Piezoelectric Sensor

(b) Typical Bending Plate or Load Cell WIM system

Source: Minbela and Klein, 2000

Figure 8. WIM Scale Installation Schemata
4.3.2 Data Communication Unit

Data transmission and communication between various units in this integrated system is of utmost necessity and can be achieved by the application of the following various technologies.

Wired or Wireless LAN
Wireless LAN technology, which is used widely in ITS applications, is used for relatively short distances. The frequency of 2.45 GHz, belongs to the ISM (Industrial, Medical, and Science) band, is introduced for use under the “ad-hoc” mode of the IEEE802.11b protocol and spread spectrum. Wired LAN technology using Ethernet architecture is generally used for long distance data transmission in this system, such as multi-DMVs transmissions, multi-WHCC's transmissions, and between WHCC and CSC. This technology is also an alternative while the on-site conditions are not suitable for wireless LAN. WAN technology is used between the system and any other private components, such as ISP and truck company's surveillance centers. A common hypertext protocol is adopted with standard internet browser as the interface.

Dedicated Short Range Communication (DSRC)
DSRC technology using infrared or microwave is adopted for data transmission between the MSS and the OBU. It is suggested that the same technology used for the Electronic Toll Collection (ETC) project should be used in this system.

4.3.3 Vehicle Identification Technologies

Loop detectors
Traditional loop detectors are able to provide fundamental traffic parameters such as volume, occupancy, and speed by determining if inductance changes are significant enough to indicate a vehicle passing over the loop. The output signal is usually binary, such as either 0 for non-presence or 1 for presence. In addition, other information including arrival time, duration, lane, and speed for individual vehicles can be collected.

Video Image Processing
It has been reported that one of video image sensing techniques is able to produce individual vehicle information. The proposed system uses overhead cameras that automatically take a picture of every passing vehicle and process the image to extract useful information including vehicle length, width, and color. The extracted information from both upstream and downstream detection stations can be correlated, and then re-identify vehicles.

Automatic vehicle identification (AVI)
AVI technologies are based on license plate identification and the use of transponder tags. Road infrastructure capable of reading in-vehicle tags identifies individual vehicle information including unique ID, speed, and location, and transmits the information to the central computer. A RFID transponder replaces the traditional paper-parking permit. Enforcement is conducted by scanning the RFID.
4.4 Weigh-in-Motion System Costs

The design and selection of WIM systems are based on the considerations such as initial capital cost, accuracy, life span, permit requirements, and maintenance costs. Each of the three primary WIM systems has different costs, life spans, and accuracies. For example, Bushman and Pratt (1998) compared the three types of technologies with respect to accuracy, life span and cost, as summarized in Table 11. The study concluded that the piezoelectric systems are the least accurate of the three technologies"(5%) and also offer the lowest expected life span at 4 years. In general, the study concluded that as the accuracy of the system increases, the cost increases; however, the system also has a longer expected life span. The most accurate system analyzed was the single load cell system with 6 percent accuracy at a 95 percent confidence level and offers the longest life span. However, an installation cost of the single load cell system is higher than that of bending plate system, while it has much lower maintenance cost than bending plate.

WIM system costs may be expressed in terms of the life cycle cost consisting of initial capital cost (in-road WIM equipment, installation labor and materials, initial calibration, and traffic control), and life cycle maintenance costs (labor and materials, traffic control, and system recalibration). Table 10 contains budgetary initial capital costs for piezoelectric, bending plate, and load cell technologies assuming typical road, traffic, and weather conditions. These costs may vary from manufacturer to manufacturer and with sensor model. Roadside cabinets, WIM electronics, power and communication connections, etc. are not included as these are common to all the technologies.

Table 10. Budgetary Initial Capital Costs of WIM Systems

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Piezoelectric</th>
<th>Bending Plate</th>
<th>Load Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (95% confidence)</td>
<td>±15 %</td>
<td>±10 %</td>
<td>±6 %</td>
</tr>
<tr>
<td>Expected Life</td>
<td>4 years</td>
<td>6 years</td>
<td>12 years</td>
</tr>
<tr>
<td>In-road equipment</td>
<td>$4,500</td>
<td>$13,000</td>
<td>$34,000</td>
</tr>
<tr>
<td>Installation labor and materials</td>
<td>$3,500</td>
<td>$6,500</td>
<td>$10,500</td>
</tr>
<tr>
<td>Traffic control</td>
<td>$1,000 (1 day)</td>
<td>$2,000 (2 days)</td>
<td>$4,000 (4 days)</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>$9,000</td>
<td>$21,000</td>
<td>$48,000</td>
</tr>
</tbody>
</table>

Source: Bushman and Pratt (1998) and Bergan, et al. (1997)

The life cycle maintenance costs vary due to differences in traffic volumes and truck weights, weather, original installation procedures, roadbed condition, onsite quality control, etc. Table 11 presents WIM system life cycle maintenance and repair costs averaged over North American installations. They assume that annual routine maintenance (e.g., road inspection and crack filling) is performed on the roadbed surrounding the WIM system. Piezoelectric sensors are assumed to require replacing every 3 years, bending plate refurbishing every 5 years, and single load cell replacing...
every 5 years. Life cycle maintenance costs may also vary with manufacturer and sensor model.

Table 11. Life Cycle Maintenance Costs of WIM Systems

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Piezoelectric</th>
<th>Bending Plate</th>
<th>Load Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-road equipment</td>
<td>$4,000</td>
<td>$6,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Installation labor and materials</td>
<td>$4,000</td>
<td>$5,500</td>
<td>$500</td>
</tr>
<tr>
<td>Traffic control</td>
<td>$1,500 (1 day)</td>
<td>$1,500 (1 day)</td>
<td>$750 (1/2 day)</td>
</tr>
<tr>
<td>Total maintenance cost</td>
<td>$9,500</td>
<td>$11,000</td>
<td>$2,250</td>
</tr>
</tbody>
</table>


The WIM system life cycle costs may be amortized over the life cycle. Based on the initial installation and life cycle maintenance costs shown in Tables * and ** and a discount rate of 10% over a 20 year WIM system life cycle, the average annual cost for each WIM technology system is estimated as
- Piezoelectric: \$3,092 per year
- Bending Plate: \$4,636 per year
- Single Load Cell: \$5,982 per year

These figures show that the incremental cost for improved WIM system accuracy, durability, and reliability is small when compared to the annual operating budget of a weight enforcement facility. Costs over other life cycle intervals may be computed as required.

4.5 WIM System Installation

The WIM system has to be installed and maintained based on the recommendations of the vendor. All of the necessary equipment, materials, WIM components, and site plans should be on-site and tested before the procedure is started. The installation process depends on the type of scale used for weigh in motion. Table 12 provides guidelines suggested by Minnesota Department of Transportation for installation of the WIM system.
Table 12. Minnesota DOT Checklist for Installation of WIM System

<table>
<thead>
<tr>
<th>Hand sketched map</th>
<th>Sketch layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>Location</td>
</tr>
<tr>
<td></td>
<td>Roadway name</td>
</tr>
<tr>
<td>o All lanes, shoulder, intersecting roads, reference post number</td>
<td>o Reference post</td>
</tr>
<tr>
<td>o Width of lanes, medians, shoulders, lane lengths needed</td>
<td>o Relative position to nearest intersection</td>
</tr>
<tr>
<td>o Power, phone</td>
<td>o Relative position to nearest city</td>
</tr>
<tr>
<td>o Cabinet location (door facing north preferred)</td>
<td>o Directions from central office</td>
</tr>
<tr>
<td>o Drainage, ditches</td>
<td>Calibration truck route</td>
</tr>
<tr>
<td>o Parking spot</td>
<td></td>
</tr>
<tr>
<td>Roadway history</td>
<td></td>
</tr>
<tr>
<td>o Age of pavement</td>
<td></td>
</tr>
<tr>
<td>o Planned rehab</td>
<td></td>
</tr>
<tr>
<td>o Type of pavement</td>
<td></td>
</tr>
<tr>
<td>o Smoothness, crown</td>
<td></td>
</tr>
</tbody>
</table>

Source: Middleton et al., 2004

4.6 WIM System Calibration

WIM system calibration is used to ensure that the estimation of the static weight produced by the WIM system is as close to the static weight as possible. A system is calibrated to offset the effects of site conditions such as pavement temperature, vehicle speed, and pavement conditions. Calibration of Weigh-In-Motion (WIM) systems is still a major concern. Improper calibration leads to incorrect estimation of recorded axle loads resulting in insufficient fatigue calculations, pavement thickness designs that are too thin, and hence premature pavement failure.

Calibration of WIM sensors is especially important, because even small errors in vehicle weight measurements caused by poorly calibrated sensors result in significant errors in estimated pavement damage when those axle weights are used in pavement design analyses.

ASTM procedures recommend an eight-step process to calibrate WIM systems (ASTM, 1994). First, all WIM system settings should be adjusted to the vendor's recommendations or to a best estimate of proper setting based on previous experience. Second, vehicles that go through the system for calibration purposes must be forced into the static scales at the site or a nearby facility to obtain static weight data. With a radar gun or other means, speed data should be taken to measure the speed that the truck moves through the WIM sensors. Third, tire loads and axle spacing should be recorded at the static scales. Fourth, the difference should be calculated between the WIM system estimate and the reference value for the speeds, wheel loads, axle loads, axle group loads, gross vehicle weights, and axle spacing measurements. The differences should be expressed in percents and a mean value should be obtained for each set of measurements.
Fifth, the calibration factors should be entered into the WIM system. Sixth, it should be determined whether or not the calibrated system can be expected to perform at the necessary tolerances. Seventh, if a large number of differences for the data occur and does not meet the tolerances levels shown in the ASTM values for the specified system, the system will most likely not perform to a beneficial level. Eighth, precision and bias information should be noted although at this time, no procedure has been developed to determine what effect this data has on WIM system performance. MNDOT and CALTRANS have calibration procedures slightly different from the ASTM guidelines (McCall and Vodrazka, 1997).

4.7 Accuracy of WIM System

Accuracy in terms of weigh-in-motion refers to the closeness between a quantity measured or estimated by a WIM system and an accepted reference value (ASTM, 1997). It is important to decide the necessary accuracy needed before deciding the type of WIM to purchase. The ASTM gives accuracy limits for each type of WIM system as a standard to be set. Additionally, there have been many experimental studies to show the level of accuracy of the various WIM systems.

The ASTM establishes functional requirements for WIM system accuracy. Table 13 presents these functional performance requirements of WIM systems as defined by ASTM (ASTM, 1994). As shown in the table, Types I, II, and III tolerances are given in terms of percentage of the original known value, while the tolerance is given for Type IV in terms of the number of pounds over or under the actual weight.

Table 13. ASTM Performance Requirements for WIM Systems

<table>
<thead>
<tr>
<th>Function</th>
<th>Tolerance for 95% Probability of Conformity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value ± lb (kg)</td>
</tr>
<tr>
<td>Wheel load</td>
<td>± 25%</td>
</tr>
<tr>
<td>Axle load</td>
<td>± 20%</td>
</tr>
<tr>
<td>Axle load group load</td>
<td>± 25%</td>
</tr>
<tr>
<td>Gross vehicle weight</td>
<td>± 10%</td>
</tr>
<tr>
<td>Speed</td>
<td>± 1 m/h (± 2 km/h)</td>
</tr>
<tr>
<td>Axle spacing</td>
<td>± 0.50 (± 150 mm)</td>
</tr>
</tbody>
</table>


Guidelines given by the ASTM do not only go into detail concerning accuracy guidelines for existing systems, but also consider procedures for acceptance testing of new systems. Some states such as California in Table 14 may impose more strict requirements (McCall and Vodrazka, 1997).
Table 14. Performance Requirements for WIM Systems in California

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Single Axle</td>
<td>± 5%</td>
<td>8%</td>
</tr>
<tr>
<td>- Tandem Axle</td>
<td>± 5%</td>
<td>6%</td>
</tr>
<tr>
<td>- Gross Weight</td>
<td>± 5%</td>
<td>5%</td>
</tr>
<tr>
<td>Axle Spacing</td>
<td>± 150 mm (6 inch)</td>
<td>300 mm (12 inch)</td>
</tr>
<tr>
<td>Vehicle Length</td>
<td>± 300 mm (12 inch)</td>
<td>460 mm (18 inch)</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>± 1.6 km/h (1 mi/h)</td>
<td>3.2 km/h (2 mi/h)</td>
</tr>
</tbody>
</table>


For testing a Type I or Type II system, it is recommended that two vehicles loaded with a non-shifting load plus 51 additional vehicles that are selected from the traffic stream be utilized. The two test vehicles make multiple passes over the WIM sensors at a minimum speed, a maximum speed, and an intermediate speed. This allows for the evaluation of WIM systems over the full range of speeds and allows for making sure that reference values of tire-load measurement procedures give values that can be reproduced. The other vehicles are used to subject the system to various vehicle classes, just as it would be used in the travel stream.

For a Type III system, the system must be able to detect a weight limit or load-limit violation as well as control traffic control devices to direct overweight vehicles to a static scale and to allow other vehicles to proceed. Test loading allows variability and accuracy to be analyzed. All vehicles used for test loading must be weighed statically at certified scales at the location in which the acceptance test is performed. For a Type IV system, the acceptance test determines whether or not the system produces results consistent with the tolerance levels shown above. This should be tested using test vehicles at a static speed and up to 10 mph (16 km/h). The overall method for measuring accuracy is thus essentially the same.
4.8 Weigh Station Operations

To consider:
- Long queues
- Delays for legal trucks
- Habitual offender being caught
- Accident delays

Similar to any transportation facility, a weigh station has characteristics such as capacity and delay that show how efficient the station operates. Long vehicle queues can cause excessive delay to the facility and at times to the adjoining highway that the weigh station is monitoring. Additionally, where traffic must enter and exit a roadway, accident rates also increase. Weigh-in-Motion has the potential to increase weigh station capacity and thus can reduce queue length and system time.

4.9 Maintenance

In order to ensure that a weigh-in-motion (WIM) system performs throughout the established site design life, states need to perform maintenance at each site. Corrective maintenance is performed after a problem is detected in the system. Preventive maintenance is performed in an attempt to circumvent future equipment and site problems.

4.10 Information Collection, Dissemination and Sharing

In a VWCS systems there are various entities involved and a proper system must be in place so that effective co-operation and information dissemination to take place.

- Various agencies involved:
  - Transportation agencies
    - U.S. Federal Highways Administration
    - U.S. Federal Railroad Administration
    - U.S. Federal Transit Administration
  - Inspection agencies
  - Municipalities
  - Non government organizations
  - Other government organizations
  - Private sector
5. Conclusions

Finally, as part of this research project we developed a prototype simulation model for the I-710 corridor which is the main access corridor to the Long Beach and Los Angeles Ports Complex. This model can be used to examine the benefits of locating a VWS at some point in this corridor.
References


Department of California Highway Patrol (CHP, 2001). 2001 Weigh Station Inventory of Needs. A report prepared in cooperation with the California Department of Transportation, Sacramento, CA.


Florida Department of Transportation (2004). Virtual Weigh-In-Motion Stations. FDOT’s Traffic Engineering and Operations Monthly Newsletter (Online Article). ITS Office,


Report prepared for the Federal Highway Administration. The Vehicle Detector Clearinghouse at New Mexico State University, Las Cruces, NM.


## Appendix A. Requirements for Commercial Vehicle Operations in California

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Documents or Permits</th>
</tr>
</thead>
</table>
| **Identification**               | **Federal US DOT Number**  
An out-of-state-domiciled commercial vehicle must have a federal U.S. DOT number to operate in California.  
**CA Number**  
Commercial vehicles must have a CA number to operate within California.  
**Trade Mark**  
Each vehicle must have a name or trademark displayed on both sides.  |
| **Permits / Licensing / Registration** | **Commercial Driver License (CDL)**  
A driver of a commercial vehicle operated in California must possess a valid commercial driver license.  
**Vehicle Registration**  
Each vehicle must be registered.  
**Motor Carrier Permit (MCP)**  
Commercial vehicles must have a motor carrier permit to operate within California.  
**Fuel Taxes (IFTA/CFTP)**  
Commercial vehicles need a fuel license.  |
| **Safety**                       | **Logbook / Hours of Service**  
Must maintain a log book and comply with hours-of-service laws.  
**Alcohol / Drug Testing**  
Must comply to test for alcohol and controlled substances.  
**Safety Equipment**  
Commercial vehicles must be equipped with safety equipment.  |
| **Protection of Infrastructure** | **Legal Size and Weight**  
Vehicle and load must meet standards for length, width, height and weight.  
**Oversize / Overweight Permits**  
If load cannot meet standards for length, width, height or weight, it may qualify for an "extra-legal" permit. This applies to single item, non-reducible loads.  |
| **Environment**                  | **Air quality**  
Vehicle must meet air quality standards.  |
| **Special Cargo**                | **Hazardous Cargo**  
If hauling hazardous waste, explosives, corrosives, petroleum products, or other hazardous materials, you may need additional permits and insurance.  
**Produce**  
If hauling fresh fruits, nuts or vegetables, vehicle may need to obtain a certificate of compliance regarding the quality and labeling of your cargo. Bills/invoices etc. must show content and origin of agricultural products.  |

Source: California Department of Transportation, 2005
Appendix B. Existing Commercial Vehicle Enforcement Facility Location Map

EXISTING COMMERCIAL VEHICLE ENFORCEMENT FACILITIES
(INSPECTION FACILITIES AND PLATFORM SCALES)

CLASS
- Port of Entry Inspection Facility (10)
- Inspection Facility (17)
- Platform Scale with Railtrack (14)
- Single Platform Scale no Railtrack (20)

Source: Department of California Highway Patrol, 2001
Appendix C. Commercial Vehicle Enforcement Facility Location List

<table>
<thead>
<tr>
<th>No.</th>
<th>Class</th>
<th>Reg.</th>
<th>Name</th>
<th>Dir.</th>
<th>Location</th>
<th>Dir.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>4</td>
<td>Murphy's</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>C/C</td>
<td>5</td>
<td>Santa Nella</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C/B</td>
<td>5</td>
<td>Cottonwood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>5</td>
<td>Dummar Gr.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>5</td>
<td>Grapevine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>5</td>
<td>Castaic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B/B</td>
<td>5</td>
<td>San Onofre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>7</td>
<td>Calexico</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>C</td>
<td>8</td>
<td>Winterhaven</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>B/D</td>
<td>10</td>
<td>Desert Hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>10</td>
<td>Blythe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>D/C</td>
<td>15</td>
<td>Cajon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>C/B</td>
<td>15</td>
<td>Rainbow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>D</td>
<td>20</td>
<td>Two Rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>D</td>
<td>50</td>
<td>Camino</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>D</td>
<td>58</td>
<td>Keene</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>C</td>
<td>58</td>
<td>Cache Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>D</td>
<td>70</td>
<td>Kaddah</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>B/B</td>
<td>80</td>
<td>Cordelia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>C/C</td>
<td>80</td>
<td>Antelope</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>B</td>
<td>80</td>
<td>Donner Pass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>C/C</td>
<td>91</td>
<td>Peralta</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>B</td>
<td>99</td>
<td>Chowlumilla Riv.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>D</td>
<td>101</td>
<td>Willits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>D</td>
<td>101</td>
<td>Little River</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>D</td>
<td>101</td>
<td>St. Vincents</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>D</td>
<td>101</td>
<td>Terra Linda</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>B/B</td>
<td>101</td>
<td>Gilroy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>C/B</td>
<td>101</td>
<td>Conejo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>D</td>
<td>108</td>
<td>Lyons Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>D</td>
<td>399</td>
<td>Whiskeytown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>D</td>
<td>299</td>
<td>Buckhorn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>D/D</td>
<td>405</td>
<td>Carson</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>D/D</td>
<td>380</td>
<td>Livermore</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>B</td>
<td>680</td>
<td>Mission Gr.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>D/D</td>
<td>680</td>
<td>Walnut Ck.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>C/B</td>
<td>880</td>
<td>Nimitz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>A</td>
<td>905</td>
<td>Oat Mesa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Department of California Highway Patrol, 2001
Appendix D. Weigh Station Bypass Sites in California

Source: California Department of Transportation, 2005
Appendix E. Weigh station Bypass Systems

<table>
<thead>
<tr>
<th>Weight Station</th>
<th>Direction</th>
<th>DIST-CORTE-REAL</th>
<th>AADTT</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antelope</td>
<td>EB</td>
<td>3-Sac-80-16</td>
<td>2,700</td>
<td>Completed 03/96</td>
</tr>
<tr>
<td>Antelope</td>
<td>WB</td>
<td>3-Sac-80-16</td>
<td>2,700</td>
<td>Completed 01/98</td>
</tr>
<tr>
<td>Blackrock</td>
<td>WB</td>
<td>3-Kirt-10-R144</td>
<td>3,948</td>
<td>Completed 11/97</td>
</tr>
<tr>
<td>Bixasa</td>
<td>WB</td>
<td>3-Kirt-10-R144</td>
<td>-</td>
<td>Proposed</td>
</tr>
<tr>
<td>Cachora Creek</td>
<td>WB</td>
<td>8-Corr-15-5-100</td>
<td>2,736</td>
<td>Completed 10/97</td>
</tr>
<tr>
<td>Capitan</td>
<td>NB</td>
<td>8-SBD-15-5-20</td>
<td>4,758</td>
<td>Completed 05/99</td>
</tr>
<tr>
<td>Capitan</td>
<td>SB</td>
<td>5-SBD-15-3-20</td>
<td>4,758</td>
<td>Completed 08/99</td>
</tr>
<tr>
<td>Caliente</td>
<td>NB</td>
<td>11-IM-7-01</td>
<td>535</td>
<td>Re-activated 08/92</td>
</tr>
<tr>
<td>Castaic</td>
<td>NB</td>
<td>7-LA-5-R24</td>
<td>6,378</td>
<td>Completed 06/95</td>
</tr>
<tr>
<td>Chicochilla</td>
<td>NB</td>
<td>10-Mar-95-1</td>
<td>3,870</td>
<td>Completed 09/97</td>
</tr>
<tr>
<td>Concho</td>
<td>NB</td>
<td>13-Con-101-9</td>
<td>1,360</td>
<td>Completed 09/90</td>
</tr>
<tr>
<td>Conejo</td>
<td>SB</td>
<td>7-Con-101-9</td>
<td>1,360</td>
<td>Completed 09/90</td>
</tr>
<tr>
<td>Corentin</td>
<td>EB</td>
<td>4-Sal-80-14</td>
<td>2,997</td>
<td>Completed 07/97</td>
</tr>
<tr>
<td>Corentin</td>
<td>WB</td>
<td>4-Sal-80-14</td>
<td>2,997</td>
<td>Completed 07/97</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>NB</td>
<td>2-Teb-5-5</td>
<td>2,283</td>
<td>Completed 12/95</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>SB</td>
<td>2-Teb-5-5</td>
<td>2,283</td>
<td>Completed 12/95</td>
</tr>
<tr>
<td>Desert Hill</td>
<td>EB</td>
<td>3-Kirt-10-R16</td>
<td>6,588</td>
<td>Completed 01/96</td>
</tr>
<tr>
<td>Desert Hill</td>
<td>WB</td>
<td>3-Kirt-10-R16</td>
<td>6,588</td>
<td>Completed 12/96</td>
</tr>
<tr>
<td>Donaies Pass</td>
<td>WB</td>
<td>3-Ner-80-19</td>
<td>1,843</td>
<td>Completed 05/99</td>
</tr>
<tr>
<td>Dunsmuir Pass</td>
<td>SB</td>
<td>2-Sal-5-8</td>
<td>2,360</td>
<td>Completed 10/96</td>
</tr>
<tr>
<td>Gilroy</td>
<td>NB</td>
<td>4-SCI-101-11</td>
<td>2,241</td>
<td>Completed 10/96</td>
</tr>
<tr>
<td>Gilroy</td>
<td>SB</td>
<td>4-SCI-101-9</td>
<td>2,241</td>
<td>Completed 12/94</td>
</tr>
<tr>
<td>Grapevine</td>
<td>SB</td>
<td>8-Neo-5-1</td>
<td>6,916</td>
<td>Completed 12/95</td>
</tr>
<tr>
<td>Livermore</td>
<td>EB</td>
<td>4-Ala-300-R5</td>
<td>6,026</td>
<td>Completed 12/96</td>
</tr>
<tr>
<td>Livermore</td>
<td>WB</td>
<td>4-Ala-300-R5</td>
<td>6,026</td>
<td>Completed 12/96</td>
</tr>
<tr>
<td>Mission Grade</td>
<td>NB</td>
<td>4-Ala-300-R5</td>
<td>2,787</td>
<td>Completed 12/96</td>
</tr>
<tr>
<td>Mountain Pass</td>
<td>WB</td>
<td>3-Sal-15-34</td>
<td>-</td>
<td>Proposed</td>
</tr>
<tr>
<td>Needles</td>
<td>WB</td>
<td>3-SBD-15-131</td>
<td>-</td>
<td>Proposed</td>
</tr>
<tr>
<td>Nutted</td>
<td>NB</td>
<td>4-Ala-300-4</td>
<td>1,190</td>
<td>Completed 01/99</td>
</tr>
<tr>
<td>Nutted</td>
<td>SB</td>
<td>4-Ala-300-4</td>
<td>1,190</td>
<td>Completed 01/99</td>
</tr>
<tr>
<td>Oat Mesa</td>
<td>WB</td>
<td>11-SD-905-12</td>
<td>1,160</td>
<td>Completed 06/00</td>
</tr>
<tr>
<td>Peralta</td>
<td>EB</td>
<td>12-Oct-91-14</td>
<td>3,549</td>
<td>Completed 04/01</td>
</tr>
<tr>
<td>Peralta</td>
<td>WB</td>
<td>12-Oct-91-14</td>
<td>3,549</td>
<td>Completed 04/01</td>
</tr>
<tr>
<td>Rainbow</td>
<td>SB</td>
<td>11-SD-15-33</td>
<td>2,691</td>
<td>Completed 05/95</td>
</tr>
<tr>
<td>San Onofre</td>
<td>SB</td>
<td>11-SD-5-867</td>
<td>2,466</td>
<td>Completed 12/96</td>
</tr>
<tr>
<td>Santa Nella</td>
<td>NB</td>
<td>10-Mar-5-23</td>
<td>2,791</td>
<td>Completed 05/93</td>
</tr>
<tr>
<td>Santa Nella</td>
<td>SB</td>
<td>10-Mar-5-23</td>
<td>2,791</td>
<td>Completed 11/94</td>
</tr>
<tr>
<td>Tecate</td>
<td>NB</td>
<td>11-SD-185-0.1</td>
<td>-</td>
<td>Proposed</td>
</tr>
<tr>
<td>Winterhaven</td>
<td>WB</td>
<td>11-IM-8-140</td>
<td>-</td>
<td>Proposed</td>
</tr>
</tbody>
</table>

Notes: 1. AADTT = average annual daily truck traffic for 5+ axle trucks (vehicles per day)
2. Directions: NB = Northbound, SB = Southbound, EB = Eastbound, WB = Westbound
3. Counties: Ala = Alameda, Im = Imperial, Kern = Kern, LA = Los Angeles, Mer = Merced,
   Nev = Nevada, Or = Orange, Riv = Riverside, Sac = Sacramento,
   SBD = San Benito, SCI = Santa Clara, SD = San Diego, Sit = Siskiyou,
   Sol = Solano, Teh = Tehama, Ven = Ventura

Source: California Department of Transportation, 2005
Effect of Weigh In Motion Accuracy on Weight Enforcement Efficiency
Effect of Weigh In Motion
Accuracy on Weight Enforcement Efficiency

A.T. Bergan Ph.D., P.Eng.
Professor Department of Civil Engineering
University of Saskatchewan, Saskatoon, Saskatchewan, CANADA

C.F. Berthelot P.Eng.
Research Engineer Department of Civil Engineering
University of Saskatchewan, Saskatoon, Saskatchewan, CANADA

B. Taylor
Manager Engineering Systems
International Road Dynamics, Saskatoon, Saskatchewan, CANADA

ABSTRACT
Weigh in motion (WIM) is employed throughout the world as an effective heavy vehicle pre-sorter at weight enforcement facilities. Weigh in motion significantly increases the capacity of weigh stations and is often employed at weigh stations that cannot accommodate the heavy truck traffic volumes.

The three most common technologies employed for weigh in motion are piezoelectric sensors, bending strain scales, and single load cell scales. This research investigates the effect WIM system accuracy has on the sorting efficiency of heavy vehicles at weight enforcement facilities, and compares the life cycle costs of the different weigh in motion technologies.

1. INTRODUCTION
Weigh in motion is commonly employed at weight enforcement facilities where truck traffic volumes exceed the static weighing capacity of the weigh station. As a weight enforcement tool, weigh in motion has traditionally been installed in the approach ramp to a weigh station to pre-sort trucks approaching a weigh station according to weight compliance. More recently, weigh in motion has been installed in the mainline approximately 1 kilometer upstream of a weigh station. Mainline WIM sorters are employed when land requirements for a ramp sorter is not available or when truck traffic volumes are too high to safely call in all trucks for ramp sorting. Mainline WIM sorters employ roadside variable message signs to call in only those trucks suspect of exceeding the maximum allowable weight limits.

Trucks identified by the weigh in motion as being over the maximum allowable weights are directed to the static scale for compliance weighing and possible citation. Trucks within legal weight limits are directed to bypass the static scale. As a result, by employing weigh in motion, the unnecessary static weighing of trucks known to be within legal weight compliance is virtually eliminated. This greatly improves the efficiency and effectiveness of weight enforcement facilities and minimizes delays imposed on the trucking industry.

The degree to which unnecessary static weighing of legal trucks is eliminated is directly dependent on the accuracy and reliability of the weigh in motion system. Because each WIM technology: piezoelectric sensors, bending strain scales, and single load cell scales, offers a range in accuracy, reliability and cost, this research investigates applicability of each WIM system for weight enforcement purposes.

2. WIM SYSTEM ACCURACY
Weigh in motion system accuracy is dependent on two primary factors:

1. Vehicle dynamics;
2. Variance inherent to the WIM system.

Vehicle dynamics are a function of: road surface roughness, vehicle suspension type, vehicle dynamic balance, vehicle weight, vehicle speed, driver maneuvering, etc. The inherent variance of the weigh in motion system is a function of the specific technology employed within the WIM system.
Measurement error of a weigh in motion system may be expressed as a function of the vehicle's true static weight:

\[
\% \text{WIM Error}(e) = \frac{\text{WIM} - \text{STATIC}}{\text{STATIC}} \times 100\% \quad (1)
\]

If a weigh in motion system is installed in a sound road structure and is subjected to normal traffic conditions, WIM system errors are normally distributed. The standard deviation (\(\sigma\)) of the WIM system errors is the measure used to indicate the reliability (accuracy) of the system. The standard deviation may be expressed in mathematical terms as:

\[
\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu_x)^2}{N-1}} \quad (2)
\]

where \(x_i\) represents each WIM measurement error, \(N\) is the total number of WIM measurements and \(\mu_x\) is the arithmetic mean of the WIM measurement errors. The lower the standard deviation of the WIM measurement errors the more accurate the WIM system. Table 1 summarizes typical WIM system accuracies in terms of one standard deviation (\(\sigma\)) of system errors with respect to axle group weights and gross vehicle weights for a sound installation subject to normal traffic conditions.

<table>
<thead>
<tr>
<th>WIM System Type</th>
<th>Axle Group WIM Accuracy</th>
<th>GVW WIM Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezoelectric</td>
<td>12%</td>
<td>10%</td>
</tr>
<tr>
<td>Bending Strain</td>
<td>6%</td>
<td>5%</td>
</tr>
<tr>
<td>Single Load Cell</td>
<td>2%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

As summarized in Table 1, it is common for weigh in motion systems to be slightly less accurate when weighing individual axle groups than gross vehicle weights.

Based on the WIM system accuracies summarized in Table 1, Figure 1 graphically illustrates the WIM system error distributions for each WIM technology with respect to gross vehicle weight.

![Figure 1 WIM System Variance for GVW](image)

The area under the error distribution curve represents the probability of a sorting decision occurring. Because WIM system errors are assumed to be normally distributed, the area under the distribution curve can be determined using normalized deviates of the error function as follows:

\[
z = \frac{x - \mu_x}{\sigma} \quad (3)
\]

where \(z\) is the normalized deviate, \(x\) is the WIM system sorting decision threshold, \(\mu_x\) is the arithmetic mean of the WIM errors (calibration) and \(\sigma\) is the standard deviation (accuracy) of the WIM system.

3. EFFECT OF WIM CALIBRATION ON HEAVY VEHICLE SORTING

When employed as a weight enforcement heavy vehicle pre-sorting system, weigh in motion calibration has a profound effect on the sorting of heavy vehicles. The calibration of a weigh in motion system is determined by the arithmetic mean of WIM system measurement errors. If the arithmetic mean of WIM measurement errors is zero (\(\mu_x = 0\)), the WIM system is considered to be perfectly calibrated. If the calibration of a WIM system is biased to weigh either light or heavy, the sorting decisions made by the WIM system are correspondingly significantly biased.

Figure 2 illustrates the effect a 5% calibration bias to weigh trucks light has on the sorting decision made.
by a bending strain scale WIM system for a truck that is at the legal weight limit.

Figure 2 Effect of WIM System Calibration Shift

As can be seen in Figure 2, if the WIM system is perfectly calibrated (i.e. mean of WIM errors $\mu = 0$), there is a fifty percent probability that a truck at the legal weight limit will be called in for static weighing. If the bending strain WIM system is biased to weigh 5% light (i.e. mean of WIM errors $\mu = -5\%$), the probability of a truck at the legal weight limit being called in for static weighing is reduced from 50% to approximately 16%. Similarly, if a piezoelectric and single load cell scale WIM system are biased to weigh 5% light, the probability of a truck at the legal weight limit being called in for static weighing is reduced from 50% to approximately 31% and 0.04% respectively. As a result, it can be concluded that weight in motion system calibration is critical to optimize heavy truck sorting efficiency.

4. EFFECT OF WIM SYSTEM ACCURACY ON SORTING THRESHOLD

As was presented in Figure 1, although a WIM system may be perfectly calibrated, (i.e. mean of WIM measurement errors $\mu = 0$), the sorting decision made by a WIM system is significantly affected by the inherent variance of the WIM system. Weight in motion system accuracy is extremely critical for the sorting of trucks that are at or near the legal weight limits. To illustrate, Figure 3 presents the effect WIM system accuracy of each WIM technology has on the sorting decision of a truck that is 2.5% over the legal weight limit. All three WIM systems are perfectly calibrated.

Figure 3 Effect of WIM System Accuracy on Sorting Decision

As is presented in Figure 3, assuming the three WIM systems are perfectly calibrated (i.e. $\mu = 0$), a truck that is 2.5% over the legal gross vehicle weight has a 40%, 31% and 5% probability of bypassing the static scale by a piezoelectric, bending strain scale and single load cell scale WIM system respectively.

Table 2 summarizes the probabilities of each WIM technology permitting a truck at various increments over the legal gross vehicle weight limit of bypassing the static scale.

<table>
<thead>
<tr>
<th>% Over Legal Gross Vehicle Weight</th>
<th>Piezoelectric WIM ($\sigma = 10%$)</th>
<th>Bending Strain Scale WIM ($\sigma = 5%$)</th>
<th>Single Load Cell Scale WIM ($\sigma = 1.5%$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>50.0%</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>2.5%</td>
<td>40.1%</td>
<td>30.8%</td>
<td>5.0%</td>
</tr>
<tr>
<td>5.0%</td>
<td>30.9%</td>
<td>15.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>7.5%</td>
<td>22.7%</td>
<td>6.7%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10.0%</td>
<td>15.9%</td>
<td>2.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>12.5%</td>
<td>10.7%</td>
<td>0.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>15.0%</td>
<td>6.7%</td>
<td>0.1%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

In addition to gross vehicle weight compliance, weight enforcement is focused on protecting and
preserving bridges throughout the road infrastructure network. To accomplish this, the combination of minimum allowable axle spacings and maximum allowable axle group weights known as the “bridge formula” must be enforced. Table 3 summarizes the probability of each WIM technology permitting a truck at various increments over the legal axle weight limit of bypassing the static scale.

Table 3
Probability of Static Scale Bypass based on Vehicle Axle Weights and WIM System Type

<table>
<thead>
<tr>
<th>% Over Legal Gross Vehicle Weight</th>
<th>Piezoelectric WIM (σ = 12%)</th>
<th>Bending Strain WIM (σ = 6%)</th>
<th>Single Load Cell WIM (σ = 2.0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>50.0%</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>2.5%</td>
<td>42.0%</td>
<td>34.0%</td>
<td>11.0%</td>
</tr>
<tr>
<td>5.0%</td>
<td>34.0%</td>
<td>20.0%</td>
<td>0.6%</td>
</tr>
<tr>
<td>7.5%</td>
<td>26.0%</td>
<td>11.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10.0%</td>
<td>20.0%</td>
<td>5.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>12.5%</td>
<td>15.0%</td>
<td>1.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>15.0%</td>
<td>11.0%</td>
<td>0.6%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

As can be seen in Tables 2 and 3, as WIM system accuracy improves, the sorting efficiency of the WIM system significantly increases. This lends to the conclusion that for weight enforcement applications, weigh in motion system accuracy is extremely critical to optimizing the efficiency of a weight enforcement facility and to minimizing unnecessary delays of the trucking industry at enforcement facilities.

5. WIM SYSTEM COST COMPARISON

Each weigh in motion technology has a unique life cycle cost profile. The life cycle cost of weigh in motion may be examined with respect to initial capital cost (in-road WIM equipment, installation labor and materials and traffic control) and life cycle maintenance costs (labor and materials, traffic control, and system re-calibration).

Table 4 summarizes budgetary initial capital costs for each WIM technology. These costs are based on only in-road WIM sensors/scales for typical road, traffic and weather conditions. All other ancillary equipment such as roadside cabinets, WIM electronics, power hook-up, etc. are not considered part of this cost analysis as these equipment are common to all WIM technologies.

It is intuitive that the life cycle maintenance costs are extremely variable due to different conditions of traffic, weather, original installation procedures, on-site quality control, etc. For purposes of this analysis, the ongoing maintenance and repair costs of each WIM system are based on the average of WIM installations throughout North America. In addition, the maintenance costs used in this analysis assumed semi-annual routine maintenance is performed on the road structure surrounding the WIM system (i.e. road inspection, crack filling, etc.).

Table 5 summarizes and presents WIM system life cycle maintenance and repair costs used in the analysis.

Table 4
Initial WIM System Capital Costs

<table>
<thead>
<tr>
<th>Capital Cost Component</th>
<th>Piezoelectric WIM</th>
<th>Bending Strain WIM</th>
<th>Single Load Cell WIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-Road Equipment</td>
<td>$4,500</td>
<td>$13,000</td>
<td>$34,000</td>
</tr>
<tr>
<td>Installation Lab. &amp; Mat.</td>
<td>$3,500</td>
<td>$6,500</td>
<td>$10,500</td>
</tr>
<tr>
<td>Traffic Control</td>
<td>$1,000 (1 day)</td>
<td>$2,000 (2 days)</td>
<td>$4,000 (4 days)</td>
</tr>
<tr>
<td>Total Capital Cost</td>
<td>$9,000</td>
<td>$21,500</td>
<td>$48,000</td>
</tr>
</tbody>
</table>

In this analysis, piezoelectric WIM sensors are assumed to require replacing every 3 years. Bending strain WIM scales are assumed to require full refurbishing every five years. Single load cell WIM
scales are assumed to require load cell replacement every five years.
Given the initial installation and life cycle costs presented above and assuming a discount rate of 10% over a 20 year life cycle of the WIM system, the WIM system life cycle cost profiles may be amortized over the life cycle of the installation in terms of an average annual cost for each WIM system:

\[
\text{Piezoelectric WIM} = \$3,092 \text{ per year} \\
\text{Bending Strain WIM} = \$4,636 \text{ per year} \\
\text{Single Load Cell WIM} = \$5,982 \text{ per year}
\]

As can be seen by the average annual life cycle costs of each weigh in motion technology, the incremental cost for improved weigh in motion system accuracy, durability and reliability is negligible when compared to the annual operating budget of a weight enforcement facility. A more complete economic analysis of WIM technologies must consider the costs of: 1) reduced delays for the trucking industry, 2) improved efficiency of weight enforcement personal, 3) down time of WIM system for unscheduled repairs, etc. Experience has shown that the reduction in maintenance and down time associated with more durable and accurate WIM technology more than offsets the incremental costs of more durable and accurate WIM systems.

6. SUMMARY AND CONCLUSIONS

Weigh In Motion (WIM) technology is employed as an extremely effective heavy vehicle pre-sorter for weight enforcement facilities. Three primary technologies employed for weigh in motion include: piezoelectric sensors, bending strain scales, and single load cell scales. This research investigated the impact weighing accuracy has on the sorting efficiency of heavy trucks at a weight enforcement facility and examined the life cycle costs associated with each weigh in motion technology.

The specific conclusions of this research are:

1. Weigh in motion system calibration is critical to optimize heavy truck sorting efficiency.
2. Weigh in motion system accuracy is critical to optimize the efficiency of a weight enforcement facility and to minimize unnecessary delays of the trucking industry at enforcement facilities.
3. The incremental cost of installing a weigh in motion system with higher accuracy, durability and reliability is negligible when compared to the annual operating budget of a weight enforcement facility.

Accurate heavy vehicle pre-sorting at weight enforcement facilities significantly reduces delays imposed on trucks that are within legal weight limits and maximizes the probability of identifying and citing trucks that are over the maximum allowable weight limits. Weigh in motion significantly improves the effectiveness of weight enforcement and is a cost effective means for facilitating optimal, fair and equitable heavy vehicle weight enforcement.
Weigh-in-motion (WM) Systems
Weigh-in-Motion (WIM) Systems

Weigh-in-motion (WIM) devices are designed to capture and record truck axle weights and gross vehicle weights as they drive over a sensor. Unlike older static weigh stations, current WIM systems do not require the subject trucks to stop making them much more efficient. Gross vehicle and axle weight monitoring is useful in an array of applications including:

- Pavement design, monitoring, and research
- Bridge design, monitoring, and research
- Size and weight enforcement
- Legislation and regulation
- Administration and planning

**Figure 1: Weight-In-Motion Graphical Output Example**

This example shows 2002 data from the WIM station on Interstate 5 north or Seattle, WA near 185th street. The data show gross vehicle weight for 5 axle semi tractor-trailer vehicles (FHWA Class 9 vehicles). The two frequency peaks near 36,000 lbs and 80,000 lbs correspond to empty full trucks respectively.
**Strengths of WIM**

1. **Processing Rate.** Trucks can be weighed as they travel at highway speeds, resulting in a significantly greater number of counted vehicles in a short period of time compared to static weight stations.

2. **Safety.** The minimization of static weighing will significantly decrease vehicle accumulation at highway lanes leading to weight stations.

3. **Continuous data processing.** WIM can be performed continuously rather than static weighing, which uses traffic streams samples. This can eliminate any inherent data bias in static weighing.

4. **Increased coverage and lower cost.** More sites may be monitored with WIM at the same cost.

5. **Minimized scale avoidance.** WIM can monitor truck traffic without alerting truck drivers. This results in more truthful data as overweight trucks are less likely to avoid weighing stations.

6. **Dynamic loading data.** Unlike static weight stations, WIM can record dynamic axle load information, which can be significantly greater than static load information.

**Shortcomings of WIM**

1. **Less accurate.** WIM systems are less accurate than static scales. According to the National Bureau of Standards, wheel load scales are required to have an accuracy of ±1% when tested for certification and must be maintained thereafter at ±2%. The best accuracy obtained with the most expensive commonly used WIM devices is 6% of actual vehicle weights for 95% of measured trucks.

2. **Reduced information.** Truck information that is easily collected at static weight stations such as fuel type, state of registry, year model, loaded or unloaded status, origin, and destination cannot be obtained with typical WIM systems.

3. **Susceptibility to damage from electromagnetic transients.** WIM systems are sensitive to electromagnetic disturbances caused mostly by lightning strikes in the vicinity of the equipment.
Contemporary WIM Technology

The most widely accepted and utilized WIM devices in North America are:

- **Piezoelectric Sensor.** The most common WIM device. The sensor is embedded in the pavement and produces a charge that is equivalent to the deformation induced by the tire loads on the pavement’s surface. It is common to install two inductive loops and two piezoelectric sensors in each monitored lane. A properly installed and calibrated Piezoelectric WIM system can provide gross vehicle weights that are within 15% of the actual vehicle weight for 95% of the measured trucks.

- **Bending Plate.** The bending scale consists of two steel platforms that are 0.6 x 2 m (2 ft. x 6 ft.), adjacently placed to cover a 3.65 m (12 ft.) lane. The plates are instrumented with strain gages, which measures tire load induced plate strains. The measured strains are then analyzed to determine the tire load. A properly installed and calibrated bending plate WIM system can provide gross vehicle weights that are within 10% of the actual vehicle weight for 95% of the measured trucks.

- **Single Load Cell.** This device consists of two 3 x 3 m (6 ft. x 6 ft.) platforms placed adjacently to cover the 3.65 m (12 ft.) monitored lane. A single hydraulic load cell is installed at the center of each platform to measure the tire load induced forces that are then transformed into tire loads. A properly installed and calibrated single load cell WIM system can provide gross vehicle weights that are within 6% of the actual vehicle weight for 95% of the measured trucks.
Map of the State of Oklahoma – 2006 Traffic Monitoring Stations
Massload – Loadcell / Computer Interface
Loadcell / Computer Interface

If it's a low cost, high accuracy computer based weighing solution that you're after, look no further. Massload's LCB computer scale interface is the most sophisticated computer based digital weight indicator available. Don't be fooled by it's small size, it packs a ton of features!

The LCB can be used for either static or dynamic weighing, and is used exclusively with Massload's ScaleScope. Each LCB comes with a premier weighing software package and it comes with each LCB FREE!

ScaleScope has been designed to offer many of the features that high end digital weight indicators have. These include a built in software that allows for remote display using a standard rs-232, protocol, up to 6 user definable set points that allow the set points are reached, counting scale module with an unlimited amount of parts, and many other features.

LCB Features:
- Sample rates of 1, 2, 4, 8, 16, 32, 64, and 128 samples per second
- Unlimited linearly adjustable (multi-point calibrations)
- No external power supply needed (device powered up to 12v)
- Unmatched simplicity and ease of use
- No setup required for a single PC
- Can be used with a computer or a printer
- Connect to up to 8 devices on a single PC
- Unmatched simplicity and ease of use

ScaleScope Features:
- USB plug & play, device and sensors are powered by the USB port
- No additional power required
- Unlimited calibration points allowed
- Can be used with any strain gauge based sensor
- Can be used with an unlimited amount of parts
- Unlimited counting scale module with an unlimited amount of parts
- Unlimited counting scale module with an unlimited amount of parts
- Unlimited counting scale module with an unlimited amount of parts
Massload – Permanent Weigh In Motion
Permanent Weigh In Motion

Weigh in motion scales are excellent for high traffic locations where vehicle speed is reduced to under 20kmh and accurate weighing needs to be done quickly, such as toll booths, border crossings, or shipping gates. You can depend on Massload weigh in motion axle pads to deliver high accuracy results and have a very long life due to the rugged design. Permanent weigh in motion systems require a pit to be poured to mount the weigh bridges into.

Simple Installation!

Installation of Massload's permanent weighpads is simple. If it is an existing roadway that the scale will be installed in, an approximate hole must be cut through the surface. The scale frames are first bolted together then suspended in the cutout. The first of 2 pours is to create the bottom of the pit. When this has cured, the second pour fills the outer portion of the cutout. The loadcells are then installed and wires run. The weigh bridges are bolted onto the loadcells. The computer is then setup. That's it.

As with any weigh in motion system that Massload sells, there are at least 3 parts:
1. The scale that the vehicle rolls over.
2. The scale interface device.
3. A PC to receive the results of the weighing.

The scales are fabricated in 2 identical pieces to keep the shipping package small, allow for some adjustment of the pads to compensate for the crown of the road surface, as well as facilitate ease of installation. If the entire WIM system is purchased from Massload, we will pre-calibrate the system in our factory with known test weights to further reduce the time before you are using the system.

The scales come in various sizes depending on the type of traffic you are weighing. See the last page of this brochure for the standard sizes, and remember, we can easily custom design a size that is right for your application.

Additional information about the vehicle can be obtained by the use of a vehicle scanning light curtain (the orange uprights in the picture to the right), massloads specially designed line sensors, as well as a host of other peripherals such as cameras and ID equipment. Contact Massload for options.

Weigh In Motion V3.1 from Massload is a very flexible, feature rich, and mature data handling software package. Keep track of all your weigh in motion statistics in one simple to use program. Just start the software, and your on your 'weigh'!

Why buy your next weigh in motion scales from Massload?
- Simple
- Low System Cost
- Simple Installation
- High Accuracy
- Long Scale Life
- Flexible Software

301-47th Street East - Saskatoon, SK, Canada - PH: 1-800-667-3625 - Fax: (306) 951-6491

Massload
How does Weigh in Motion work?
Weigh in motion is the weighing of a moving object over a scale that is stationary. WIM3.1 from Massload handles all of the complex processes of weighing automatically for you. As a vehicle starts to drive over the scale, the software begins gathering data. Data is gathered until the vehicle has passed completely over the scale with all of its axles. When this is complete, the software analyses the data that was captured to determine the actual axle weights. The axle weights, total weight, speeds and other statistics are then calculated. If turned on, a post weighing screen comes up and prompts for additional information. The data is then written to the hard disk of the computer and a report for the vehicle can then be printed. The system is immediately ready for another vehicle to pass over the scale.

Weigh In Motion V3.1 Software Features

Features:
- All regular scale functions such as zero, real-time weight display, grad size, etc.
- Built in calibration utility with unlimited linearity point capability
- Static / Dynamic mode allows you to use the scale to weigh axles statically
- Scoreboard support  •  Dual traffic light support
- Export data to Excel or delimited text files for archiving
- Full sheet report generation with configurable reports
- Configurable vehicle types database
- Full database management
- Configurable main screen - show only the data that you want to see
- Post weighing screen allows you to fill in additional information
- Many program security features
- Graphing capabilities
- Configurable full screen weight display
- Automatic detection of LC/EB signal

Database Fields:
- Axle Weight • Axle Speed • Total Weight • Average Speed • Date • Time • Speed Units • Weight Units
- Zero Factor • Grad Size • Sample Length • Number of Axles • Tractor Tare • Trailer Tare • Vehicle Type
- Vehicle ID • Scale Operator • Driver Name

*Manually entered after the weighing process
Note: Additional fields are available depending on the peripheral options that you have (cameras, line sensors, etc)
## Permanent WIM (Cont.)

### Scale Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard Sizes</strong></td>
<td>105&quot; x 12&quot; x 6&quot; (for cars) 144&quot; x 30&quot; x 6&quot; (for all traffic)</td>
</tr>
<tr>
<td><strong>Rated Capacity</strong></td>
<td>15,000 lbs (5lb graduations) 50,000 lbs (10lb graduations)</td>
</tr>
<tr>
<td><strong>Dynamic Accuracy</strong></td>
<td>+/- 1% &lt;5km/h, +/-5% &lt;20km/h +/-3% &lt;5km/h, +/-5% &lt;20km/h</td>
</tr>
<tr>
<td><strong>Static Accuracy</strong></td>
<td>0.25% Full Scale or better</td>
</tr>
<tr>
<td><strong>Overload Capacity</strong></td>
<td>150% of full scale</td>
</tr>
<tr>
<td><strong>Shipping Weight</strong></td>
<td>420 lbs / pad (2 pads per system) 670 lbs / pad (2 pads per system)</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>High strength steel w/diamond plate decking, your choice of finish and color. Loadcells are heat treated, nickel plated alloy steel</td>
</tr>
<tr>
<td><strong>Loadcell Excitation</strong></td>
<td>Minimum 5VDC, Maximum 15VDC</td>
</tr>
<tr>
<td><strong>Ground Level Requirement</strong></td>
<td>Level and flat concrete surface required within 1/16&quot; for most accurate results (poor approach and departure will affect accuracy)</td>
</tr>
<tr>
<td><strong>Operating Temp Range</strong></td>
<td>-40°C to +50°C for scales; LCIB and computer need to be maintained at room temperature</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>0.5% Full Scale / Year</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Scale is powered by the LCIB, which is powered from the USB port of the computer. (Draws &lt; 500mA)</td>
</tr>
</tbody>
</table>

### LCIB Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample Rate</strong></td>
<td>2,000 samples/second continuously</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>16 Bit</td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>Up to 100 individual calibrations can be stored on the device</td>
</tr>
<tr>
<td><strong>Linearity Adjustment</strong></td>
<td>Up to 100 linearity adjustment points per calibration</td>
</tr>
<tr>
<td><strong>Computer Interface</strong></td>
<td>Fully Rated USB 1.1</td>
</tr>
<tr>
<td><strong>Scale Interface</strong></td>
<td>Rugged DB9 Connector</td>
</tr>
<tr>
<td><strong>Power Requirements</strong></td>
<td>None, powered by the USB port of the computer</td>
</tr>
<tr>
<td><strong>Computer Requirements</strong></td>
<td>Pentium 3, 1GHz or better, 10GB of disk space (for raw data storage), 256MB RAM, Keyboard, Monitor, 1 free USB port, Windows 2000 or Windows XP</td>
</tr>
<tr>
<td><strong>Note</strong></td>
<td>1 or more serial ports may be required for additional devices, Massload can supply the computer if required.</td>
</tr>
</tbody>
</table>

A typical weigh in motion system from Massload includes:
- 1 scale of your choice, painted with your choice of finish and color
- 1 LCIB interface device
- 1 Summation box for the loadcells
- 1 length of cable to run from the summation box to the scale house (please specify when ordering)

Options available:
- 1 USB cable.
- Additional Equipment may include:
  - Conduit to run the loadcell wires in
  - Drainage pipe
  - Tools and materials related to pouring concrete
  - A Windows based PC (See specs next page)

Optional Equipment
- IR Light curtain for automatic separation of vehicles
- Tire sensor to determine single or dual tires per axle
- Various ID tag systems for automatic logging of trucking activities
Massload – Portable Weigh In Motion
Portable Weigh In Motion

If it's a reliable, portable weigh in motion system that you are looking for, look no further. Using our highly successful Ultraslim weighpads, Massload is able to offer a reliable and robust portable weighing solution that will not only fit your needs, but will also fit your budget!

Operation of the system is simple. A single person can setup and operate the system with ease. Just lay the weighpads down, layout the track, connect the weighpads to the computer and your up and running! It's just that easy.

System Components

2 - Ultraslim Weighpads (20,000lb or 40,000lb capacity)
1 - Y-Cable Connects the 2 weighpads to the LCIB computer interface
1 - LCIB Scale Interface Device
1 - USB Cable connects the LCIB to the computer
4 - Sets of leveling track. Each set should be as long as the longest vehicle you are going to be weighing. Please specify at the time of order.
1 - Windows based PC (See specs next page.)

Portable weigh in motion systems are useful when the location for weighing is constantly changing. This system can be setup in a very short period of time. It is recommended that you consider purchasing the leveling track to go with the system. This will ensure that the vehicle rolls over the Ultraslim weighpads with a minimum of disturbance, ensuring a more accurate weight reading. The leveling track stays in position due to the unique puzzle lock connections.

For the ultimate in portability, Massload has developed a case that houses a laptop computer, full sized sheet printer, and LCIB device. An integrated power supply is also included that is capable of charging both the printers internal battery, as well as the laptop's internal battery. Use either the included 12VDC wall power supply, or a standard 12VDC cigarette lighter from a vehicle to run the entire system. Underneath the top layer, there is ample room to store spare paper and the cables. All components fit snugly and neatly into the high quality Pelican carrying case.
Portable WIM (Cont.)

Ultrasonic Weightpad Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Capacity</td>
<td>20,000 lbs (5lb graduations) or 40,000 lbs (10lb graduations)</td>
</tr>
<tr>
<td>Dynamic Accuracy</td>
<td>+/- 3%&lt;5km/h; +/- 5%&lt;20km/h (with the use of leveling track)</td>
</tr>
<tr>
<td>Static Accuracy</td>
<td>0.25% Full Scale or better</td>
</tr>
<tr>
<td>Overload Capacity</td>
<td>200% of full scale</td>
</tr>
<tr>
<td>Weight</td>
<td>42 lbs / pad (2 pads per system)</td>
</tr>
<tr>
<td>Material</td>
<td>High strength aluminum alloy</td>
</tr>
<tr>
<td>Loadcell Excitation</td>
<td>Minimum 5VDC, Maximum 15VDC (5000 +/-500)</td>
</tr>
<tr>
<td>Ground Level Requirement</td>
<td>Level, flat, and hard surface required. Level within 1/8&quot; over 4' for most accurate results (poor approach and departure will affect accuracy)</td>
</tr>
<tr>
<td>Operating Temp Range</td>
<td>-10°C to +55°C for scales; LCIB and computer need to be maintained at room temperature</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Max. 30 1/2” x 28 3/8” x 0.7”; Weighing Surface: 28 3/8” x 16 1/2”</td>
</tr>
<tr>
<td>Power</td>
<td>Scale is powered by the LCIB, which is powered from the USB port of the computer. (Draws &lt; 500mA)</td>
</tr>
</tbody>
</table>

LCIB Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Rate</td>
<td>2,000 samples/second continuously</td>
</tr>
<tr>
<td>Resolution</td>
<td>16 Bit</td>
</tr>
<tr>
<td>Calibration</td>
<td>Up to 100 individual calibrations can be stored on the device</td>
</tr>
<tr>
<td>Linearity Adjustment</td>
<td>Up to 100 linearity adjustment points per calibration</td>
</tr>
<tr>
<td>Computer Interface</td>
<td>Fully Rated USB 1.1</td>
</tr>
<tr>
<td>Scale Interface</td>
<td>Rugged DB9 Connector</td>
</tr>
<tr>
<td>Power Requirements</td>
<td>None, powered by the USB port of the computer</td>
</tr>
<tr>
<td>Computer Requirements</td>
<td>Pentium 3, 1GHz or better, 10GB of disk space (for raw data storage), 256MB RAM, Keyboard, Monitor, 1 free USB port, Windows 2000 or Windows XP Note: 1 or more serial ports may be required for additional devices Massload can supply the computer if required.</td>
</tr>
</tbody>
</table>

Typical System Layout

Weigh In Motion V3.1 Software Features

- All regular scale functions such as zero, real-time weight display, grad size, etc
- Built in calibration utility with unlimited linearity point capability
- Static / Dynamic mode allows you to use the scale to weigh axles statically
- Scoreboard support - Export data to Excel or delimited text files for archiving
- Full sheet report generation with configurable reports
- Configurable vehicle types database
- Full database management
- Configurable main screen - show only the data that you want to see
- Post weighing screen allows you to fill in additional information
- Many program security features
- Graphing capabilities
- Configurable full screen weight display
- Automatic detection of LCIB signal

Database Fields

- Axle Weight - Axle Speed - Total Weight
- Average Speed - Date - Time - Speed Units - Weight Units - Zero Factor - Grad Size - Sample Length - Number of Axles - Tractor Tare1 - Trailer Tare1 - Vehicle Type1 - Vehicle ID - Scale Operator1 - Driver Name1

1Manually entered after the weighing process

Note: Additional fields available depending on the peripheral options that you have (camera, fire sensors, etc)
Commercial Vehicle Information Systems and Networks (CVISN) Program Update

May 2006
Commercial Vehicle Information Systems and Networks (CVISN) Program Update

ITS America Annual Meeting
May 8, 2006

Jeff Secrist, FMCSA Office of Research and Analysis
Washington, DC
jeff.secrist@dot.gov, (202) 385-2367
Outline

- CVISN Deployment Program Update
  - Overview
  - Core CVISN
  - Expanded CVISN
  - Listening Sessions
- Ad Hoc Team Status
  - Driver Information Sharing
  - Roadside Identification
  - Heavy Vehicle Use Tax
  - COMPASS Coordination
- CVISN Relationships
- CVISN Program Next Steps
SAFETEA-LU Provisions – CVISN Deployment Program

- Provides FMCSA $25 million in FY’s 2006-09
- Complete the deployment of Core CVISN capabilities nationwide
- Define, develop, and implement Expanded CVISN capabilities
- Eligible States are currently completing CVISN grant applications
CVISN Program

• Focus of Core CVISN
  – Complete core deployment nationwide
  – Address key issues
• Focus of Expanded CVISN
  – Federal investment: Driver Information Sharing
  – Other expanded program areas
    • Engage relevant stakeholders
    • Leverage synergies and opportunities
• Initial thoughts for Technology Applications at the Roadside
**Status of States – Core CVISN Deployment**

- **Completed Core Deployment**: 14 States
- **CVISN Core Deployment**: 28 States
- **CVISN Core Planning & Design**: 8 States & DC
Recent Core CVISN Deployment Activities

- Continued coordination and communications
  - Monthly conference calls
  - CVISN and PRISM
  - Interaction with COMPASS and CSA 2010
  - Relationships with other FMCSA projects and grant programs
- Proactive support for Core CVISN Planning and Design States
- Address key Core CVISN issues
  - Standardized information sharing
  - Data quality
  - Interoperability
  - Sharing credentials data
Recent Expanded CVISN Activities

- Expanded CVISN stakeholder conference calls
- Federal investment focused on Driver Information Sharing capabilities
- Identified ad hoc teams to continue work from Expanded CVISN Working Groups
- Continued internal coordination and planning
CVISN Listening Sessions

• During the February 2006 stakeholder telecons, we asked the states about
  – Issues and barriers related to deploying CVISN
  – Opportunities for enhancing national interoperability in the areas of safety, security and/or efficient operations
• Responses fall into these categories:
  – Data availability
  – Data quality – data processing – business rules
  – Institutional
  – Sustained deployment
  – Roles – relationships – processes
• Stay tuned for further discussion on issues
Driver Information Sharing

- Charter: lay the groundwork for improved sharing of information about drivers of commercial vehicles among authorized users
- Champion: Tim Adams, AAMVA
- Representatives: States, AAMVA, CVSA, Industry, others
- Recent accomplishments
- Key concepts
- Next steps
**Roadside Identification**

- Charter: address the need for standards and improved technology to help identify entities on the road
- Co-champions: Joe Foster, MD & Joe Crabtree, KY
- Representatives: States, AAMVA, CVSA, Industry, others
- Recent accomplishments
- Planned activities
Heavy Vehicle Use Tax

- Charter: work with the Internal Revenue Service to clarify requirements, establish workable design, and prototype solutions for both electronic filing of Form 2290 and on-line verification of HVUT payment at time of registration
- Champion: Tim Adams, AAMVA
- Representatives: States, AAMVA, Industry, others
- Recent accomplishments
- Planned activities
COMPASS Coordination

- Charter: represent CVISN stakeholders’ interests to the COMPASS team through ongoing coordination and communication
- Champion: Don Baker, NY
- Representatives: States, AAMVA, CVSA, Industry, others
- Recent accomplishments
- Planned activities
Security Flags

- Charter: develop the concepts for leveraging ITS/CVO resources to address security issues by providing “security flags” to roadside enforcement
- Held discussions with Transportation Security Administration, CVFM, and CVSA
- Held initial conference call with ad hoc team on May 4
- Planned activities
CVISN Relationships: Collaboration and Coordination

COMPASS
CSA 2010
Data Quality/
IMA
PRISM
ENS
Enterprise
Architecture
Border
Enforcement
CDLIS
Improvement
Wireless
Inspection
etc...

Other FMCSA
Initiatives/
Grant Programs/
Projects

Primary
Stakeholders

States
Motor carrier
industry
Drivers
cetc...

AAMVA
CVSA
CVFM
ITS America
Corridor coalitions
AASHTO
Service bureaus
Industry groups
cetc...

Federal
Agencies

FHWA, TSA, CBP,
IRS, DOJ, etc.

Organizations

CVISN Program

Federal
Agencies

FHWA, TSA, CBP,
IRS, DOJ, etc.

Organizations

CVISN Program

Primary
Stakeholders

States
Motor carrier
industry
Drivers
cetc...

AAMVA
CVSA
CVFM
ITS America
Corridor coalitions
AASHTO
Service bureaus
Industry groups
cetc...
CVISN Program Next Steps

- Support States in CVISN deployment activities
- Continue to collaborate and coordinate with other activities and organizations
- Explore start of a new initiative – Smart Roadside Applications for Commercial Vehicle Operations
- Develop action plans to address issues raised in listening sessions
Appendix 2 - Survey of “Best Practices” for Oversize/Overweight Vehicle Enforcement
WIM Survey Report 2006

By

Mouhammad Al-Aktoumi
Abstract

Weigh-in-Motion (WIM) technology is used for measuring and recording the axle and gross weights of moving vehicles. This technology improves upon the weaknesses found in the traditional static weighing in terms of utility and efficiency. Further enhancements to truck weight enforcement were developed to improve the efficiency and availability of WIM technology, this approach is the Virtual Weigh Station (VWS). VWS was developed for the purpose of using the data generated by WIM sensors without having to man the weigh stations. Through the use of VWS, commercial vehicle weight violators would be deterred from operating since the location and status of these manned sites is unknown. Overweight vehicles have tremendous effects on road surface life; decreasing their life span by almost 30% and impacting the safety of highway traffic. The purpose of this report is to introduce the VWS and summarize the recent activities and practices of other states. This survey will provide a general look at the technologies used, cost, dates of installation, type of weigh stations (virtual, motion or static), and number of weigh stations implemented.

Introduction

Virtual Weigh Station is basically the same structure as any WIM station but adding to it the ability to use the real-time data coming out from the sensors efficiently on the highways without manning the stations. Mostly, violators are commercial vehicles within commercial vehicle classes 6 - 13. In the following sections the following topics are discussed: what types of applications other states are using, in what ways can these applications enhance our current system, and then a conclusion will be made to summarize the report.

Applications & Practices
The results collected from the survey done on all states are summarized in Table 1; the subjects stated in the table are: the project sponsor, the average cost of the projects, the accuracy of the sensors used, types of sensors used, types of stations, dates of installation, and total number of stations found in each state.

The data was collected during the last quarter of 2006 from searches of state DOT websites. Most states have their weigh stations concentrated on their borders; this is due to the great number of commercial vehicles that traverse multiple states during their route. It is noticeable that Hawaii is the only state that doesn’t have any weigh stations of any type.

The project sponsors for weight enforcement plans are generally the state departments of transportation. The cost of a static weigh station is very high due to facilities and manpower costs whereas WIM and Virtual Weigh station average much less. The accuracy of the scales show how precise the sensor can be in measuring the weight of the vehicles and that is dependent on the type of sensors used. The least accurate sensor is the piezoelectric sensor (85-90%) which is also the cheapest. Bending plates sensors are 90-95% accurate and load cells, most expensive, are 95-98% accurate.

The state’s choice of sensors used depends on three main parameters: cost, accuracy, and maintenance. The higher the accuracy, the more time needed for maintenance, and the higher the cost of the sensors. An approximated total capital cost of the piezoelectric sensor is $9000 per sensor, the bending plate total cost is $21,500, and the load cell cost is approximately $48,000 per sensor. In an analysis done, piezoelectric sensors necessitate replacement every 3 years, bending plates require full refurbishing every 5 years and load cells need replacement every 5 years. On a yearly basis, the piezoelectric WIM average annual cost is $3,092, the bending plate WIM annual average cost is $4,636 and the load cell WIM annual average cost is $5,982 per sensor.

The number of stations shown is an approximate number and could change due to new installations of weigh stations. All the numbers found in this survey are based on the best data available at this time and are subject to change.
<table>
<thead>
<tr>
<th>States</th>
<th>Project</th>
<th>Average Cost</th>
<th>Accuracy of scale</th>
<th>Types of sensors</th>
<th>Virtual/Motion/Static</th>
<th>Dates of Installation</th>
<th>Total number of Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alabama</td>
<td>ALDOT</td>
<td>$200 Thousand</td>
<td>Load Cells</td>
<td>Static</td>
<td>Feb. 26th 1999</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ITS-CVO Business Plan</td>
<td></td>
<td></td>
<td>Motion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref:


| 2        | Alaska  | ADOT&PF      | $300 Thousand     | piezoelectric and bending plate sensors | Motion/Static         | Since 1996 and till 2002 | 13                       |

Ref:


| 3        | Arizona | AzDOT        | 90-95%             | piezoelectric and bending plate sensors | Motion/Static         |                         | 9                        |

Ref:


<table>
<thead>
<tr>
<th></th>
<th>Arkansas</th>
<th>AHDT</th>
<th>piezoelectric sensors</th>
<th>Motion</th>
<th>Since 1990</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AHDT</td>
<td>$300 Thousand</td>
<td>piezoelectric sensors</td>
<td>Virtual</td>
<td>August 24th 2006</td>
<td>1</td>
</tr>
</tbody>
</table>

Ref:


<table>
<thead>
<tr>
<th></th>
<th>California</th>
<th>CDOT</th>
<th>90-95%</th>
<th>piezoelectric, bending plate &amp; load Cell sensors</th>
<th>Motion</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Caltrans</td>
<td></td>
<td>65%</td>
<td>Virtual</td>
<td>Nov-05</td>
<td>1</td>
</tr>
</tbody>
</table>

Ref:


California, Davis, 2005.


| Ref | “Weigh in Motion (WIM) – Automatic Vehicle Identification (AVI)”, CDOT – ITS Branch. |
| Ref | Colorado Department of Transportation, www.dot.state.co.us/ |

<table>
<thead>
<tr>
<th></th>
<th>Colorado</th>
<th>CDOT</th>
<th>$500 Thousand</th>
<th>95%</th>
<th>load Cell sensors</th>
<th>Motion</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref:


<table>
<thead>
<tr>
<th></th>
<th>District of Columbia</th>
<th>DDOT</th>
<th>$600 Thousand</th>
<th>Static</th>
<th>1</th>
</tr>
</thead>
</table>

Ref:


<table>
<thead>
<tr>
<th>Ref</th>
<th>Contributors</th>
<th>Details</th>
<th>Year</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FDOT</td>
<td>Florida</td>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>FDOT</td>
<td>Georgia</td>
<td>1998</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>FDOT</td>
<td>Hawaii</td>
<td>1998</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>FDOT</td>
<td>Idaho</td>
<td>1998</td>
<td></td>
</tr>
</tbody>
</table>

References:


<table>
<thead>
<tr>
<th></th>
<th>Illinois</th>
<th>IDOT</th>
<th>90-95%</th>
<th>piezoelectric, bending plate &amp; load Cell sensors</th>
<th>Virtual/Motion/Static</th>
<th>1990</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ref:


<table>
<thead>
<tr>
<th></th>
<th>15</th>
<th>Indiana</th>
<th>INDOT</th>
<th>$250 Thousand</th>
<th>90-95%</th>
<th>piezoelectric, bending plate &amp; load Cell sensors</th>
<th>Virtual/Motion/Static</th>
<th>10</th>
</tr>
</thead>
</table>

Ref:


Ref:


[3] Prof. Jon Fricker , "Weigh-In-Motion Data Checking and Imputation", INDOT Division of Research, TRB Subject Code: 53-9 Weigh-In-Motion August 2003
Publication No.: FHWA/IN/JTRP-2003/16, SPR-2470.


[5] Indiana Department of Transportation, www.state.in.us/dot/

<table>
<thead>
<tr>
<th>Ref</th>
<th>16</th>
<th>Iowa</th>
<th>IOWA DOT</th>
<th>90-95%</th>
<th>piezoelectric, bending plate &amp; load Cell sensors</th>
<th>Motion/Static</th>
<th>17</th>
</tr>
</thead>
</table>

Ref:

[1] "Iowa Statewide Transportation Improvement Program 2007-2010", Iowa Statewide Transportation Improvement Program, Iowa Department of Transportation.

[2] "Location of Enforcement Scale Sites", Iowa Department of Transportation, June 1, 2006.

[3] Iowa Department of Transportation, http://www.dot.state.ia.us/

<table>
<thead>
<tr>
<th>Ref</th>
<th>17</th>
<th>Kansas</th>
<th>KSDOT</th>
<th>Static</th>
<th>5</th>
</tr>
</thead>
</table>

Ref:


<table>
<thead>
<tr>
<th>Ref</th>
<th>18</th>
<th>Kentucky</th>
<th>KDOT</th>
<th>90%</th>
<th>piezoelectric sensors</th>
<th>Motion/Static</th>
<th>1001</th>
<th>0</th>
</tr>
</thead>
</table>


<table>
<thead>
<tr>
<th>Ref</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Louisiana LDOTD</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Ref</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Maine MaineDOT</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Ref</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Maryland MDOT</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>State</th>
<th>Agency</th>
<th>Year</th>
<th>Equipment Type</th>
<th>Load Type</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massachusetts</td>
<td>MADOT</td>
<td>1991</td>
<td>$200 Thousand</td>
<td>Motion/Static</td>
<td>1991</td>
</tr>
<tr>
<td>Michigan</td>
<td>MDOT</td>
<td>1980</td>
<td>Static</td>
<td></td>
<td>1980</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Mn/DOT</td>
<td>1993</td>
<td>95%</td>
<td>Motion/Static</td>
<td>1993</td>
</tr>
<tr>
<td>State</td>
<td>Agency</td>
<td>Load Type</td>
<td>Accuracy</td>
<td>Detection Method</td>
<td>Year</td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>-----------</td>
<td>----------</td>
<td>------------------</td>
<td>------</td>
</tr>
<tr>
<td>Mississippi</td>
<td>MDOT</td>
<td>Motion/Static</td>
<td>95%</td>
<td>Load Cell sensors</td>
<td>1994</td>
</tr>
<tr>
<td>Missouri</td>
<td>MoDOT</td>
<td>90%</td>
<td>piezoelectric and bending plate sensors</td>
<td>1994</td>
<td>20</td>
</tr>
<tr>
<td>Montana</td>
<td>MDT</td>
<td>$700 Thousand</td>
<td>90%</td>
<td></td>
<td>1994</td>
</tr>
</tbody>
</table>

Ref:


[2] Orna Raz, Rebecca Buchheit, Mary Shaw, Philip Koopman, and Christos Faloutsos, "Detecting Semantic Anomalies in Truck Weigh-In-Motion Tra-o Data Using Data Mining".

<table>
<thead>
<tr>
<th>Ref:</th>
<th></th>
</tr>
</thead>
</table>

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Nebraska</td>
<td>NDOR</td>
<td>97%</td>
<td>1998</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref:</th>
<th></th>
</tr>
</thead>
</table>

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Nevada</td>
<td>NevadaDOT</td>
<td></td>
<td></td>
<td>Static</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref:</th>
<th></th>
</tr>
</thead>
</table>

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>New Hampshire</td>
<td>NHDOT</td>
<td></td>
<td></td>
<td>Static</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ref:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>New Jersey</td>
</tr>
<tr>
<td>----</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Ref:</strong></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>New Mexico</td>
</tr>
<tr>
<td><strong>Ref:</strong></td>
<td></td>
</tr>
<tr>
<td>[1] &quot;New Mexico 2025 Statewide Multimodal Transportation Plan&quot;, New Mexico Department of Transportation.</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>New York</td>
</tr>
<tr>
<td><strong>Ref:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>North Carolina</td>
</tr>
<tr>
<td>Ref.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North Carolina Department of Transportation, <a href="http://www.ncdot.org/">http://www.ncdot.org/</a></td>
</tr>
<tr>
<td>35</td>
<td>North Dakota</td>
</tr>
<tr>
<td>Ref.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“AASHTO Technology Implementation Group Nomination of Technology Ready for Implementation”, North Dakota Department of Transportation.</td>
</tr>
<tr>
<td></td>
<td>North Dakota Department of Transportation, <a href="http://www.dot.nd.gov/">http://www.dot.nd.gov/</a></td>
</tr>
<tr>
<td>36</td>
<td>Ohio</td>
</tr>
<tr>
<td>Ref.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>37</td>
<td>Oklahoma</td>
</tr>
<tr>
<td></td>
<td>CDOT</td>
</tr>
</tbody>
</table>

Ref:


| 38 | Oregon | CDOT | $650 Thousand | 95% | load Cell sensors | Virtual | 1 |
|    |   |   |  |   | piezoelectric, bending plate & load Cell sensors |   |   |
|    |   |   |   |   |   | Motion/Static | 22 |

Ref:


<table>
<thead>
<tr>
<th>Ref.</th>
<th>State</th>
<th>Agency</th>
<th>Cost</th>
<th>Technology</th>
<th>Type</th>
<th>Duration</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>Pennsylvania</td>
<td>PennDOT</td>
<td></td>
<td>Static</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Rhode Island</td>
<td>RIDOT</td>
<td>$1.8 Million</td>
<td>90% piezoelectric sensors</td>
<td>Motion/Static</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>South Carolina</td>
<td>SCDOT</td>
<td></td>
<td>Static</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>South Dakota</td>
<td>SDDOT</td>
<td></td>
<td>Motion/Static</td>
<td>2000</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Ref</th>
<th>State</th>
<th>Agency</th>
<th>%</th>
<th>Sensor Type</th>
<th>Methodology</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Tennessee</td>
<td>TDOT</td>
<td>95%</td>
<td>Load Cell sensors</td>
<td>Motion/Static</td>
<td>5</td>
</tr>
<tr>
<td>[1]</td>
<td>Texas</td>
<td>TxDOT</td>
<td>90%</td>
<td>Piezoelectric and bending plate sensors</td>
<td>Motion/Static</td>
<td>20</td>
</tr>
<tr>
<td>[4] Utah</td>
<td>UDOT</td>
<td>90%</td>
<td>Piezoelectric, bending plate</td>
<td>Motion/Static</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Vermont</td>
<td>VAOT</td>
<td>$2 Million</td>
<td>Motion/Static</td>
<td>1992</td>
<td>2</td>
</tr>
<tr>
<td>----</td>
<td>---------</td>
<td>------</td>
<td>------------</td>
<td>---------------</td>
<td>------</td>
<td>---</td>
</tr>
</tbody>
</table>

**Ref:**


<table>
<thead>
<tr>
<th>47</th>
<th>Virginia</th>
<th>VDOT</th>
<th>90%</th>
<th>piezoelectric, bending plate &amp; load Cell sensors</th>
<th>Motion/Static</th>
<th>15</th>
</tr>
</thead>
</table>

**Ref:**


489


<table>
<thead>
<tr>
<th>Ref.</th>
<th>48</th>
<th>Washington</th>
<th>WSDOT</th>
<th>Motion/Static</th>
<th>47</th>
</tr>
</thead>
</table>


<table>
<thead>
<tr>
<th>Ref.</th>
<th>49</th>
<th>West Virginia</th>
<th>WVDOT</th>
<th>Static</th>
<th>6</th>
</tr>
</thead>
</table>

- 1. West Virginia Department of Transportation, http://www.wvdot.com/

<table>
<thead>
<tr>
<th>Ref.</th>
<th>50</th>
<th>Wisconsin</th>
<th>WiDOT</th>
<th>Motion/Static</th>
<th>15</th>
</tr>
</thead>
</table>

- 1. "Solving challenges, meeting needs", Wisconsin Department of Transportation.
- 2. Wisconsin Department of Transportation, http://www.dot.state.wi.us/
<table>
<thead>
<tr>
<th>Wyoming</th>
<th>WYDOT</th>
<th>State</th>
</tr>
</thead>
</table>

Ref:


Table 1
In Oklahoma, there are 13 weigh stations although only 10 are functional. The commercial vehicles passing on the highways stated in the table below also stop at static weigh stations to be weighed. The gross weight of the vehicle should be within the Oklahoma highway regulations weight for commercial vehicles. Data from weigh stations is collected and used for statistical purposes as well. Here is a list of the truck weigh stations found in the state of Oklahoma:

<table>
<thead>
<tr>
<th>Weigh Station Name</th>
<th>Highway / Route</th>
<th>Mile</th>
<th>Truck Scale Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boise City</td>
<td>RT 3 56 64 267 385 - EB</td>
<td></td>
<td>Boise City (in the panhandle)</td>
</tr>
<tr>
<td>Boise City</td>
<td>RT 3 56 64 267 385 - EB</td>
<td></td>
<td>Boise City (in the panhandle)</td>
</tr>
<tr>
<td>Woodward</td>
<td>RT 3 183 270 - NB</td>
<td></td>
<td>Woodward (1 mile north of OK 15)</td>
</tr>
<tr>
<td>Woodward</td>
<td>RT 3 183 270 - SB</td>
<td></td>
<td>Woodward (1 mile north of OK 15)</td>
</tr>
<tr>
<td>Davis</td>
<td>I 35 - NB</td>
<td>53.5</td>
<td>Davis (3 miles south of OK 7)</td>
</tr>
<tr>
<td>Davis</td>
<td>I 35 - SB</td>
<td>53.5</td>
<td>Davis (3 miles south of OK 7)</td>
</tr>
<tr>
<td>Tonkawa (Blackwell)</td>
<td>I 35 - NB</td>
<td>216</td>
<td>Tonkawa (1.5 miles north of US 60)</td>
</tr>
<tr>
<td>Tonkawa (Blackwell)</td>
<td>I 35 - SB</td>
<td>216</td>
<td>Tonkawa (1.5 miles north of US 60)</td>
</tr>
<tr>
<td>El Reno</td>
<td>I 40 – EB</td>
<td>129.25</td>
<td>El Reno (3.5 miles east of US 81)</td>
</tr>
<tr>
<td>El Reno</td>
<td>I 40 – WB</td>
<td>129.25</td>
<td>El Reno (3.5 miles east of US 81)</td>
</tr>
<tr>
<td>Erick</td>
<td>I 40 – EB</td>
<td>13.5</td>
<td>Erick</td>
</tr>
<tr>
<td>Erick</td>
<td>I 40 – WB</td>
<td>13.5</td>
<td>Erick</td>
</tr>
<tr>
<td>Henrietta</td>
<td>I 40 – EB</td>
<td>251</td>
<td>East of Henrietta</td>
</tr>
<tr>
<td>Henrietta</td>
<td>I 40 – WB</td>
<td>251</td>
<td>East of Henrietta</td>
</tr>
<tr>
<td>Weigh Station Name</td>
<td>Highway / Route</td>
<td>Mile</td>
<td>Truck Scale Location</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------</td>
<td>------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Webbers Falls</td>
<td>I-40 – E8</td>
<td>283</td>
<td>West of Webbers Falls</td>
</tr>
<tr>
<td>Webbers Falls</td>
<td>I-40 – W8</td>
<td>285</td>
<td>West of Webbers Falls</td>
</tr>
<tr>
<td>Colbert</td>
<td>RT 66 75 – NB</td>
<td>3</td>
<td>Ord (at the Texas border)</td>
</tr>
<tr>
<td>Colbert</td>
<td>RT 69 75 – SB</td>
<td></td>
<td>Colbert (at the Texas border)</td>
</tr>
<tr>
<td>Hugo</td>
<td>RT 271 – NB</td>
<td></td>
<td>Hugo (7 miles south of Hugo, at the Texas border)</td>
</tr>
<tr>
<td>Hugo</td>
<td>RT 271 – SB</td>
<td></td>
<td>Hugo (7 miles south of Hugo, at the Texas border)</td>
</tr>
</tbody>
</table>

Table 2

Table 2 is from the following link:

There are 21 WIM sites spread across Oklahoma as shown in Table 3. These Weigh-In-Motion systems collect traffic volume count, vehicle classification, vehicle speed and vehicle weight, by individual vehicle record, by hour each day. These sites are maintained by the Planning and Research Division of ODOT and the data is collected to support AADT reporting. Another type of systems that deals only with collecting traffic volume count, vehicle classification, and traffic speed by hour each day is the Automatic Vehicle Classifier (AVC). In Oklahoma there are 65 AVC sites, 55 of which are currently active. These AVC sites are also maintained by Planning and Research.
<table>
<thead>
<tr>
<th>Site</th>
<th>Highway</th>
<th>Location</th>
<th>Status</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Section</th>
<th>County</th>
<th>Control</th>
<th>Misc</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM 001</td>
<td>US-70/US-412</td>
<td>Rolandville</td>
<td>Active</td>
<td>86 29 12.01</td>
<td>36 00 42.65</td>
<td>522</td>
<td>Washington</td>
<td>74-21</td>
<td>12.94</td>
</tr>
<tr>
<td>WM 002</td>
<td>US-370</td>
<td>Fort Smith</td>
<td>Active</td>
<td>86 27 45.12</td>
<td>36 02 45.71</td>
<td>521</td>
<td>Roger Taney</td>
<td>50-22</td>
<td>5.28</td>
</tr>
<tr>
<td>WM 006</td>
<td>US-70</td>
<td>Mountain Home</td>
<td>Active</td>
<td>86 24 36.14</td>
<td>36 25 45.33</td>
<td>521</td>
<td>Eureka Springs</td>
<td>56-22</td>
<td>17.58</td>
</tr>
<tr>
<td>WM 007</td>
<td>US-70</td>
<td>Springdale</td>
<td>Active</td>
<td>86 23 26.71</td>
<td>36 25 01.26</td>
<td>521</td>
<td>Springdale</td>
<td>56-22</td>
<td>17.58</td>
</tr>
<tr>
<td>WM 008</td>
<td>US-70/Greensboro</td>
<td>Active</td>
<td>86 20 00.17</td>
<td>36 21 38.32</td>
<td>521</td>
<td>Mountain Home</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 009</td>
<td>US-70/McCord</td>
<td>Active</td>
<td>86 18 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Mountain Home</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 010</td>
<td>US-70/McCord</td>
<td>Active</td>
<td>86 18 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Mountain Home</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 011</td>
<td>US-70/Hot Springs</td>
<td>Active</td>
<td>86 17 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Hot Springs</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 012</td>
<td>US-70/Hot Springs</td>
<td>Active</td>
<td>86 17 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Hot Springs</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 013</td>
<td>US-70/Hot Springs</td>
<td>Active</td>
<td>86 17 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Hot Springs</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
<tr>
<td>WM 014</td>
<td>US-70/Hot Springs</td>
<td>Active</td>
<td>86 17 45.67</td>
<td>36 23 40.17</td>
<td>521</td>
<td>Hot Springs</td>
<td>56-22</td>
<td>17.58</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

Reviewing practices of other states, the weigh-in-motion stations found in Oklahoma should be upgraded to virtual weigh stations. As was mentioned previously, Virtual WIM sites can reduce manpower while still providing weight enforcement. To accomplish this, a license plate recognition camera should be mounted close to the WIM site. By developing a software application, all the data from the WIM site and license plate recognition camera will be sent to be examined by highway patrol officers and ODOT Field Divisions. Highway patrol officers are able to view the information once they are linked to a wireless access point that provides the necessary info in the form of a web browser interface.

Not only in the US but WIM sites and advanced weight enforcement plans are found in so many different countries in the world. One of the countries that are using highway enforcement techniques is Australia. As shown in Table 4, there are 371 WIM sites spread across the country. The mass sensor types used over there are close to what is used in the US plus two other types: strain gauge and capacitive strip. A strain gauge is a device used to measure the strain of an object and thus the strain
A gauge sensor is used for weighing vehicles according to the pressure exerted on the sensor. A capacitive strip is another type of sensors with excellent sensitivity and repeatability.

<table>
<thead>
<tr>
<th>WIM System Name</th>
<th>Mass Sensor Type</th>
<th>Country of Origin</th>
<th>Installations in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASRT 4</td>
<td>Sheet Gauge</td>
<td>Australia</td>
<td>10</td>
</tr>
<tr>
<td>ASRT 4</td>
<td>Load Cell</td>
<td>Australia</td>
<td>4</td>
</tr>
<tr>
<td>ASRT 4</td>
<td>Sheet Gauge</td>
<td>Australia</td>
<td>2</td>
</tr>
<tr>
<td>Golden River Technical Inc</td>
<td>Capacitive Cell</td>
<td>United Kingdom</td>
<td>2</td>
</tr>
<tr>
<td>Golden River Technical Inc</td>
<td>Capacitive Pod</td>
<td>South Africa / United Kingdom</td>
<td>2</td>
</tr>
<tr>
<td>TSO</td>
<td>Tension Force</td>
<td>Canada</td>
<td>3</td>
</tr>
<tr>
<td>TSU</td>
<td>Tension Force</td>
<td>Germany</td>
<td>10</td>
</tr>
<tr>
<td>Tern DAWB</td>
<td>Preload Bar</td>
<td>United Kingdom</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4 WIM sites in Australia

Canada is also another leading country in the research and development of weigh stations (static, mobile, virtual and remote). International Road Dynamics Inc. (IRD) in Canada is one of the leading companies in the world that specializes in highway traffic management products and systems, operating internationally in the Intelligent Transportation Systems (ITS) industry. A new type of weigh stations that IRD has designs is the Remote Control Weigh Station (RCWS). The RCWS complements or supplements the operation of any weigh station in data collection, monitoring and analysis. In figure 1, a layout of a RCWS, this system reduces operational cost with less required number of operators (approximately one). Through web-based communication, the weigh station can be controlled and operated from a central location.
Conclusion

For highway safety and long term enforcement purposes, an advanced system should be deployed to help prolong the highways by deterring non-permitted overweight vehicles from traveling on state roads. The technology for that is VWS which are already deployed in several states. A new technology of sensors that enhance the accuracy of WIM implementations is the Fiber-Bragg-Grating. This type of sensors provides a more accurate measurement than the Load Cells which has a 2% measurement error. Future work will concentrate on producing more accurate systems with higher communications speeds. This will guarantee the ability of detecting overweight vehicles and thereby deterring their non-permitted travel; thus increasing the life expectancy of roads and highways all over the nation.
Appendix 3 - Truck Weight Enforcement Using Advanced Weigh-in-motion Systems – System Requirements Document
Truck Weight Enforcement using Advanced Weigh-in-Motion Systems

System Requirements Document

Prepared By:

James J. Sluss, Jr., Ph.D. – Principal Investigator
Robert C. Huck – TCOM Lab Manager
Fares N. Beany – Graduate Research Assistant
Mouhammad K. Al-Akkoumi – Graduate Research Assistant

School of Electrical & Computer Engineering
University of Oklahoma – Tulsa Campus
4502 East 41st Street, Room 4403
Tulsa, Oklahoma 74135

June 5, 2006
Table of Contents:

Table of Contents .................................................................................................................. 2
List of Figures .......................................................................................................................... 3
List of Tables ........................................................................................................................... 4
List of Tables ........................................................................................................................... 4
1.0 Introduction ....................................................................................................................... 5
  1.1 System Purpose ................................................................................................................. 5
  1.2 System Scope ...................................................................................................................... 5
  1.3 Definitions, Acronyms, and Abbreviations ...................................................................... 5
     Definitions ............................................................................................................................ 5
     Acronyms ................................................................................................................................ 6
     Abbreviations ....................................................................................................................... 6
  1.4 References ......................................................................................................................... 6
  1.5 System Overview ............................................................................................................... 7
2.0 General System Description ............................................................................................... 7
  2.1 System context .................................................................................................................... 7
  2.2 System modes and states .................................................................................................... 8
  2.3 Major system capabilities ................................................................................................. 8
  2.4 Major system conditions .................................................................................................... 8
  2.5 Major system constraints .................................................................................................. 8
  2.6 User characteristics ......................................................................................................... 8
  2.7 Assumptions and dependencies ....................................................................................... 8
  2.8 Operational scenarios ....................................................................................................... 8
3.0 System capabilities, conditions, and constraints ................................................................. 8
4.0 System interfaces .............................................................................................................. 9
Appendices ................................................................................................................................ 10
   Appendix 1 .............................................................................................................................. 11
      Oklahoma Transportation Center Proposal for Truck Weight Enforcement using Advanced
      Weigh-in-Motion Systems .................................................................................................... 11
   Appendix 2 .............................................................................................................................. 19
      International Road Dynamics, Inc. Interface Description .................................................. 19
   Appendix 3 .............................................................................................................................. 20
      Excerpt from the FY 2006 Commercial Vehicle Information Systems and Networks
      (CVISN) Deployment Grant Program for reference .......................................................... 20
List of Figures

Figure 1 – Typical WIM System ........................................................................... 7
List of Tables

None at this time
1.0 Introduction

Weigh-In-Motion (WIM) is described as “the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle” in the American Society for Testing and Materials (ASTM) Standard Specification E 1318-94.

WIM equipment provides highway planners and designers with traffic volume and classification data by time of day and day of week. In addition, WIM equipment also provides planners and designers with Equivalent Single Axle Loadings (ESAL) that heavy vehicles place on pavements. Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities. In summary, the uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues.

The Truck Weight Enforcement Using Advanced Weigh-In-Motion System is a demonstration project that will provide research opportunities and generate results that will lead to the development of a deployment plan for Advanced WIM systems in the State of Oklahoma.

1.1 System Purpose

This system is intended as a concept demonstrator. Research on image capture and license plate recognition will be performed. Additionally, research into dynamic weigh sensor technology and over height detection sensor technology will be performed.

1.2 System Scope

The scope of this system is to demonstrate the ability to correlate over-weight and over-height vehicles with images captured and be able to transmit them to an enabled computer remotely located downstream of traffic flow. Additionally, it is to demonstrate the ability of image capture cameras to recognize license plate numbers and potentially read Department of Transportation (DOT) tag numbers of moving vehicles.

1.3 Definitions, Acronyms, and Abbreviations

Definitions

Enabled Computer

An enabled computer is a computer with the appropriate authorization to connect to the hot spot and access the weigh station web page.

Target Vehicle

A target vehicle is a vehicle that exceeds the enforcement officer selected threshold for weight or the preset height limits for the WIM site location.
Weigh-In-Motion

The process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle.

Acronyms:

ALPR – Automatic License Plate Recognition
ASTM – American Society for Testing and Materials
CCTV – Closed-Circuit Television Camera
CVISN – Commercial Vehicle Information Systems and Networks
CVO – Commercial Vehicle Operations
DOT – Department of Transportation
DPS – Department of Public Safety
ECE – School of Electrical and Computer Engineering
ESAL – Equivalent Single Axle Loading
FHWA – Federal Highway Administration
FMCSA – Federal Motor Carrier Safety Administration
FTE – Full Time Equivalent
IRD – International Road Dynamics, Inc.
ITS – Intelligent Transportation System
OCC – Oklahoma Corporation Commission
OCR – Optical Character Recognition
ODOT – Oklahoma Department of Transportation
OHP – Oklahoma Highway Patrol
OHSO – Oklahoma Highway Safety Office
OTA – Oklahoma Transportation Authority
OTC – Oklahoma Tax Commission
OU – University of Oklahoma
WIM – Weigh-In-Motion

Abbreviations:

TCOM – Telecommunications

1.4 References

Application for Participation in the FY 2006 Commercial Vehicle Information Systems and Networks (CVISN) Deployment Grant, dated May 31, 2006
ASTM E 1318-94, Standard Specifications for Highway Weigh-in-Motion (WIM) Systems
Advanced Weigh-in-Motion System Proposal submitted to the Oklahoma Transportation Center

The requirement of this project is derived from the Truck Weight Enforcement using the System Center

2.0 General System Description

The truck weigh enforcement system will be implemented in a separate location for connection to the enabled computer, along with a separate controller. The server will be implemented in the road

Figure 1 - Typical Weigh-in-Motion System

Video Camera

WIM Cabinet

Sensors

WIM System

Three cameras will be installed to provide images of the vehicle. The controller will use the images to determine the weight of the vehicle. The information will be sent to the database and reported to the enforcement personnel.
and from the FY 2006 Commercial Vehicle Systems and Networks (CVSN) Deployment Grant Program. The FY 2005 CVSN Deployment Grant Program addresses E-screening enhancements to augment the CVSN Core Capability Deployment. While this project is specific in scope, all efforts will be made to ensure project portability and compliance with Deployment Grant Program requirements with respect to integration into the overall objectives of the State CVSN Team.

2.2 System modes and states
2.3 Major system capabilities
2.4 Major system conditions
2.5 Major system constraints
2.6 User characteristics
2.7 Assumptions and dependencies
2.8 Operational scenarios

The enforcement officer will park near the designated hot spot and the enabled computer will automatically connect to the wireless network once in range (approximately 200 feet). The enabled computer will display the web page sent from the web server located in the controller cabinet via a point-to-point wireless link (approximately 2 miles). Based on user selections, the target vehicle information will be displayed and refreshed as new target vehicles pass the WIM station. Once the enforcement officer selects a target vehicle for enforcement, the enabled computer will freeze the display and maintain the target vehicle information until cleared by the enforcement officer.

3.0 System capabilities, conditions, and constraints

This project will create a Hot Spot by installing the necessary equipment for a wireless point-to-point and a wireless hot spot for linking with an enabled computer. The hot spot will be used to receive target vehicle information from the WIM station. The hot spot will be approximately 2 miles from the WIM site located on US-69, 4.75 miles North of SH-113 South near McAlester, Oklahoma. The hot spot will be a designated location on the side of the road down stream of traffic flow in which the enforcement officer will park their car. The hot spot will have an access point with 802.11b capability allowing the enforcement officer to have a wireless network connection with the WIM site from the enabled computer.

Vehicle speed, ESAL, and gross weight data from the WIM site will be processed by the web server. Detection of over height vehicles will be accomplished by separate equipment installed at roadside. Over height detection data will be processed by the web server.

A CCTV camera will take photos of the target vehicle, drivers cab, load, and vehicle side. These
The IoT server will interface with the wireless Link for transmission of information

The embedded controller will interface with the web server to provide data on all vehicles

System Interface

The system will have an interfaced web-based application. The web application will be driven

The web server will store the data collected for all vehicles and maintain a history for the

Identification and the user interface

Photos will be processed for ALPR and character recognition and sent to the web server for
Appendices

1 – Proposal
2 – IRD Interface Document
3 – FY 2006 CVISN Deployment Grant Application
Appendix 1

Oklahoma Transportation Center Proposal for Truck Weight Enforcement using Advanced Weigh-in-Motion Systems
Truck Weight Enforcement using Advanced Weigh-in-Motion Systems

A Proposal Submitted to:

The Oklahoma Transportation Center

By:

James J. Sluss, Jr., Ph.D. – Principal Investigator
Joseph P. Havlicek, Ph.D. – Co-Principal Investigator
Monte P. Tull, Ph.D. – Co-Principal Investigator
Thordur Runolfsson, Ph.D. – Co-Principal Investigator

School of Electrical & Computer Engineering
University of Oklahoma
Norman, Oklahoma

September 19, 2005
1. Problem Statement

Truck weight enforcement is an important component in preserving and extending the life of Oklahoma’s roads and bridges. Weigh-in-Motion (WIM) technology is a tool that can assist the Oklahoma Department of Transportation (ODOT) and the Oklahoma Highway Patrol (OHP) in their efforts to reduce damage to transportation infrastructure. This proposal focuses on three tasks: (1) a pre-defined demonstration project at ODOT’s McAlester WIM site using advanced vehicle imaging and wireless communications technology to allow OHP officers to more effectively intercept overweight violators, (2) a survey of other state DOTs to determine “best practices” for oversize/overweight vehicle enforcement, (3) a determination of the best mix of technology based on Oklahoma’s transportation system and the development of a plan for deployment of WIM-based technology for oversize/overweight vehicle enforcement throughout Oklahoma. Although the investigators have been in discussion with the ODOT Planning and Research Division and OHP Troop S for several months prior to the release of the 2005 Oklahoma Transportation Center - Request for Proposals, it is important to note that Truck Weight Enforcement is identified as a “Top-Down” topic.

2. Research Approach and Methodology

States conduct traffic monitoring for many reasons, including (1) highway planning and design, and (2) motor vehicle enforcement. Weigh-in-Motion (WIM) is a major tool used to collect traffic data. WIM is described as “the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle” in the American Society for Testing and Materials (ASTM) Standard Specification E 1318-94. The uses of traffic and truck weight data include enforcement, pavement, bridge, and legislative and regulatory issues. Motor vehicle enforcement officers use heavy truck axle load data to plan enforcement activities.

Truck weight enforcement activities can benefit from advances in WIM technology, as well as the combination of WIM with other imaging and communications technology. With new technology and technological approaches as goals, this proposal puts forth three tasks that will contribute to the missions of ODOT and OHP with regard to oversize/overweight vehicle detection and enforcement.
Task 1 – McAlester Demonstration Project

The Oklahoma Highway Patrol (OHP) has responsibility for commercial vehicle enforcement in the State of Oklahoma. In discussions with Ron Curb of the ODOT Planning and Research Division and Lt. Greg Allen and Lt. Les Johnson of OHP Troop S, a need exists for a system that can detect overweight vehicles and notify OHP officers located down road for enforcement. Photos of the vehicle, driver, and load as well as weight, speed, and height should be made available remotely. The OHP trooper could sit down road near a “hot spot” to receive the information, but must not be physically connected. We propose to develop a proof-of-concept system that will enable such functionality.

The fixed WIM site selected by ODOT for the prototype system is near McAlester, Oklahoma, on US-69 - 4.75 miles North of SH-113 South. The project will include the evaluation of video capture capability, integration into the existing WIM site, and provision of on-event video via wireless link to a remote trooper. The demonstration project will include two months for design, specification and procurement activities, four months for software development and hardware integration, one month for testing and calibration, two weeks for traffic flow preparation (signage and flow control), and two months for actual traffic condition testing, followed by one month for preparing documentation and providing training.

Task 2 - Survey of “Best Practices” for Oversize/Overweight Vehicle Enforcement

The intended use of WIM data should determine the approach the state chooses in developing the WIM data collection site and the resources required to maintain the site over the expected site design life. WIM equipment provides highway planners and designers with traffic volume and classification data by time of day and day of week. In addition, WIM equipment also provides planners and designers with equivalent single axle loadings that heavy vehicles place on pavements. This task will investigate how other states utilize WIM technology for oversize/overweight vehicle enforcement.

Preliminary background research indicates that other states have successfully combined WIM-based technology with mobile enforcement activities to reduce overweight vehicles [1-5]. Montana reported a 22% decrease in the percentage of overweight vehicles, with a reduction in the amount overweight by nearly 16% [1]. States have various types of WIM systems in place, for example, California is using bending plates, Missouri is using piezoelectric sensors, and
Oregon is using load cells, to name a few. The focus will not be limited to these states, but where successful practices and procedures from other states are available, they will be investigated. This investigation will require four months to carry out a thorough survey.

**Task 3 – Develop a Deployment Plan for Oklahoma**

Based upon “lessons learned” from Task 1 and “best practices” from survey information gathered in Task 2, this task will focus on the development of a roadmap for technology insertion, or deployment plan, for WIM-based systems for oversize/overweight enforcement. The plan will identify high-impact locations across Oklahoma for early adoption (3-years), as well as recommendations for a phased deployment (5-years and ten-years). A benefit-to-cost analysis will also be carried out. The integration of additional features, such as seatbelt compliance, license tag readers, DOT registration readers, will also be investigated. This task will begin subsequent to completion of Task 2 and will run in parallel with the later part of Task 1, as indicated in the following time schedule put forth in Part 9 of this proposal.

3. Expected Results

For Task 1, the McAlester demonstration project, we have already given significant consideration to the video imaging and wireless communications technology required for a successful integration into the existing WIM facility. We derive benefit from our previous experience with such technologies through our partnership with ODOT in deploying Intelligent Transportation Systems (ITS) components throughout the Oklahoma City and Tulsa metropolitan areas. We expect a successful exhibition of enhanced truck weight enforcement capability as a result of this project.

For Task 2, we expect to identify how other states utilize WIM technology for oversize/overweight vehicle enforcement. Based on these findings, we will be in a position to make recommendations to ODOT and OHP for adoption of new technologies and strategies for enforcement.

For Task 3, expect to develop a deployment plan for WIM-based truck weight enforcement systems in Oklahoma. This plan will leverage upon the “lessons learned” from the McAlester demonstration project (Task 1) and the “best practices” findings (Task 2).
4. Deliverables

This project will provide helpful, constructive deliverables to ODOT for their ongoing truck weight enforcement activities. The location of the McAlester demonstration project was strategically chosen by OHP Troop S as it is subject to a heavy concentration oversize/overweight violators. Successful delivery of the demonstration project capability (Task 1) will allow Troop S to significantly enhance the performance of their enforcement mission. Further, delivery of the “best practices” survey (Task 2) and deployment plan (Task 3) will provide the ODOT Planning and Research Division with a documented strategy for moving forward with advanced WIM systems with a specific aim toward truck weight enforcement.

5. Qualifications

Drs. Sluss and Havlicek have served as Co-Directors of the ITS Integration Laboratory in Norman since its inception in 1999. The lab provides a testbed for evaluating ITS technologies, developing software, and ensuring the seamless integration of ITS components. They have worked closely with the Traffic Engineering and Planning and Research Divisions of ODOT, the Oklahoma Highway Safety Office, and the Department of Public Safety, on a number of ITS-related projects since 1998. Drs. Tull and Rumolffson joined these efforts within the last year and provide important technical and managerial expertise. Over the course of working on these projects, the ITS team has managed the development of software to implement an ITS operator console, a database for ITS inventory management, a scheduler and database for collecting data from remote traffic sensors, and an automated traveler information system. Their expertise in the areas of systems and software development will insure a successful outcome to this proposed project.

6. Facilities

This project will be principally supported out of the OU-Tulsa Telecommunications Interoperability Laboratory. The lab offers a full range of telecommunications and hardware/software integration testing capability. In addition, the lab provides closer proximity to the site of the proposed demonstration project in McAlester.
The OU ITS Integration Laboratory on OU's north campus in Norman will provide back-up assistance. The lab contains a variety of ITS and telecommunications networking equipment used for in-depth integration testing.

7. Itemized Budget

An institutional budget sheet is included as an attachment.

8. Budget Justification

The largest percentage of funds being requested in this budget will go to support 2 graduate research assistants at 0.5 FTE for 12 months. These research assistants will provide much of the "hands on" effort necessary to complete the project. In addition, funds are requested 0.1 FTE of our TCOM lab manager’s time to assist with the deployment and integration of the demonstration project and provide technical guidance to the research assistants. The $10k PIP’s cameras will permit multiple images of the overweight trucks to be capture. The $6k in project materials will go to purchase wireless network components and a laptop PC for the demonstration project. The $2k request for travel will support mileage charges for trip between OU and McAlester, OK. The balance of the funding request goes toward benefits and indirect costs. The required 20% matching funds will be provided by a combination of faculty salaries, tuition waivers, and unrecovered indirect costs.

9. Time Schedule

<table>
<thead>
<tr>
<th>Tasks:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1 - McAlester Demonstration Project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design, specifications, procurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software development and hardware integration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing and calibration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic flow preparation and actual &quot;live&quot; testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documentation and training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 2 - Survey of Best Practices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 3 - Develop a Deployment Plan for Oklahoma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. References


Appendix 2

International Road Dynamics, Inc. Interface Description
Appendix 3

Excerpt from the FY 2006 Commercial Vehicle Information Systems and Networks (CVISN) Deployment Grant Program for reference
Section 2.3 Pilot Project to Enhance Mobile Screening Operations

This project was identified in the Oklahoma CVISN Design Document and Program Plan, but has been modified to reflect the addition of optical character recognition devices (OCRs) to the virtual weigh station configuration. A site will be selected on the Oklahoma Turnpike for the virtual weigh station installation. The virtual weigh station installation will include mainline quartz piezoelectric WIM, OCR devices (to capture both plate number and USDOT number), CCTV camera(s) to capture an image of the truck itself and related communications. A truck will drive over the quartz piezoelectric WIM, and its DOT number and license plate would be read by the OCR devices, generating an automated query to the CVIEW. Two OCR devices are planned to enable capture of each number for several reasons:

• Given that OCR devices exhibit a +/- 30% accuracy rate when faced with the challenges presented by varying placement / format of the identifiers being read, the dual read capabilities may result in a higher overall “hit” rate against the CVIEW.

• Because only 20-some states are currently sending data to CVIEW, CVIEW does not currently contain “universal” vehicle data as it does for interstate carrier data. All interstate DOT numbers should be associated with a carrier and at least an ISS score in SAFER and thus CVIEW. Where a plate number does not return information from the CVIEW query, a secondary DOT query should, at a minimum, return some level of safety status information as a basis for screening. The CVIEW query will generate a pass / fail decision which will be integrated with the WIM decision and CCTV image. Where either the CVIEW or WIM screening results in a failed condition, the results and CCTV image will be displayed on the laptop unit of the Turnpike Trooper on duty downstream from the virtual weigh station installation, to alert the
waiting officer as to which vehicle to stop for further inspection, and which parameters generated a "fail" decision.

The funds requested for this project would be used to:

1. Evaluate screening installations using OCR in Florida, Kentucky, Tennessee and other locations to ascertain lessons learned, optimal configuration for equipment, etc.
2. Evaluate and select preferred location for virtual weigh station installation.
3. Procure required hardware, software, communications, integration services.
4. Device installation and testing.
5. Integration testing.
6. Full deployment and user training.

Lead Agency – The Oklahoma Turnpike Authority as the "owner" of the roadway is the Lead Agency for this project. Project Manager – OTA, specific individual TBD.

Participating Entities – Participating entities include:

• The DPS IT Division and Troop S, related to integration of the CVIEW query in the virtual weigh station screening process, user requirements analysis, user training and assessment of pilot test results to determine desirability of additional installations in other (non-turnpike) locations.
• CVIEW vendor – related to integration of the CVIEW query in the virtual weigh station screening process.
• ODOT – as the funding agency (via CVISN deployment funding), ODOT, in concert with the Turnpike Authority and the Oklahoma FMCSA Division Office, the ODOT CVISN Program Manager is responsible for budget/schedule oversight. ODOT and DPS are implementing a similar project (without automated query capabilities) near McAlester. This project will provide a pilot for integrating automated queries in a virtual weigh station application. Similar
Exemption of the Project to Other FDOT Programs

needs

contract, covering both individual device maintenance and operations and ongoing improvement

for OAD associated with the project. Vendor contacts will include annual maintenance

Long term Operations and Maintenance - The ODOT Traffic Authority will be responsible

OAD

• Proposta forers will be involved in project deployment, integration, testing and operations.

Operational Testing

• ODOT Traffic Association - will assist Iowa in working with selected cameras on

providing the service on ODOT's MOnitor Project as well.

Service, quarterly maintenance and evaluation / analysis of the project. ODOT is

of school or community and external audiences with work with participating vendors on

the capabilities as implemented meet documented requirements

furnishings and participating agencies in opinion evaluation, analysis of project results;

• Connected Systems Archer and Project Managers - responsible for assisting the Project

responsible for bridge / schedule coordination

• FDOT Operations Division Office - in concert with ODOT and the Traffic Authority.

street installations and related CCTV, proper configuration of fixed real-time stations to assist in

DOT will then also be involved in the field test extraction design and related materials.

instructions may be incorporated in the type on other local areas with ODOT as interaction.
Deployment of the virtual weigh station project will assist in implementation of FMCSA's motor carrier safety assurance program, as well as FHWA's size and weight program.

will be provided. The exact format and content of the web page will be agreed upon by ODOT, DPS, and OU based on the available data from the WIM site and video capture system.

Data collection will occur even if the trusted computer is not located near the “hot spot”. The historical data will be made available upon request to the trusted computer near the “hot spot” via the web page.
Appendix 4 - Demonstration Final Report
Truck Weight Enforcement using Advanced Weigh-in-Motion

By

Fares N. Beainy

The University of Oklahoma

Friday, April 20, 2007
Table of Contents:

Table of Figures: ........................................................................................................... 3
Table of Tables: ................................................................................................................ 4
1. Background and Motivation: ....................................................................................... 5
2. Goal: .............................................................................................................................. 5
3. System Architecture: .................................................................................................. 6
   3.1. System Description: ............................................................................................. 6
3.2. Software development: ............................................................................................. 7
   3.2.1. File Watcher VB Application: .......................................................................... 8
   3.2.2. Serial to MySQL VB Application: ..................................................................... 9
   3.2.3. PHP Webpage: .................................................................................................. 17
   3.2.4. "db_wim" Database Structure: ................................................................. 22
   3.2.5. WIM System Synchronization: ....................................................................... 23
3.3. Hardware Integration: .............................................................................................. 23
   3.3.1. Automatic License Plate Recognition System: .......................................... 23
   3.3.2. Automatic License Plate Recognition system precision test: ...................... 24
   3.3.3. Wireless communication links: ......................................................................... 25
3.4. Power: ....................................................................................................................... 29
3.5. Security: .................................................................................................................. 29
4. Testing, calibration and live demonstration: .................................................................. 30
5. Conclusion: .................................................................................................................. 30
6. References: .................................................................................................................. 32
Appendices ....................................................................................................................... Error! Bookmark not defined.
Table of Figures:

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Advanced Weigh in Motion system layout</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>File Watcher VB Application block diagram</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>Serial to MySQL VB application block diagram</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>WIM Webpage screen shot</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Thresholds changing popup window</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>WIM webpage block diagram</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>P372 &quot;Spike&quot; an integrated Automatic License Plate Recognition System</td>
<td>24</td>
</tr>
<tr>
<td>8</td>
<td>WIM Canopy system module</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>D-Link Fast Wireless Ethernet Switch</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>From Left to right: Solar panel, WGR614 wireless router and eight 12V batteries</td>
<td>29</td>
</tr>
</tbody>
</table>
Table of Tables:

Table I the 1068 IRD Data Collector WIM record format in help mode .................. 13
Table II buffered WIM data stored in variables.............................................. 15
1. **Background and Motivation:**

   Overweight vehicles cause huge structural damage to roads and bridges, that leads to their permanent transfiguration, and limits their lifespan from the standard 30 years to 8 [1]. In addition, there is a great loss in the state’s regulation fees and tax income, and a lot of harm to the traffic security [2]. Every engineer and scientist is urged to start developing more advanced systems to solve the overweight problem and stop road and traffic damage.

   The weigh in motion (WIM) system has been widely used as a pre-clearance program for static weigh stations, in a way to improve efficiency by screening trucks while traveling at high speed and only requiring trucks within a threshold of a maximum permissible weight to be weighed on more accurate static scales, thus reducing delays and making it more fair for legal and empty trucks [3].

   Weigh in Motion is a new emerging technology that provides departments of transportation and highway patrols with a cost effective tool to monitor and enforce truck weights on bypass or secondary routes. WIM sensors are used on highways to get the weights of all vehicles passing by and send them to a law enforcement officer, such as a state highway patrolman (trooper), to pull off violators. Adjacent to the WIM sensors, there is roadside controller that saves all the data 24 hours a day. The trooper dials in using a mobile phone and a laptop in his patrol car.

2. **Goal:**

   A piezoelectric WIM sensor is already installed, calibrated and used by the Oklahoma Department of Transportation for statistical data collection, and it is located near McAlester, Oklahoma, on US-69 - 4.75 miles North of SH-113 South.

   The goal of the project is to demonstrate the ability of image capture cameras to: (1) recognize license plate numbers and overview pictures of moving vehicles, (2) to correlate weight data with the captured images and to transmit the information to a trooper's computer remotely located downstream of the traffic flow, and (3) to provide the trooper with a user friendly web interface to generate the received information with alerting capabilities in case of overweight vehicles [4].
The contributions of this project have been the evaluation and implementation of a video capture capability for moving vehicles, the integration of this video capture system into an existing WIM site such that the WIM data can be correlated with images, and the provision of this fused vehicle data to law enforcement officers via a wireless network link.

3. System Architecture:

3.1. System Description:
This project will create a Hot Spot by installing the necessary equipment for a wireless point-to-point and a wireless hot spot for linking with the trooper Laptop. The hot spot will be used to receive target vehicle information from the WIM station. The hot spot will be approximately 2 miles away from the WIM site located on US-69, 4.75 miles North of SH-113 South near McAlester, Oklahoma. The hot spot will be a designated location on the side of the road, down stream of traffic flow, in which the enforcement officers will park their cars. The hot spot will have an access point with 802.11b capability allowing the enforcement officer to have a wireless network connection to the WIM site from his/her computer.

Vehicle speed, Equivalent Single Axle Loads (EASL), and gross weight data from the WIM site will be processed by the WIM server.

An Automatic License Plate Recognition System (ALPR) will take two photos of the target vehicle, an overview picture and another for the license plate. These photos will be processed for ALPR and character recognition, and then sent to the WIM server for incorporation into the web page.

The WIM server will store the data collected for all vehicles and maintain a history for the duration of the test.

The system will have a connection between the WIM site and the hot spot using point-to-point wireless system. Target vehicle information will be sent automatically from the web server to the hot spot and on to the 802.11b access point located at the hot spot. The enforcement officer parked near the spot will get the data on the trooper Laptop through a wireless link from the 802.11b access point.
The web application is written using Visual Basic control code along with PHP server-side HTML embedded scripting language. The web server will automatically generate web pages based on the enforcement officer threshold selection and automatically display the information on the trooper’s computer at the hot spot.

3.2. Software Development:

The WIM server is a desktop computer that is going to be installed inside the cabinet that already has the data collection system, the IRD 1068 system electronics. The WIM server is a Personal Computer on which Windows XP is installed along with Apache Web Server, 3CDaemon FTP server, PHP 5.0, Framework.Net 2.0, MySQL Database, ODBC connector between PHP and MySQL.

![Diagram of Advanced Weigh in Motion system layout.](image-url)
Data from the WIM Sensor and the two inductive loops on the road are already being collected by the IRD 1068, formatted and then will be received by the serial port of the WIM Server (see figure1). At this point, a VB Application will be reading data from the serial port and will be writing every record in the database. At the same time, the ALPR system is taking pictures of all the vehicles on the highway. A VB application will detect any new picture received by the FTP server, read the file name that has the information (date, time, license plate...), spit it and then put it in the database in separate columns. As a result, WIM data, Pictures and Identification Info are obtained by the WIM server. Data integration is used to match records and display the ones that exceed the predefined thresholds set by the trooper on the highway.

3.2.1. File Watcher VB Application:
As mentioned earlier, a VB application will take care of watching the directory where the FTP server is configured to upload images of vehicles passing by the WIM station. At this point, no weight filters are applied. This application will just sense the addition of new pictures to the FTP directory, read the file name, split it and insert the required fields into one of two separate tables, one for the Overview pictures and another for the Plate pictures (see Figure 2).

The file name of either an overview or plate picture will have 14 fields separated by commas, the following is an example:

```
f1002,16321305,1,124520,40,1820,0,NONE,1,0,11,250,160,36.
```

Only field number 1, 2 and 4 (marked in red) are of interest for this project. The first field will be of the following format: **tmmdd**

Where:

- **t** indicates the picture type (plate or overview)
- **mm** month
- **dd** day

The second field will have the following format: **HHMSST**

Where:
HH hour
MM minute
SS second
T tenth second

Filed number four will have the following format: PPPPP

Where:

PPPP license plate

In the ALPR configuration software, one can decide the format of the picture to be created and sent to the FTP server, either JPG or BMP. There is a tradeoff between the two image types. With BMP, new directory is created inside the FTP directory where that new created directory has a limit defined by the Directory Size parameter in the ALPR configuration software and every time the limit is reached, a new directory is created. However, with BMP a confidence level can be defined that indicates how much the ALPR algorithm is sure about the plate number, images with low confidence will not be sent to the FTP server. On the other hand, with JPG, all images are uploaded to the main FTP directory. But with JPG, there is no confidence level set option in configuration software what results in the creation of No-Read images. No-Read images are like spam Email, i.e., they make no sense and have no use but to flood the FTP server. Based on the Advanced WIM system design, a decision was made to use JPG where a simple application can be created to daily delete No-Read images from the ftp server.

3.2.2. **Serial to MySQL VB Application:**

Overview and plate pictures are being uploaded by the camera to the FTP server and the file name is being extracted, read, sliced and inserted into the db_wim database. Those pictures will not be usable unless matched with the corresponding WIM data. A VB application was developed in order to read vehicle records from the 1068 IRD data collector, located inside the cabinet at the WIM site in McAlester, and inserted into the db_wim database to be correlated with the appropriate vehicle pictures.
Figure 2 File Watcher VB Application block diagram.

The serial port of the WIM server is connected to the serial port of the 1068 data collector via an RS232 serial null modem cable. The 1068 data collector continuously sends standard ASCII characters WIM records to the WIM server using one of the five different formats: IRD, Help, advantage CVO, Extended Help and Binary (Japan). The Serial to MySQL application can robustly handle both formats Help and Extended Help (see Appendix 1). Table 1 shows the Help mode format of WIM records sent by the IRD 1068 data collector.

<table>
<thead>
<tr>
<th>Bytes</th>
<th>Content</th>
<th>Description</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SOH</td>
<td>Start of Header</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>Message Context</td>
<td>Message ID</td>
<td>C</td>
</tr>
<tr>
<td>0</td>
<td>WIM</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Remote Console</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>WIM2</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>PrePass Sort Decision Override</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>IRD Sort Decision Override</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Health</td>
<td>WIM</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>STX</td>
<td>Start of Text</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>&lt;</td>
<td>Start of Vehicle Record</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>Lane</td>
<td>lane number, 1 digit signed number (18)</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>Lane direction</td>
<td>lane number, 1 digit signed number (18)</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Month</td>
<td>Calendar Month (0112)</td>
<td>MM</td>
</tr>
<tr>
<td>2</td>
<td>Day</td>
<td>Day of Month (0131)</td>
<td>DD</td>
</tr>
<tr>
<td>2</td>
<td>Year</td>
<td>Year (0059)</td>
<td>YY</td>
</tr>
<tr>
<td>2</td>
<td>Hour</td>
<td>Hour format (0023)</td>
<td>HH</td>
</tr>
<tr>
<td>2</td>
<td>Minutes</td>
<td>Minute format (0059)</td>
<td>MM</td>
</tr>
<tr>
<td>2</td>
<td>Seconds</td>
<td>Seconds past the minute (0059)</td>
<td>SS</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Format/Range</td>
<td>Notes</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>2</td>
<td>H5=hundredths of sec</td>
<td>Hundreds of a minute (0999)</td>
<td>TT</td>
</tr>
<tr>
<td>6</td>
<td>Vehnum=vehicle num</td>
<td>5 digit vehicle sequence number (165000)</td>
<td>NNNNN</td>
</tr>
<tr>
<td>2</td>
<td>NA=number of axles</td>
<td>Number of Axles (099)</td>
<td>NN</td>
</tr>
<tr>
<td>2</td>
<td>CL=class</td>
<td>Vehicle Classification (013)</td>
<td>NN</td>
</tr>
<tr>
<td>4</td>
<td>GROS=gross weight *100</td>
<td>Gross Vehicle Weight (9999) lbs *100</td>
<td>NNNNN</td>
</tr>
<tr>
<td>4</td>
<td>LEN=overall length *10</td>
<td>(bumper to bumper) (09999) ft *10</td>
<td>NNNNN</td>
</tr>
<tr>
<td>4</td>
<td>SPD=speed *10</td>
<td>MPH *10</td>
<td>NNNNN</td>
</tr>
<tr>
<td>3</td>
<td>SP1=Axle spacing 2*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP2=Axle spacing 3*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP3=Axle spacing 4*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP4=Axle spacing 5*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP5=Axle spacing 6*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP6=Axle spacing 7*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP7=Axle spacing 8*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>SP8=Axle spacing 9*10</td>
<td>Axle spacing (01400) ft *10</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>3</td>
<td>WT=weight of axle *100</td>
<td>Axle weight (0999) lbs *100</td>
<td>NNN</td>
</tr>
<tr>
<td>1</td>
<td>&gt;</td>
<td>End of Vehicle Record</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>ETX</td>
<td>End of Text</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>LRC</td>
<td>Calculated by XORing from SOH to ETX inclusively. XX Transmit the MSB first.</td>
<td></td>
</tr>
</tbody>
</table>
The Extended Help mode format is the same as Help mode format, but in the latter, axle spacing and axle weight information is repeated twice. The following is an example for a WIM record in Help mode:

```
E08:1,00,02,09,07,13,22,17,53,008162, 2, 3, 31, 149, 702, 95, 0, 0, 0, 0, 0, 0, 0, 17, 14, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 17, 14, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0>1AE
```

The previous example shows how WIM records arrive to the WIM server serial port. When the Serial to MySQL application is started (see Figure 3), a new Serial Port object is created and Hardware handshaking is enabled using DTR (Data Terminal Ready) and RTS (Request to Send) flow control signaling. A console window will popup prompting the operator to enter Serial port properties:

- **Name:** Indicates which Serial Port is used out of the available ports in the WIM server.
- **Speed:** Serial ports use binary signaling, so the data rate in bits per second is equal to the symbol rate in baud. Common bit rates per second are 300, 1200, 2400, 9600, 19200 baud, etc.
- **Data Bits:** 8 data bits are almost universally used.
- **Parity:** is a method of detecting some errors in transmission.
- **Stop bits:** Are sent at the end of every byte transmitted in order to allow the receiving signal hardware to resynchronize.
- **Flow Control:** is the process of managing the rate of data transmission

The Serial-To-MySQL application calls a specific function for each property to be set. The 1068 Data collector uses the following set of setting:
Speed: 9600

Data Bits: 8

Parity: None

Stop bits: 1

Flow Control: None

The first task of the Serial-To-MySQL application is to precisely define the boundaries of each record and buffer it in an array. This is accomplished by continuously reading one byte from the serial port and checking whether it is start of header (SOH) character indicating the start of a record. After an SOH character is read, interpreting bytes from the serial port will continue, but now each read byte is checked until the end of record defined an End of Transmission character (EOT). If the read character is not an End of Transmission, it will be buffered in an array called buffer[], otherwise the record buffering process is complete. The next step will be making sure the buffered record is a WIM Vehicle Record and it is error free. Finding out the type of record is done by four nested if statements:

- The first character in buffer[] is SOH.
- The second character in buffer[] is 0 (indicating Message ID WIM see table 1).
- The third character in buffer[] is Start of Text (STX).
- The fourth Character in buffer[] is "<" which means start of vehicle record.

If one of the above conditions is not met, the application will discard the buffered record and start over. Otherwise, the record is defined to be a WIM Vehicle Record. Next the LRC is calculated by XORing from SOH to ETX inclusively using a while loop with a condition that the XORed Byte is not End of Vehicle Record ">".

The result of LRC calculation is compared with the actual LRC included in the record. In case of transmission error (LRC Calculated does not equal LRC Transmitted). The application will discard the buffered record and start over. Otherwise, the required information are extracted from the record by storing characters from the buffered array into variables based on the format of table 1 and the way it was stored in the buffered array (see table II).
<table>
<thead>
<tr>
<th>Lane</th>
<th>buffer[4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>buffer[15] &amp; buffer[16]</td>
</tr>
<tr>
<td>Hour</td>
<td>buffer[18] &amp; buffer[19]</td>
</tr>
<tr>
<td>Minutes</td>
<td>buffer[21] &amp; buffer[22]</td>
</tr>
<tr>
<td>HSeconds</td>
<td>buffer[27] &amp; buffer[28]</td>
</tr>
<tr>
<td>AxlesNumber</td>
<td>buffer[37] &amp; buffer[38]</td>
</tr>
<tr>
<td>VehicleClass</td>
<td>buffer[40] &amp; buffer[41]</td>
</tr>
</tbody>
</table>

**Table II: Buffered WIM Data Stored in Variables.**

After the information being extracted from the record and stored into variables, a connection is established with MySQL server using ODBC driver to insert the information into the appropriate columns of the data_wim table inside the db_wim database. After successfully storing the WIM record in the database with a time stamp “MatchVio” (see table 2), the user is prompted with the following message “No Transmission Error”, the 1068 IRD data collector is acknowledge by sending an ASCII ACK Character “0x06” and the application will go back to beginning and start over by flashing the buffer array and start looking for new record.
3.2.3. **PHP Webpage**

Overview and license plate pictures are stored in the FTP server's directory. The WIM information and license plate number along with the corresponding picture paths are stored in the database too. WIM information, pictures and license plate number have the detected time stamps stored in the database. A PHP webpage is developed in order to retrieve vehicle's information by matching time stamps of WIM information, License Plate and Pictures (see Figure 4). Once a complete vehicle record is retrieved from the database, it will go through a weight compliance check based on three thresholds: Single Axle, Tandem Axles and Gross Vehicle Weight (GVW). The webpage is divided into two main parts: Current Detected Vehicle and Previous Detected Vehicles. The webpage will show the trooper all the detected vehicles whether they are overweight or not. The trooper is given an option to change all three thresholds, using a button on the top of the webpage.

![Image of PHP Webpage](image-url)

**Figure 4 WIM Webpage screen shot.**
Figure 6 shows a block diagram of the WIM webpage. First, HTML tags are used to create CSS style sheets to give the page a nice look and to create a title. Then, a PHP script calls for an external file "db.php" to connect to MySQL database in order to retrieve data. After successfully connecting to MySQL and selecting db_wim as the database to be used, the three tables that have all the vehicle information are queried: overview_pics, plate_pics, and wim_data. mysql_query() function is used to query data from tables then mysql_num_rows() is used to make sure that tables are not empty. In case one, two or all the tables are empty, a message is displayed to inform the operator. Otherwise, the number of overview pictures in overview_pics table is determined and the pointer of the array holding the queried overview pictures table is moved so it point to the newest picture. At this point a loop is used to go through all the overview pictures, retrieve the date and time (time stamp) of picture detection which is stored earlier by “WIM Watcher” V3 application in one string field called “o_violation_time”, after retrieving the violation time, both tables: plate_pics and wim_data are queried in order to correlate the overview picture with its corresponding license plate picture and WIM data using time stamp as matching parameters. Two types of vehicle records are defined: complete and incomplete. If the targeted overview picture has both license plate picture and WIM data, the corresponding “complete” field in the overview_pics table is set to “1” otherwise to “0”. The same procedure is repeated until all overview pictures are accessed.

The overview_pics table is queried to filter all the complete records. Now that the overview picture information of all the complete records is stored in an array, the array pointer is moved to the newest complete record to be displayed in the current vehicle area. As one sees in picture4, under Current Vehicle, all the information about the vehicle are displayed: vehicle class, axle weights, axle spacing, gross vehicle weight, bumper to bumper length, license plate, speed and the current used weight thresholds. Axle weights and Gross Weight that exceeds the thresholds are shown in the color red so as to alert the trooper of a possible violation. A drawing of the vehicle based on its class number is drawn which links to a table of vehicle classes with weight allowance. The right side of the current vehicle area displays the overview and license plate pictures on top of each other. To build the current vehicle area, the time stamp of the newest overview picture is used to get license plate picture file name, license plate number and WIM data. From the WIM data, the vehicle class number is used to pick the vehicle drawing and
Another pfp (basic) function is the main View, which displays the only difference that
variables are passed: the overview, the name and the number of vehicles in history. The
variables are: a pump picture is clicked, another pfp (basic) function is called and two

whether a pump picture is clicked, another pfp (basic) function is called and two

will be executed by red frame

extracted and used to check if any threshold is exceeded to help decide which pump picture
are of six times are needed, based on the time stamp of the over view picture. With there

variable records is performed. The captured number of records is used to define how many pfp
variable records are already defined earlier. A query for the overall pump with complete

area is replaced with the information of the clicked pump picture. Since the complete
when any pump picture is clicked, the current vehicle information fills the current vehicle
set of six pump. The pump picture is displayed on the current pump picture.

Under the current vehicle area, the previous vehicle area is then generated to give the triggerer
open the original enabled version

whether the enabled vehicle from the database: A mouse click on any of the two pictures will
more details later:

a button is located on the top right of the current vehicle area: expanded in

the second column reveals the time stamps that the time display is shown in bold using CSS style "bold. The second column reveals the time stamps that the time display is shown in bold using CSS style "bold.

two columns of information are displayed. On the top of the first column,

the green vehicle weight is displayed. The "frame" with vehicle information are displayed, then the make of

display under which a table of the make and spec is displayed in a meaningful way.
As stated before, the trooper is given the option to set the three thresholds to some convenient numbers that can help maximize the precision of the system. When the “Change Thresholds” link is clicked, “Threshold.php” is called (see Figure 5). After connecting to the database using “db.php”, the same file used by all PHP pages to connect to “wim_db” database, “Threshold.php” checks for id and threshold passed variables. If no variables passed, the three thresholds are displayed using a clickable link in the following format: Threshold name and Value. When one of those threshold links is clicked, “Threshold.php” is called again but this time passing threshold name and id as variables. Since this time “Threshold.php” is called and variables are passed, a submit form is built to allow thresholds update based on the id and threshold variables passed by the main WIM webpage.
Figure 6 WDM webpage block diagram
3.2.4. "db_wim" Database Structure:

MySQL database is used since it has the cost effective advantage of being an open source database. MySQL does not need any driver to be supported by PHP scripts. By default, MySQL libraries are included in the PHP extension directory. However, a .Net Open Database Connectivity (ODBC.NET) is used so MySQL database becomes accessible through the Microsoft based V8 .Net programming environment.

```
<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Field</th>
<th>Type</th>
<th>Field</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>o_file_name</td>
<td>char(100)</td>
<td>p_file_name</td>
<td>char(100)</td>
<td>v_file_name</td>
<td>char(100)</td>
</tr>
<tr>
<td>oViolationTime</td>
<td>char(200)</td>
<td>pViolationTime</td>
<td>char(200)</td>
<td>vViolationTime</td>
<td>char(200)</td>
</tr>
</tbody>
</table>
```

The "db_wim" database is designated as the data storage for the advanced WIM system gathered and processed information coming from different sources on the WIM site. "db_wim" is consisting of three tables: "overview_pics", "plate_pics" and "wim_data". The
first two tables will carry the plate number, file names and time stamps of pictures captured by the ALPR system while the latter will hold the data collected by the IRD 1068 data collector from road sensors (WIM sensor, inductive loops, etc). Figure 8 shows the structure of the "db_wim" database.

3.2.5. WIM System Synchronization:
Synchronization is a main concern for the advanced WIM system because WIM information and Pictures correlation is based on time stamps. A precision of the order of 500 ms is required for the system to operate properly and be able to match WIM information with the right pictures of vehicle that belongs to. The WIM server is configured to operate as a Network Time Protocol (NTP) server. The ALPR camera has time synchronization capabilities and is configured to automatically synchronize with the WIM server. On the other hand, the IRD 1068 data collector lacks the option of automatically synchronizing with an NTP server. A small code is planned to be added to the Serial to MySQL VB application to synchronize the data collector with the WIM server. The IRD 1068 sends periodic time records (see Appendix 1). The time record will provide the WIM server with the current date and time update. The VB application will just read the time information and update the system time. However, another way to do it is just update the WIM server system time with each WIM vehicle record time stamp. In summary, The WIM server will get the IRD 1068 data collector, update its own system time and update the ALPR camera’s time too.

3.3. Hardware Integration:
3.3.1. Automatic License Plate Recognition System:
P372 "Spike", an integrated ALPR camera processor from PIPS Technology is used in the project (see Figure 7). Spike is a compact, rugged, fully integrated license-plate reading camera incorporating: the camera, the illuminator and the ALPR processor within a single sealed enclosure. The unit comprises a monochrome CCD camera with a built-in infra-red (IR) light-emitting diode (LED) illuminator. A 5-Link 10/100 Fast Ethernet Switch is used to connect the ALPR camera to the WIM server using Category 5 twisted pair (Cat5) cables. The ALPR camera is
installed on a tripod and placed on the grass just off to the highway's shoulder. After configuring the ALPR camera, it was able to capture two pictures: overview picture and plate picture. The camera can capture plates from up to 50 meters and with a maximum angle of 10°. After the camera was successfully tested on the OU-Tulsa campus, it was tested many times next to the highway in McAlester. The camera configuration and positioning was modified many times in a way to maximize the capture rate and license plate reading confidence.

Figure 7 P372 “Spike” an integrated Automatic License Plate Recognition System.

3.3.2. **Automatic License Plate Recognition system precision test:**

After collecting the captured pictures by the ALPR from McAlester, a VB application was developed to find out the effectiveness of the camera. The VB application called ALPRprecision is a windows application written in VB Net 2005. As shown in Figure 8, the ALPRprecision displays the Overview picture along with its corresponding plate picture. On the left side of the plate picture and under the overview picture, the license plate number is presented as read by the ALPR system in a read only Textbox. Another Textbox gives the operator the ability to enter the correct license plate number after looking at the enlarged plate picture. A click on the “Set Plate NUMBER” prompts the user with a “YesNoCancel!” message box to make sure the entered number is correct (see figure 9). If the yes button is
clicked, ALPRPrecision will go ahead and enter the correct license plate number into the database in a separate field and set the “CorrectedPlateNumber” field into ‘1’. A precision rate is calculated for the current displayed picture and the cumulative precision rate for the camera every time the next button is clicked and a new set of pictures is shown. To calculate the current picture precision rate, first the number of read characters is compared to actual character number of the plate. If the result was a positive comparison, which means the ALPR read all the characters on the license with missing or extra characters, the Characters are compared and a ratio of (number of correct characters / number of total characters) is calculated to be the current picture precision rate. However, if one or more characters are missing or added, the ALPRPrecision will ask the user to calculate the rate by entering the number of correct characters and the number of total characters (see figure 9), to avoid unpredictable misjudgments by the application so a realistic precision rate is calculated. On the other hand, the cumulative ALPR precision rate is calculated by adding the rates of all the corrected pictures from the database and dividing by the total number.

With the current achieved configuration and positioning of the camera, a precision of 82 % is achieved.

3.3.3. **Wireless communication links:**

A Canopy Line of Sight Point to Multipoint Solution (see Figure 8) is used for the Wireless connection between the WIM site and the hot spot. The system consists of: Canopy 5.7GHz multipoint access point (AP), Canopy
Figure 8 the ALFRPrecision application with the prompting message showed.

Figure 9 the ALFRPrecision asking the operator to calculate precision rate.
5.7GHz multipoint subscriber modem (SM). Support Brackets, Motorola ACPS110 power over Ethernet supplies and 300SS surge suppressors. The surge suppressor provides a path to ground that protects WIM equipment and other connected devices from near-miss lightning strikes. The power over Ethernet supply provides the Canopy AP and SM the ability to use the Cat5 cable to carry both data and power signals. A support bracket facilitates mounting the AP and SM to various surfaces of a structure, such as a utility pole. The AP provides a network link between the WIM site and the Hot Spot in a 60° sector. On the other hand, the SM will take care of receiving the microwave signal from AP and pass it to the wireless router installed on the trailer next the Hot Spot. Both AP and SM are configurable through a web interface. With no Reflector at a frequency of 5.7 GHz, the AP and SM can communicate with a useful data rate of 6.8 Mbps within 3.2 km (2 miles) and using DES encryption.
Figure 10 WIM Canopy system module

Now the information is available at the Hot Spot through the Canopy SM. The Canopy SM uses a proprietary wireless communication protocols and standards different than the one used by the 802.11 wireless network card installed in the laptops of the highway troopers. The Canopy SM has an RJ-45 Ethernet plug that provides connection to the wireless channels. A NetGear Wireless Router uses a Cat5 cable to get the information from the Canopy SM and then broadcast it to the trooper’s laptop. The 54 Mbps Wireless Router WGR614 v4 with 4-port switch that is used is 802.11g and b wireless networking standards compliant (see Figure 9). The WGR614 uses 64-bit and 128-bit WEP encryption security and the Wireless access can be restricted by MAC address. In addition, the wireless network name broadcast can be turned off so that only devices that have the network name (SSID) can connect.
3.4. Power:

On the WIM site Power is already available to power all the previously installed equipment. However, power at the hotspot is provided by an 800 Watt inverter powered by eight 12V batteries connected in parallel. These batteries are charged by three solar panels connected in series, while a MAXR/20 charge controller is used to make sure those batteries won’t get over charged (see Figure 19). The Solar power system has been under continues use since August 2006 and proved high reliability under various weather conditions.

3.5. Security:

Even though the transmitted information between the WIM Site and the Hot Spot is not critical and confidential, security is still addressed by the advanced WIM system. The canopy system is using the Data Encryption Standard (DES) block cipher that provides a fair amount of security for the current scope of the project. A new version of the Canopy AP and SM embedded software
uses the Advanced Encryption Standard (AES) which is adopted as an encryption standard by the U.S. government. On the other hand, the WGR614 wireless router uses DES as security encryption method. Same as the Canopy equipments, the new version of NetGear wireless routers uses AES encryption for added security.

4. **Testing, calibration and live demonstration:**
During the months of January through April, 2007, testing and calibration of the different subsystems of the advanced WIM system took place in McAlester. Data was gathered so the subsystems were evaluated to update configurations and source codes in a way to optimize system reliability, precision and robustness.

Traffic flow preparation (signage and flow control), and actual traffic condition testing, is expected to take place in McAlester during the month of May.

5. **Conclusion:**
After finishing the survey in McAlester in the first week, the installation and configuration of the canopy wireless link and the 802.11 wireless router were completed in the following two weeks.

Then after two month the design of the software architecture was completed. In addition, the required FTP, NTP, Apache web servers and the MySQL database server were installed. Moreover, a suitable software development environment was created by installing the following: ODBC.net driver, Microsoft Visual Studio .Net 2005 and PHP binaries.

The following six months, were all devoted for the development of the MySQL to Serial and the File Watcher VB applications along with the PHP main WIM webpage. A lot of field testing took place in McAlester in parallel with software development and hardware integration.

Earlier this month, the first complete system test was conducted. The test was successful with some minor problems in system synchronization. More work was done to solve these problems and a final test is scheduled sometime next week before the live demonstration.
The contributions of this project have been the evaluation and implementation of a video capture capability for moving vehicles, the integration of this video capture system into an existing WIM site such that the WIM data can be correlated with images, and the provision of this fused vehicle data to law enforcement officers via a wireless network link.
6. References:


Appendices

1 – WIM data format.

2 – Source code for WIM Watcher

3 – Source code for Serial to MySQL

4 – Source code for the WIM WebPages.
Imports System.Data.Odbc

******************************************************************************
Copyright. 2007 - The Software and the Copyright in the Software are a product of and belong to the University of
Oklahoma. They are not to be provided or used in any format
without the express written permission of the University of
Oklahoma. Dr. James J. Sluss, Jr.

File name: WMMFileWatcher.vb
Creator: Fares Bazzi
Creation Date: 10/25/2006
Description: This application will watch the folder that
FTP server of the WMM system will use to
upload pictures on the WMM server. Whenever
a picture is uploaded, the file name is read
and then copied to extract the needed
information like plate number, time and date.

Comments: CHANGE 102

Data       Author  Description
----------  ------  --------------

******************************************************************************

Public Class Watcher

Public Shared Sub Main()
    ' call the run function to start watching the folder.
    Run()
End Sub

Private Sub Run()
    ' request FileIOPermission for full access to the specified folder
    ' because WMM application must have at least this permission to run the code.
    ' <PermissionsSet (SecurityAction.Demand, Name := "FullTrust")>

    Dim arg() As String = System.Environment.GetCommandLineArgs()!
    If arg.Length <> 2 Then
        ' display the proper way to call the program.
        Console.WriteLine("Usage: Watcher.exe (directory)")
        Return
    End If

    ' Create a new FileSystemWatcher and set its properties.
    Dim watcher As New FileSystemWatcher
    watcher.Path = arg(1)
    ' watch for changes in LastAccess and LastWrite times, and
    ' the renaming of files or directories.
    watcher.NotifyFilter = NotifyFilters.LastAccess Or NotifyFilters.LastWrite Or NotifyFilters.FileName Or NotifyFilters.DirectoryName

    ' watch all files.
    watcher.Filter = "*.*"
    ' add event handlers.
    AddHandler watcher.Created, AddressOf OnChanged
    AddHandler watcher.Deleted, AddressOf OnChanged
    AddHandler watcher.Changed, AddressOf OnChanged

    ' begin watching.
    watcher.EnableRaisingEvents = True

    ' wait for the user to quit the program.
    Console.WriteLine("Press 'q' to quit the sample.")
    While Char.IsControl(Console.ReadLine()) AndAlso Not "q"
End While
End Sub

Private Shared Sub OnChanged(ByVal source As Object, ByVal e As FileSystemEventArgs)
    ' specify what is done when a file is changed, created, or deleted.
    ' get the file name.

557
Dim FileName As String = e.Name
' Chop the file name based on the comma separator.
Dim charSeparators() As Char = [',']
Dim result() As String
result = FileName.Split(charSeparators, StringSplitOptions.RemoveEmptyEntries)
' Extract the plate number.
Dim PlateNumber As String = result(3)
If Not (PlateNumber = "no-read") Or Not (PlateNumber = "") Then
    ' Put the filename in a character array to put date and time together.
    Dim Pieces As Char() = FileName.ToCharArray()
    Dim PictureTime As String = Pieces(1) & Pieces(2) & Pieces(3) & Pieces(4) & Pieces(5) & Pieces(6) & Pieces(7) & Pieces(8) & Pieces(9) & Pieces(10) & Pieces(11) & Pieces(12)
    ' Define picture type (plate or overview)
    Dim PictureType As String = Pieces(0)
    ' Establish connection with MySQL database.
    Dim connectionString As String = "Data Source=\{MySqlDac3.83 Driver};SERVER=localhost;DATABASE=sh_wm;USER=root;PASSWORD=302sQwim;OPTION=3;"
    Dim myCmd As New OdbcCommand()
    Dim myConnection As New OdbcConnection(connectionString)
    ' Open connection
    myConnection.Open()
    myConnection = myConnection
    ' Based on the picture type, prepare the appropriate command to insert information into the database.
    If (PictureType = "0") Then
        myCmd.CommandText = "INSERT INTO overview_pic (o_file_name, o_violation_time, o_plate_number, o_pic_type) VALUES('" & e.Name & ", " & PictureTime & ", " & PlateNumber & ", " & PictureType & ")"
    ElseIf (PictureType = "p") Then
        myCmd.CommandText = "INSERT INTO plate_pic (p_file_name, p_violation_time, p_plate_number, p_pic_type) VALUES('" & e.Name & ", " & PictureTime & ", " & PlateNumber & ", " & PictureType & ")"
    End If
    ' Execute the MySQL command to write the data in the database.
    myCmd.ExecuteNonQuery()
    ' Close connection with database.
    myConnection.Close()
    ' Display the inserted filename into the screen.
    Console.WriteLine("File: " & e.FullPath & "; Type: " & e.ChangeType)
End If
End Sub

Private Shared Sub OnRenamed(ByVal source As Object, ByVal e As RenamedEventArgs)
    ' Specify what is done when a file is renamed.
    Console.WriteLine("File: (0) renamed to (1): " & e.OriginalPath & e.FullPath)
End Sub

End Class
seriallywrapping source code
Imports System
Imports System.IO
Imports System.Threading
Imports System.Data.Odbc

Module SerialToDatabase
Public Class PortComm
    ' Declare _continue and _SerialPort variables.
    Shared _continue As Boolean
    Shared _SerialPort As SerialPort

    Public Shared Sub Main()
        Dim message As String
        Dim sComparer As StringComparer = StringComparer.OrdinalIgnoreCase
        Dim readThread As Thread = New Thread(AddressOf Read)

        ' Create a new SerialPort object with default settings.
        _SerialPort = New SerialPort()

        ' Allow the user to set the appropriate properties.
        ' call the appropriate function for each parameter.
        _SerialPort.PortName = SetPortName(_SerialPort.PortName)
        _SerialPort.BaudRate = SetBaudRate(_SerialPort.BaudRate)
        _SerialPort.Parity = SetParity(_SerialPort.Parity)
        _SerialPort.DataBits = SetDataBits(_SerialPort.DataBits)
        _SerialPort.StopBits = SetStopBits(_SerialPort.StopBits)
        _SerialPort.Handshake = SetHandshake(_SerialPort.Handshake)

        ' Set the read/write timeouts
        _SerialPort.ReadTimeout = 500
        _SerialPort.WriteTimeout = 500

        ' Open the Serial Port.
        _SerialPort.Open()
        _continue = True

        ' Call the read function and make it run in parallel.
        readThread.Start()

        While _continue
            ' Read data from the serial port of the 1068 Systems Electronics IED data collector. Locate valid records, chop it and put it in the database for later use by the Weigh In Motion enforcement webpage.
    End Sub
End Class

Const _continue As Boolean = True
' give the user the option to quit application.
Console.WriteLine("Type QUIT to exit")
' Enter the loop to decide whether the user wants to quit.
While _continues
    ' Read from console.
    message = Console.ReadLine()
    ' Compare what the user writes with "Quit"
    If message.Equals("quit") Then
        ' If the user types "Quit" makes _continue = False.
        _continue = False
    End If
End While
' Block read thread and close the serial port.
readThread.Join()
_serialPort.Close()

End Sub

******************************************************************************
(C) Copyright, 2007 -- The Software and the Copyright in the Software are a product of and belong to the University of Oklahoma. They are not to be provided or used in any format without the express written permission of the University of Oklahoma, Dr. James J. Bluss, Jr.

File name: SerialToDatabase.vb
Function Name: Read()
create:   James W. Bluss
Creation Date: October 25 2006
Description: Reads data from the serial port chop it, perform error check and put it in the data base.
Calling function: Main()
Functions called:  
Comments:  

CHANGE LOG
Date  Author  Description
-----------------------------------

Variables used in this module:
buffer:   It's character array used to buffer data from serial port.
st:      It's a character array used to buffer the start of the record.
end:     It's a character array used to buffer the end of the record.
CRC:     Used to calculate error redundancy check.
LRC:     Used to buffer the actual LRC.
count:   Used as counters.
myConnection: it's an ODBCConnection object used to connect to MySQL database
myCMD:   an ODBCCommand object that will carry the MySQL command to insert data into database.

Public Shared Sub Read()
    ' Make sure the user did not quit.
    While _continue
        Try
            ' Declare variables.
            Dim buffer As Char() = New Char(200) ()
            Dim st As Char() = New Char(8) ()
            Dim end As Char() = New Char(8) ()
            Dim count As Integer = 0
            ' Read from serial port one byte at a time and put it in st(0).
            _serialPort.Read(st, 0, 1)
' Check if the read byte is start of header (S0).
If (st(0) = Chr(1)) Then

' Read from serial port one byte and put it in st(1).
_serialPort.Read(st, 1, 1)
' Check if the read byte '0' which means the
' content of the record is WIM data.
If (st(1) = Chr(48)) Then

' Read from serial port one byte and put it in st(2).
_serialPort.Read(st, 1, 1)
' Check if the read byte Start of Text (STX)
If (st(2) = Chr(2)) Then

' Read from serial port one byte and put it in st(3).
_serialPort.Read(st, 1, 1)
' Check if the read byte Start of Vehicle record (=)
If (st(3) = Chr(61)) Then

' Xor the ASCII equivalent of the first three bytes.
Dim LRC = Asc(st(0)) Xor Asc(st(1)) Xor Asc(st(2)) Xor Asc(st(3))

' Read from Serial port and put it in buffer(0).
_serialPort.Read(buffer, 0, 1)
' Declare i.
Dim i As Integer = 0
' Make sure it's not the End of Vehicle record (e).
While Not (buffer(i) = Chr(62))

' Xor the read byte with LRC.
LRC = LRC Xor Asc(buffer(i))
i = i + 1
' Read from Serial Port and put it in buffer(i).
_serialPort.Read(buffer, i, 1)
End While

' add the End of Vehicle record (e) to LRC.
LRC = LRC Xor Asc(buffer(i))
' Read the next Byte.
i = i + 1
_serialPort.Read(buffer, i, 1)
' Check if it's End of Text (ETX).
If (buffer(i) = Chr(3)) Then

' add ETX to LRC.
LRC = LRC Xor Asc(buffer(i))
' Read the next Byte.
i = i + 1
_serialPort.Read(buffer, i, 1)
' Check if it's End of Transmission (EOT).
If (buffer(i + 2) = Chr(4)) Then

' read the Actual LRC from the record.
Dim LRCtrans = buffer(i) & buffer(i + 1)
' write the read record on the screen.
Console.WriteLine(buffer)
' Write actual LRC on the screen.
Console.WriteLine("" & LRCtrans & ")
' Convert actual LRC into decimal.
LRCtrans = CInt("" & LRCtrans)
' Write the calculated LRC with the Actual LRC
' on the screen.
Console.WriteLine(LRC & "+" & LRCtrans)
' Compare the calculated LRC with the Actual LRC
If (LRC = LRTerm) Then

' Chop the WIN record.
Dim Lane As String = buffer[0]
Dim LaneDirection As String = buffer[2] &
Dim Day As String = buffer[8] & buffer[9]
Dim Hour As String = buffer[12] & buffer[13]
Dim Seconds As String = buffer[16] & buffer[17]
Dim Milliseconds As String = buffer[18] & buffer[19]
Dim VehicleNumber As String = buffer[20] & buffer[21]
Dim VehicleClass As String = buffer[22] & buffer[23]

Minutes & Seconds & buffer[21]

' Prepare the connection command string.
ODBC 3.11 Driver].SERVER=localhost;DATABASE=database;UID=UserName;PASSWORD=Password;OPTION=OPTION

' Declare an Odbc Command.
Dim myCommand As New OdbcCommand

' Declare a new connection to the database using
Dim odbcConnection As New OdbcConnection(m_ConnectionString)

' Open connection.
odbcConnection.Open
Dim myConnection As New
myConnection.Open() myConnection.Open Connection = myConnection

' Insert data into database.
Public Shared Function GetPortName(ByVal defaultPortName As String) As String
    Dim a As String = 
    a = net_readPortName('Available Ports:')
    For Each s In SerialPort.GetPortNames()
        If s = defaultPortName Then
            Return s
        End If
    Next
    Return defaultPortName
' Set the port name as the user writes.
newPortName = Console.ReadLine()
'
' if nothing was written set it into default.
If newPortName = "" Then
    newPortName = defaultPortName
End If
Return newPortName
End Function

*******************************************************************************

(c) Copyright, 2007 -- The Software and the Copyright in the
software are a product of and belong to the University of
Oklahoma. They are not to be provided or used in any format
without the express written permission of the University of
Oklahoma. Dr. James J. Sluss, Jr.

File name: serialToDatabase.vb
Function Name: SetPortBaudRate()
Creator: Parei Bealny
Creation Date: October 25 2006
Description: Set the Serial Port Rate.
Functions called:
Comments:

CHANGE LOG

Date            Author                  Description

------------------- --------------------- ----------------------------------------

Variables used in this module:

newBaudRate: Used to read the user's input and then
set the baud rate.

*******************************************************************************

Public Shared Function SetPortBaudRate(ByVal defaultPortBaudRate As Integer) As Integer
Dim newBaudRate As String

' Define the default Baud Rate.
Console.Write("Baud Rate:\012\012", defaultPortBaudRate)
newBaudRate = Console.ReadLine()

' Set the Baud Rate.
If newBaudRate = "" Then
    newBaudRate = defaultPortBaudRate.ToString()
End If

Return Integer.Parse(newBaudRate)
End Function

*******************************************************************************

(c) Copyright, 2007 -- The Software and the Copyright in the
software are a product of and belong to the University of
Oklahoma. They are not to be provided or used in any format
without the express written permission of the University of
Oklahoma. Dr. James J. Sluss, Jr.

File name: serialToDatabase.vb
Function Name: SetPortParity()
Creator: Parei Bealny
Creation Date: October 25 2006
Description: Set the Serial Port Parity.
Functions called:
Comments:

CHANGE LOG

Date            Author                  Description

------------------- --------------------- ----------------------------------------

Variables used in this module:

newParity: Used to read the user's input and then
set the port parity.

s: Used to store the available parities

*******************************************************************************
Public Shared Function SetPortParity(ByVal defaultPortParity As Parity) As Parity
    Dim newParity As String

    ' Check available Parity options.
    Console.WriteLine("Available Parity options:")
    Dim s As String
    For Each s In [Enum].GetNames(GetType(Parity))
        Console.WriteLine(" ", s)
    Next

    ' Define the default parity.
    Console.Write("Parity([ ])"); defaultPortParity.ToString()
    newParity = Console.ReadLine()

    ' Set the user's parity if not blank.
    If newParity <> Then
        newParity = defaultPortParity.ToString()
    End If

    Return CType([Enum].Parse(GetType(Parity), newParity), Parity)
End Function

Public Shared Function SetPortDataBits(ByVal defaultPortDataBits As Integer) As Integer
    Dim newDataBits As String

    ' Define the default data bits options.
    Console.Write("Data Bits([ ])"); defaultPortDataBits
    newDataBits = Console.ReadLine()

    ' Set the data bits as the user input if not blank.
    If newDataBits <> Then
        newDataBits = defaultPortDataBits.ToString()
    End If

    Return Integer.Parse(newDataBits)
End Function

**************************************************************************************

([C] Copyright, 2007 -- The Software and the Copyright in the Software are a product of and belong to the University of Oklahoma. They are not to be provided or used in any format without the express written permission of the University of Oklahoma. Dr. James J. Bluss, Jr.

File name: SerialToDatabase.vb
Function Name: SetPortParity()
Creator: Faraz Beatty
Creation Date: October 25 2006
Description: Set the Serial Port parity.
Functions called:
Comments: ;

change log
Date Author Description

Variables used in this module:
newDataBits: Used to read the user's input and then set the port data bits.

**************************************************************************************

([C] Copyright, 2007 -- The Software and the Copyright in the Software are a product of and belong to the University of Oklahoma. They are not to be provided or used in any format without the express written permission of the University of Oklahoma. Dr. James J. Bluss, Jr.

File name: SerialToDatabase.vb
Function Name: SetPortDataBits()
Creator: Faraz Beatty
Creation Date: October 25 2006
Description: Set the Serial Port stop bits.
Functions called:
Comments: ;

**************************************************************************************
Public Shared Function SetPortStopBits(ByVal defaultPortStopBits As StopBits) As StopBits
   Dim newStopBits As String

   ' Check for available options.
   Console.WriteLine("Available Stop Bits options: ")
   For Each s In Enum.GetNames(GetType(StopBits))
       Console.WriteLine("[" & s & "]")
   Next s

   ' Define the default Stop Bits value.
   Console.Write("Enter Stop Bits value: ")
   Console.Write(defaultPortStopBits.ToString)()
   newStopBits = Console.ReadLine()

   ' Set the Stop Bits value as the user input if not blank.
   If newStopBits <> ">
      newStopBits = defaultPortStopBits.ToString()
   End If

   Return CType([Enum].Parse(GetType(StopBits), newStopBits), StopBits)
End Function

Public Shared Function SetPortHandshake(ByVal defaultPortHandshake As Handshake) As Handshake
   Dim newHandshake As String

   ' Check for available options.
   Console.WriteLine("Available Handshake options: ")
   For Each s In Enum.GetNames(GetType(Handshake))
       Console.WriteLine("[" & s & "]")
   Next s

   ' Define the default option.
   Console.Write("Enter Handshake value: ")
   Console.Write(defaultPortHandshake.ToString())
   newHandshake = Console.ReadLine()

   ' Set the Hand Shake value as the user's input if not blank.
   If newHandshake <> ">" Then
      newHandshake = defaultPortHandshake.ToString()
   End If

   Return CType([Enum].Parse(GetType(Handshake), newHandshake), Handshake)
End Function

567
Return CType({string}, Parle.IDType)(nameName, nwnnameName, nwhName)
End Function

End Class

End Module
<?

/*
 * This file is part of the website of the McLean County Department of Revenue in Bloomington, Illinois.
 * It contains the HTML code for the main page of the website.
 * Copyright 2007 - The McLean County Department of Revenue.
 */

<?php

// Define the FTP directory used to store vehicle pictures.
include 'db.php';

// Define the width of the display frame.

?>

<!DOCTYPE HTML PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
<head>
<title>Weight in Motion - McLean County</title>
</head>

<body>
<table width="625" height="60" border="1" align="center" bgcolor="#E4F1FF" cellspacing="0">
<tr>
<td width="61" rowspan="2" valign="top" width="61" height="58" color="#000000">
</td>
</tr>
<tr>
<td align="center"><a href="http://www.mcleanco.org/ovcs/WeightInMotion/">
Overweight Vehicle Enforcement System</a></td>
</tr></table>
</body>
</html>
$width = "size";

// Query all the data.
$sql = mysql_query("SELECT * FROM overview_pic");
$sql9 = mysql_query("SELECT * FROM plate_pic");
$sql10 = mysql_query("SELECT * FROM win_data");

// Make sure the database has data.
if($numberofvrio = mysql_num_rows($sql) > 0)
{
    if($numberofvrio = mysql_num_rows($sql9) > 0)
    {
        if($numberofvrio = mysql_num_rows($sql10) > 0)
        {
            // Query overview_pic
            $sql1 = mysql_query("SELECT * FROM overview_pic");
            // Determine the number of Overview Pictures in the database.
            $numberofvrio = mysql_num_rows($sql1);
            // Move the pointer to the newest record.
            $i = "1";
            mysql_data_seek($sql1, $numberofvrio-$i);
            // Fetch the Overview data and store the violation time.
            $row = mysql_fetch_array($sql1);
            foreach($counter = 1; $counter < $numberofvrio; $counter++)
                $viotime = "time":
            // Query and Fetch the Matching Plate from plate_pic table.
            $sql2 = mysql_query("SELECT * FROM plate_pic WHERE ipViolation_time = "$viotime";
            // Query and Fetch the Matching WIM data from the win_data table.
            $sql3 = mysql_query("SELECT * FROM win_data WHERE (MatchVio = "$viotime";
            // Move the pointer for Overview_Pics.
            $i++;
            mysql_data_seek($sql1, $numberofvrio-$i);
            // Fetch the Overview data from WIM Table
            $row = mysql_fetch_array($sql1);
            $viotime = "time":
            // Query and Fetch the Matching Plate from plate_pic table.
            $sql4 = mysql_query("SELECT * FROM plate_pic WHERE ipViolation_time = "$viotime";
            // Query and Fetch the Matching WIM data from the win_data table.
            $sql5 = mysql_query("SELECT * FROM win_data WHERE (MatchVio = "$viotime";
            if(mysql_num_rows($sql2) == 1 & mysql_num_rows($sql3) == 1)
                mysql_query("UPDATE IGNORE overview_pic SET Complete = 1 WHERE (violation_time = "$viotime";
            else
                mysql_query("UPDATE IGNORE overview_pic SET Complete = 0 WHERE (violation_time = "$viotime";
        }
    }
}
if ($numberofvio > 0) {
    // Move the pointer to the newest record.
    $it = 1;
    mysql_data_seek($sql, $numberofvio - 1);

    // Fetch the Overview data from WIM Table
    $row = mysql_fetch_array($sql);
    $viotine = $row['violation_time'];

    // query and fetch the Matching plate from plate_pic table.
    $sql1 = mysql_query("SELECT * FROM plate_pic WHERE ip_violation_time = '$viotine'"), $sql2 = mysql_query("SELECT * FROM wim_info WHERE Matchtime = '$viotine'"),

    // Display the Top main Bar of the page
    print '<table align="center" border="5" cellpadding="2" cellspacing="2">
    <tr><td align="center">Vehicle/number</td><td align="center">Violation</td></tr>
    <tr><td align="center">$filename</td><td align="center">$viotine</td></tr>
    </table>
    
    // Store the Fetched Overview Pic info into variables
    $filename = $row['o_file_name'];
    $plaintext = $row['o_Plate_Number'];

    $row = mysql_fetch_array($sql2);
    // Store the Fetched Plate Pic info into variables
    $filename = $row['p_pic_name'];
    $viotine = $row['p_violation_time'];

    // Store the Fetched Vehicle class into a variable.
    $class = $row['CL'];

    // Query and Fetch the Thresholds.
    $sql4 = mysql_query("SELECT * FROM thresholds WHERE id = '4'"), $sql5 = mysql_query("SELECT * FROM thresholds WHERE id = '5'"), $sql6 = mysql_fetch_array($sql4);
    $sql7 = mysql_query("SELECT * FROM thresholds WHERE id = '1'"), $sql8 = mysql_fetch_array($sql4), $sql9 = mysql_query("SELECT * FROM thresholds WHERE id = '12'"), $sql10 = mysql_fetch_array($sql4), $sql11 = mysql_query("SELECT * FROM thresholds WHERE id = '11'"), $sql12 = mysql_fetch_array($sql4), $sql13 = mysql_query("SELECT * FROM thresholds WHERE id = '10'"), $sql14 = mysql_fetch_array($sql4);

    // Store the Fetched Thresholds into variables
    $DoubleThreshold = $row4['Threshold'];
    $SingleThreshold = $row5['Threshold'];

    // Based on the class number using a switch statement
    // define the appropriate vehicle drawing to display.
    // where the case number indicates the class number.
    switch ($class) {
    case '2',
        // Store the Fetched WIM data into Variables.
        $axle1 = $row['MT1'] / 100;
        $axle2 = $row['MT2'] / 100;
        $SSI = $row['SSI'] * 1.2;
        $Speed = $row['SPEED'] * 0.1;
        $Length = $row['LENG'] * 0.1;

    572
// Display Vehicle Class number and drawing.
print <td rowspan="2">
Vehicle Class: &nbsp;&nbs
<a target="_blank" href="drawings\original.JPEG" img

src="\Drawings\Class4.bmp" width=671 border=0</a>
<tt width=572 border=1>
<td width=30></td>
<td width=50></td>
<td width=80></td>
	<dt width=200></dt>
	// Determine Whether each axle is overweight or not
	// and spacing.
	if(AXial > $Single_Threshold){print"<span class="style3">";}
	print"Axial " $AXial</div><td>
<td width=240></td>
<td width=500></td>
	 // Store the Fetched XML data into Variables.
	$AXial = $row["WT1"] + 100;
	$AXial2 = $row["WT2"] + 100;
	$SP1 = $row["SP1"] + 1.2;
	$GrossWeight = $row["GROS"] + 100;
	$Speed = $row["SPEED"] + 0.1;
	$Length = $row["LEN"] + 0.1;

// Display Vehicle Class number and drawing.
print "<td rowspan="2">Vehicle Class:<strong>3</strong> [-Class]";</n
src="\Drawings\Class5.bmp" width=671 border=0</a>
<tt width=572 border=1>
<td width=30></td>
<td width=50></td>
<td width=80></td>
	<dt width=200></dt>
	// Determine Whether each axle is overweight or not
	// and spacing.
	if(AXial > $Single_Threshold){print"<span class="style3">";}
	print"Axial " $AXial</div><td>
<td width=240></td>
<td width=500></td>
	 // Store the Fetched XML data into Variables.
	$AXial = $row["WT1"] + 100;
	$AXial = $row["WT2"] + 100;
	$AXial = $row["WT3"] + 100;
	$SP1 = $row["SP1"] + 1.2;
	$GrossWeight = $row["GROS"] + 100;
	$Speed = $row["SPEED"] + 0.1;
	$Length = $row["LEN"] + 0.1;

// Display Vehicle Class number and drawing.
print "<td rowspan="2">Vehicle Class:<strong>3</strong> [-Class]";</n
src="\Drawings\Class6.bmp" width=671 border=0"/>a>
<tt width=572 border=1>
<td width=30></td>
<td width=50></td>
<td width=80></td>
	<dt width=200></dt>
	// Determine Whether each axle is overweight or not
	// and spacing.
	if(AXial > $Single_Threshold){print"<span class="style3">";}
	print"Axial " $AXial</div><td>
<td width=240></td>
<td width=500></td>
	 // Store the Fetched XML data into Variables.
	$AXial = $row["WT1"] + 100;
	$AXial = $row["WT2"] + 100;
	$AXial = $row["WT3"] + 100;
	$SP1 = $row["SP1"] + 1.2;
	$GrossWeight = $row["GROS"] + 100;
	$Speed = $row["SPEED"] + 0.1;
	$Length = $row["LEN"] + 0.1;

// Display Vehicle Class number and drawing.
print "<td rowspan="2">Vehicle Class:<strong>3</strong> [-Class]";
<td width="50"></td>
<td width="50"></td>

// Determine whether each axle is overweight or not
// if overweight, change font to red. Display Weights
// and spacings.
if (Axle > $Simple_Threshold)
  print '<span class="style3">"</span>';
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>
  </td>

// Display Vehicle Class number and drawing.
print '<div overflow=""">Vehicles Class</div>';
src="/drawings/Class3.png" width="50" border="0" />;
<table width="572" border="1" cr>
  <td width=150;
  <td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>
  </td>

// Display Vehicle Class number and drawing.
print '<div overflow=""">Vehicles Class</div>';
src="/drawings/Class3.png" width="50" border="0" />;
<table width="572" border="1" cr>
  <td width=150;
  <td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>';
  td width=100;
  td width=50;"align="center";"
  if (Axle > $Simple_Threshold or Axle2+Axle3) >
$Tandem_Threshold[print='span class="style3">"']
  print 'Axle 1b</div>
```html
// Store the Fetched VMU data into Variables.
$sql1 = $row['WT1'] * 100;
$sql2 = $row['WT2'] * 100;
$sql3 = $row['WT3'] * 100;
$sql4 = $row['WT4'] * 100;
$sql5 = $row['WT5'] * 100;
$sql6 = $row['WT6'] * 100;
$sql7 = $row['WT7'] * 100;
$sql8 = $row['WT8'] * 100;
$sql9 = $row['WT9'] * 100;
$sql10 = $row['WT10'] * 100;
$SSP = $row['SSP'] * 1.2;
$SSP2 = $row['SSP2'] * 1.2;
$SSP3 = $row['SSP3'] * 1.2;
$SSP4 = $row['SSP4'] * 1.2;
$SSP5 = $row['SSP5'] * 1.2;
$SSP6 = $row['SSP6'] * 1.2;
$SSP7 = $row['SSP7'] * 1.2;
$SSP8 = $row['SSP8'] * 1.2;
$SSP9 = $row['SSP9'] * 1.2;
$ax1 = $row['WT1'] * 100;
$ax2 = $row['WT2'] * 100;
$ax3 = $row['WT3'] * 100;
$ax4 = $row['WT4'] * 100;
$ax5 = $row['WT5'] * 100;
$ax6 = $row['WT6'] * 100;
$ax7 = $row['WT7'] * 100;
$ax8 = $row['WT8'] * 100;
$ax9 = $row['WT9'] * 100;
$ax10 = $row['WT10'] * 100;
$GrossWeight = $row['GROS'] * 100;
$Speed = $row['SPEE'] * 0.1;
$Length = $row['LEN1'] * 0.1;
```

```html
// Display Vehicle Class number and drawing.
print "<td rowspan='3'>";
VehicleClass="<strong>$Class</strong>";
print "</td>
<br>
</table>
```

```html
// determine whether each axle is overweight or not
// if overweight, change foot to red. Display Weights
// and spacings
if($ax1 > $Simple_Threshold) {
print '<span class="styles1">$ax1</span>
```

```html
</div></td>
<td width="60">$ax1</td>
</tr>
<tr bgcolor="#0000FF"
```

```html
```

```html
```

```html
```

```html
```

```html
```

```html
```
```php
print('<table align=center bordercolor=#FFDDCC width=100% border=5 cellspacing=2 cellpadding=3>'
    .tr bcolor=#FFDDCC
    .td strong,nbsp,nbsp,nbsp,nbsp,

Vehicles:<pre>:&lt;/div&gt;

    // Start new row that will have the previous violators.
    print('&lt;tr&gt;');
    // Query number of overview pics.
    $numberofviol = mysql_num_rows($sql);
    // make sure we jump once at a time.
    $jump = $numberofviol / $page;
    // check if the user jumped to a new set of violators.
    if ($jump &gt; 0) {
        // Move the pointer to the next page.
        mysql_data_seek($sql, $jump);
        // move thru the violators.
        for ($i = $max_results ; $i &gt; 0 ; $i--)
        {
            if ($row = mysql_fetch_array($sql))
                {&n
                    $filename = $row['o_file_name'];
                    $violtime = $row['o_Violation_time'];
                    $sql7 = mysql_query("SELECT * FROM win_data WHERE (MatchVIo
                    . 'violtime')");
                    $row7 = mysql_fetch_array($sql7);
                    $Class = $row7['CLASS'];
                    $Axle1 = $row7['AXLE1'] * 100;
                    $Axle2 = $row7['AXLE2'] * 100;
                    $Axle3 = $row7['AXLE3'] * 100;
                    $Axle4 = $row7['AXLE4'] * 100;
                    $Axle5 = $row7['AXLE5'] * 100;
                    $Axle6 = $row7['AXLE6'] * 100;

                    print '&lt;td&gt;';
                    switch (Class)
                        {&n
                            case '2' or '4' or '2' or '8' or '11':
                                $ScoreWeight=$Score_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                break;
                            case '6' or '9':
                                $ScoreWeight=$Score_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                break;
                            case '7':
                                if ($ScoreWeight=$Score_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                break;
                            case '10':
                                if ($ScoreWeight=$Score_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                $Axle6=$Single_Threshold or
                                $Axle5=$Single_Threshold or
                                $Axle4=$Single_Threshold or
                                $Axle3=$Single_Threshold or
                                $Axle2=$Single_Threshold or
                                $Axle1=$Single_Threshold or
                                break;

```
print "There is no complete WIM information in the database";
}
}
else
{
print "There is no WIM Data Information in the database";
}
else
{
print "There is no Plate Picture Information in the database";
}
else
{
print "There is no Overview Picture Information in the database";
}
?>
</body>
</html>
<html>
<body>

```php
<?php
include 'db.php';
$id=0; GET('id');
$thresholds = $_POST['Threshold'];
if (!($id)) {
    if ($_POST['submit']){
        $sql = "UPDATE thresholds SET Threshold='\$Threshold' WHERE id=$id";
        $result = mysqli_query($sql);
        $result = mysqli_query("SELECT * FROM thresholds");
        while ($myrow = mysqli_fetch_array($result)) {
            print("<a href=""$PHP_SELF"">$id</a><br>

        }
    } else {
        // query the DB
        $sql = "SELECT * FROM thresholds WHERE id=$id";
        $result = mysqli_query($sql);
        $myrow = mysqli_fetch_array($result);
    }
}

// echo 'The new threshold has been set. Please close this window.';

} else {
    // display threshold
    $result = mysqli_query("SELECT * FROM thresholds");
    while ($myrow = mysqli_fetch_array($result)) {
        print("<a href=""$PHP_SELF"">$id</a><br>

    }
}

?>
</html>

586
PIPS Camera Configuration

By

Mouhammad Al-Akkoumi
Introduction

The P372 is an Automatic License Plate Recognition (ALPR) camera system and a product of PIPS Technology. This camera system incorporates the camera, illuminator, and the ALPR processor within a single sealed enclosure. This camera is not affected by vehicles’ headlights and bright sunlight during its plate recognition process because of the built-in infrared Light-Emitting Diode (LED) illuminator, a patented filter, and multi-level flash techniques. This ALPR provides reliable performance during the day and night in virtually all weather conditions. The ALPR system outputs the following: time, date, location, license plate patch image or full IR image, overview image (if camera fitted), and read confidence. The P372 detects the retro reflective return from a license plate in hardware using Digital Signal Processing (DSP) algorithms and captures the field containing the best image of the license plate.

Camera Configuration

A web browser interface is used for configuring and monitoring the P372 (Figure 1).
Figure 1 – PPS Web Browser Interface

Figure 2 shows the system platform page where the user can view the software version, network configuration, hardware characteristics and even does a system reset for the whole system.
P372 built for VES - (violation enforcement system)

Version 1, release v0.9, build 169
Built at Aug 17 2006 13:2:35
Running on C:FSRC/TVF 3.3

Loadable JVM: version: USA-Texas & surrounding from the fflachwork.org

TLV version: 1.2 (expecting 1.2)

This system is booting from ILL and the file on the hard disk is called vss_108.0.

To install new software please click here
or to change the configuration using a script: click here.

**Network configuration**

This system's ethereal IP address is 10.5.6.223
Its netmask is 255.255.255.0
and its gateway is 10.5.6.1
and its broadcast address is 10.5.6.255
To change these network parameters please use the network entry in the configuration panel.

This system's default FTP server is 10.5.6.223.
The system logs into this server with the username CWM and password 30saCWM

**Hardware**

P372 system with an Intel 1p board
Serial number 336

Memory: 128MB installed as 128M
EEPROM: 512k
192 VRFs available

Ethernet MAC address is 000037223714

System has 2 camera video channels available with two control IR and color cameras

* Installed software: 0000010
* Raised VFS with no security
* USA Licence plate recognition
* CWM-342

**System reset**

Reset System

---

Figure 2 – System Platform
In the following part, we’ll discuss the configuration schemes we used to configure the camera and the different values that resulted in the current camera setup. Figures 3 and 4 show the monitor and Configuration drag lists. These lists contain several configuration and monitoring setups that are discussed throughout this document.

Figure 3 – Monitor Drag List
First, we start with the Automatic Number Plate Recognition (ANPR) Engine setup and Figure 5 is a screen capture of its setup. The ANPR version uses this file “flash:ustx.eng” which is the file used for Texas & surrounding states’ license plates.
Next is the Bitmap Images setup, where the user specifies all the FTP server setup for sending the images. Figure 5 shows a screen shot of the Bitmap Images setup.
Figure 7 shows the camera configuration setup where the plate width in the camera settings specifies the plate width for this channel in pixels.

![Camera Configuration Setup](image)

**Figure 7 – Camera Configuration Setup**

The client setup, as shown in Figure 8, specifies what the camera will be sending to the user. The P372 is set to send just the plate patch instead of the entire image; also if the system is not producing overviews and the plate read confidence was less than the value given in the “Threshold” field then plate patch will not be sent to the client.

![Client Setup](image)

**Figure 8 – Client Setup**
Figure 9 shows the Closed Loop Camera Control setup. The “Brightness cutoff” field is used to determine the pixel brightness. With this set to the default value “5” the camera won’t be capturing any headlights that might have been considered as very bright plates.

![Closed Loop Camera Control Setup](image)

Figure 9 – Closed Loop Camera Control Setup

The P372 allows the host machine to send emails to specified IP addresses, as shown in Figure 10.

![Electronic Mail (SMTP) Setup](image)

Figure 10 – Electronic Mail (SMTP) Setup

An external trigger system is used to set a trigger for the ALPR by setting a specific mode of operation. In our setup we choose to enable the detector on Camera 1 by having 0x0100 as the trigger mode (Figure 11).
The “flash.html.a22” is the file which contains the HTML pages on the system and the “Idle Timeout” is the time for a link to be closed if no data has been transferred. Figure 12 shows a screen capture of this setup.

One of the most important setups for the P372 is the Image Capture setup. It specifies how the process of capturing the image occurs. Figure 13 shows a screen capture of the Image Capture Setup. The “Capture Filter” field is used to enable certain image filters to pre-select plates.
One of the values we gave this field is 0x0400, a combination of 0x0400 and 0x0080 which forwards best image on completion of fast trigger gate or whenever it's open. We also tried the 0x0500, a combination of 0x0400 and 0x0100, which forwards best image on completion of fast trigger gate and only enables capture on a camera when the detector for that specific channel shows that a vehicle is present. Both values didn't give us efficient results and we were getting a lot of no reads and sometimes no images were captured at all. The last value we used was the 0x0040 which in any series of images separated by a number of blank fields with no plate trigger, only forwards the image with the best confidence figure for further processing. This value is considered to be the best for the purpose of our project.

The FTP setup can be edited in the JPEG Images setup found in the P371 web interface as shown in Figure 14.
There's also a part for the Kermit Serial File Transfer which specifies the type of device which Kermit files will be transferred to. Kermit is a computer file transfer/management protocol that is used between computer hardware and operating systems platforms. A screen capture of the setup is shown in Figure 15.

Light sensor setup is used to determine the light levels thresholds and the way we set it up is as shown in Figure 16.
To determine where the files will automatically be sent by the FTP then a Host IP address should be written in the “Log Host Address” in the Logging system setup as shown in Figure 17.

The Camera’s IP address as well as the FTP Username, server and password can be entered among others in the miscellaneous settings as shown in Figure 18.

Figure 16 – Light Sensor Setup

Figure 17 – Logging System Setup
In case a modem is used then the user can modify its parameters in the modem setup as shown in Figure 19.

The gateway, broadcast address, netmask and other network parameters can be modified in the Network setup as shown in Figure 20.
The pictures collected by the camera are sent to a database on the server. All of these settings are found in the plate database setup shown in Figure 21.

The plate database entries setup is only functional when the plate database is enabled as shown in Figure 22.
Figure 22 — Plate Database Entries Setup

The system parameters setup contains various important variables from the time server address to plate type to telnet timeout as shown in Figure 23.

Figure 23 — System Parameters Setup

Camera Monitoring

The P372 has several monitoring schemes among those are the View Finder and the Client Monitor as shown in Figures 24 and 25 respectively. The View Finder enables the user to view the four cameras in a specified refresh time interval, JPEG quality, and resolution. The client monitor shows the picture captured on the left with the license plate and the communications happening on the left.
Figure 24 – View Finder
Figure 25 – Client Monitor

Also the ALPR can be reached through Telnet as shown in Figure 26.
Figure 26 – Telnet
P372 License Plate Recognition Camera User Manual

4.3 Example functional specification .............................................. 44
4.4 OEM specific configuration ...................................................... 44
4.5 Data format ........................................................................ 46
4.5.1 Log files ..................................................................... 46
4.5.2 Packet files .................................................................. 46
4.5.3 File locations ................................................................. 47
4.6 Time Synchronisation ............................................................... 47
4.7 PC configuration ................................................................. 48
4.8 System connection ............................................................... 48
4.8.1 Initial connection ........................................................... 48
4.8.2 Network configuration ...................................................... 48
Appendix 5  OEM Journey time system ............................................. 52
5.1 Journey time system specific configuration ................................. 52
5.2 Vehicle tag message .................................................................. 53
5.2.1 Format of tag message ................................................... 53
5.3 Heartbeat message ................................................................. 53
5.3.1 Format of heartbeat message ......................................... 53
5.3.2 Heartbeat status report ................................................... 54
5.4 Time synchronisation ............................................................... 54
Appendix 6  P372 Application Notes .................................................. 56
6.1 Tolling system ....................................................................... 56
6.1.1 File formats .................................................................. 56
6.1.2 Time stamps .................................................................. 57
6.1.3 Command channel .......................................................... 57
6.1.4 Message channel ............................................................ 58
6.1.5 Keep alive ..................................................................... 59
6.1.6 Error codes .................................................................. 59
6.1.7 Status report ................................................................. 60
6.1.8 Tolling specific configuration options ................................. 60
6.2 Security monitoring system ...................................................... 62
6.3 Car parking .......................................................................... 62
Appendix 7  High level commands at the CLI interface ....................... 64
Appendix 8  Customer command protos ............................................ 70

© PIPS Technology Ltd
Copyright Notice

The information within this handbook is authorized for distribution to customers, authorized service center personnel, and distributors of PIPS Technology. Every effort has been made to supply information within this handbook that is correct. However, PIPS Technology assumes neither responsibility for its use, nor any infringements of patents or other rights of third parties which would result. No license is granted by the manufacturer under any patent or patent rights. The manufacturer reserves the right to modify and update the equipment at any time without prior notice.

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means to a third party without the prior consent of the copyright holder.

The manufacturer’s warranty will be invalidated if untrained personnel operate the equipment or if any attempt is made to service the equipment by untrained personnel.

Warranty

PIPS Technology warrants products and spare parts of its own manufacture against faulty materials and workmanship for a period of 12 months, or as modified by the contract, from the date of purchase or on site acceptance, if installed by PIPS Technology authorized personnel.

The warranty excludes consumable materials and parts with an inherently limited life and excludes faults arising from misuse, neglect or vandalism.

PIPS Technology will replace or repair at its option and at no cost to the purchaser any faulty items reported to it within the warranty period.

Service

Service of this equipment by replacement of parts, on site repair or routine maintenance inspections is available. Please contact PIPS Technology for a quotation.

Technical Support

Should you require technical support, please contact PIPS Technology in the United Kingdom.

Users finding errors or omissions in this document are requested to advise PIPS Technology.

Write or telephone:

PIPS Technology Ltd
York House
School Lane
Chandlers Ford
Eastleigh
Hampshire
SO53 4DG

Tel: +44 (0) 2380 240250
Fax: +44 (0) 2380 240251

e-mail support@pipstechnology.co.uk

If you telephone please have the following information available:
product name and version number
operating system and version number

Design Changes

PIPS Technology reserves the right to change the design of any product from time to time without notice and with no obligation to make corresponding changes in products previously manufactured.

Trademarks

Windows and NT are registered trademarks of Microsoft Corporation.
Notification de Copyright

L'information dans ce manuel est autorisée pour la distribution aux clients, au personnel des services de maintenance autorisés, et aux distributeurs de PIPS Technology Ltd (ci-après dénommée "La compagnie"). Tout effort a été fait pour que l'information dans ce manuel soit correcte. Cependant, "La compagnie" n'assume ni la responsabilité pour son usage, ni aucune infraction à des brevets ou à d'autres droits des tiers qui résulteraient de son utilisation. "La compagnie" n'accorde aucune licence sous aucun brevet ou propriété industrielle. "La compagnie" se réserve le droit de modifier et mettre à jour le matériel à tout moment sans préavis.

Aucune partie de cette publication ne peut être reprise, reproduite ou enregistrée sous quelque forme que ce soit sans l'accord écrit préalable de "La compagnie".

La garantie de "La compagnie" sera infirmée si le matériel est utilisé ou si n'importe quelle tentative est faite de le réparer par un personnel non formé par "La compagnie".

Garantie

Cette garantie s'étend aux produits et pièces de rechange fabriquées par "La compagnie" contre les matériaux défectueux et l'exécution défectueuse pendant une période de 12 mois ou comme modifiée par le contrat, de la date de l'achat ou sur l'acceptation de site, si le matériel est installé par "La compagnie" ou un personnel autorisé.

La garantie exclut les matériaux consommables et les parties avec une durée de vie limitée et exclut des défauts redoutant l'abus, de la négligence ou du vandalisme.

"La compagnie" substituera ou réparera, à son option, et à aucun coût à l'acheteur tous les éléments défectueux reportés au cours de la période de garantie.

Service

Le service de ce matériel par le remplacement des parties, par des inspections de maintenance ou de réparation sur de site est disponible. Prière de contacter "La compagnie" pour la liste des coûts.

Support Technique

Pour tout support technique, prière de contacter "La compagnie" au Royaume-Uni.

Si vous trouvez des erreurs ou des omissions dans ce document prière d'informer "La compagnie"

Écrivez ou téléphonez :

PIPS Technology Ltd.
York House
School Lane
Chandlers Ford
Eastleigh
Hampshire
SO53 4DG
UK.

Téléphone : +44 (0) 2380 240250
Fax : +44 (0) 2380 240251

E-mail : support@pipstechnology.co.uk

Si vous téléphonez, prière d'avoir l'information suivante disponible :

- nom de produit et nombre de version
- système d'exploitation et nombre de version

Changements de Conception

"La compagnie" se réserve le droit de changer la conception de n'importe quel produit de temps à autre sans communication préalable et sans l'obligation de faire les changements correspondants des produits construits antérieurement.

Marques déposées

Windows NT sont des marques déposées de Microsoft Corporation.
## Modification History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Draft</td>
<td>March 2004</td>
<td>Initial release</td>
</tr>
<tr>
<td>2nd Draft</td>
<td>27th March</td>
<td>2nd Draft</td>
</tr>
</tbody>
</table>
1. Introduction

This user manual will provide the reader with sufficient information to set up and operate the P372 License Plate Recognition Camera safely and to carry out any routine maintenance tasks that may be necessary.

NOTE. This manual is to be read and clearly understood before operating the equipment.

1.1. Layout of the manual

The manual is organized into chapters as follows:

Section 1
This section is an introduction to the P372 License Plate Recognition Camera and gives an outline description of the contents of the manual.

Section 2
This section deals with the preparation of the system for use, describes the controls and interfaces to the P372. Example notes on software installation are provided.

Section 3
This section describes the maintenance tasks required to ensure continued successful operation of the P372.

Section 4
This section is a troubleshooting guide that helps in the diagnosis of the most common problems and, in most cases, suggests the appropriate course of action.

The appendices provide information on the configuration of the P372 with examples of customer applications.
2. Equipment Overview

The P372 is a single or dual camera complete with video processing/ control/ Automatic License Plate Reader (ALPR). The P372 is encased in a rugged extruded aluminum housing sealed to IP67.

The P372 can be supplied with CCIR (50Hz) or EIA (60Hz) camera(s).

The P372 offers the following functions:

- Integral monochrome camera module, with lens and optical band-pass filter.
- Integral color camera module (optional).
- Integral infrared (IR) pulsed light emitting diode (LED) illuminator that compensates for sunlight and vehicle headlights.
- Camera control. The P372 controls its camera(s). The settings for the camera(s) can be changed on a field-by-field basis to implement the PIPS Technology patented triple flash exposure control.
- Plate Detection. The P372 detects the retro reflective return from a license plate in hardware using digital signal processing (DSP) algorithms and captures the field containing the best image of the license plate.
- Plate Recognition. The P372 streams the captured image to the software ALPR engine that performs OCR on the image and reports the VRN with an associated confidence of the result.
- Trigger. The P372 generates an internal trigger, from the DSP algorithm, to capture the image or an external trigger may be supplied to capture the image.
- Color Overview. The P372 can be fitted with a color overview camera to provide an overview image associated with the captured VRN image.
- Control. The P372 can be controlled from a PC or network using RS232 or Ethernet links.
- Modem. The P372 can be controlled from a modem allowing the P372 to work at remote sites and report the data over a GPRS modem link.
- Hot list. The P372 can check, in real time, the detected VRN against a white or black list of VRNs. Alarms can be raised when a match is found. New hot lists can be downloaded to the P372.
- Image handling. The P372 can store the images as BMP or compressed JPEG files to local memory or they can be transmitted over the Ethernet link to a server. Groups of images, VRN and overview can be grouped together and associated as one record. This group can be watermarked and hashed to ensure the integrity of the data.
- Upgrades. The P372 can receive software upgrades over the Ethernet link and store the file in flash memory.
- File system. The P372 has a battery backed SRAM file system used to store the event and analysis logs. All files are date and time stamped from the internal clock. The internal clock can be synchronized to an external time server.
2.1. **Siting the P372**
The P372 can be sited on poles, gantries or any elevated position giving a clear view of the road or carriageway to be monitored.

2.2. **Rear connection panel**

![Diagram of rear connection panel](image-url)

**Figure 1 P372 Rear Connections**

Details of the Connector 'Pin-Outs' are included in Appendix 2.

2.3. **Installation**
The P372 can be supplied with a breakout box for easy evaluation. This box provides Ethernet, video and serial connectors and the trigger and relay connections are also available at the serial connector. It also provides easy connection of the PSU unit.

For permanent installations information is provided in Appendix 2 for the cable configuration.
2.4. Computer configuration of the P372

This section describes the process required to prepare the software for a complete P372 demonstration system. Not all operations or procedures described here may be required in every demonstration or evaluation situation. The assumption is that the P372 will be connected to a single host PC.

2.4.1. Communications Link

In its current development and demonstration incarnation the P372 requires two communications links. These are the debug serial port and a TCP/IP connection to an ftp server for software loading and optional application software.

In this document, it is assumed that the TCP/IP connection is to a host PC running MS WINDOWS™ 2000™ service pack 4.

The PC must have TCP/IP protocol and FTP server installed. The detailed mechanism for doing this is beyond the scope of this document.

2.4.2. IP Addressing

The P372 must be issued with an IP (Internet protocol) address in order to communicate with management and application software. Also, the P372 needs to know the address of its host PC server for software loading. An IP address is usually seen as a group of four numbers separated by dots. e.g. 100.100.100.100.

The IP addresses used need to match the rest of the network system in which the P372 is installed. The local network administrator will usually be responsible for issue of IP addresses.

For the purposes of this document assume that the PC is allocated 10.10.10.254 and the P372 is allocated 10.10.10.100.

2.4.3. PC Support Software

This section covers the PC software required to load and manage a demonstration or evaluation P372 system.

Confirm the IP address of the PC:

START | CONTROL PANEL | SETTINGS | NETWORK | PROTOCOLS | TCP/IP | PROPERTIES

2.4.4. FTP Server

If it is not already in place:

Add the FTP server:

START | CONTROL PANEL | SETTINGS | NETWORK | SERVICES | ADD | MICROSOFT PEER WEB SERVICES

Configure the web server:

START | PROGRAMS | MICROSOFT PEER WEB SERVICES | INTERNET SERVICE MANAGER
P372 License Plate Recognition Camera User Manual

Select FTP. Uncheck “Allow only anonymous connections”
Select directories. Add the desired directory. Typically d:\inetpub\ftp\root
Add the FTP account.
Username: ftp_boot
Password: ftp_boot
Allow guest permissions with access only to the FTP directory set above

2.4.5. Keatrm

A telnet compatible terminal emulation program is required to interact with the P372
Command Line Interpreter (CLI). Hyperterm or telnet as supplied by Microsoft may be
used. However these are of limited functionality. PIPS Technology recommend and use
Attachmate KEA420 – KeaTerm. There are other flexible packages available which
would also be very suitable.

Install Keatrm, following the installation guidelines. Novell support is not required.
Create a short cut to Keatrm.exe and drag this onto the desktop. Copy the KEA debug
configuration file into place:
copy cd:\372debug.ktc \keatrmuser
Edit the short out:
..keatrm.exe \keatrmuser\372debug.ktc

Connect the 372 to the PC via the supplied debug serial lead. By default connect to
COM1.

2.5. Set up tools

2.6. Aligning number plates

To aid the alignment of the P372 can export the image captured to a viewfinder application.
Double click on the PIPS Viewfinder application on the desktop and the following screen appears.
Figure 2 PIPS Viewfinder application

Confirm that the P372 is detecting a plate. Enter the IP address of the P372 and select the Run button.

The camera can be adjusted to align the plate in the image box in the viewfinder window.

This tool makes the alignment of the P372 camera possible when the P372 is looking at moving traffic. Using a monitor would result in only a few fields of images moving down the screen. The viewfinder application captures and holds the image until it is overwritten by the next image. This allows fine alignment adjustments of the of the P372 camera to be made.
3. Maintenance
The P372 operates with a power supply unit outputting a voltage between 12 and 16 volts. There are no user serviceable parts within the P372.
Routine maintenance of the P372 is limited to cleaning the unit and ensuring that the unit is properly secured and aligned.

4. Fault Finding
If the fault persists after following the procedures described in the table below, contact PIPS Technology for advice.

<table>
<thead>
<tr>
<th>Serial</th>
<th>Fault</th>
<th>Possible Cause</th>
<th>Check/Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Video</td>
<td>Cable damage or failure</td>
<td>Check all cables and power supply. Replace/repair damaged cable. Restore power supply.</td>
</tr>
<tr>
<td>2</td>
<td>Poor Retro-Reflection from Number Plate</td>
<td>Poor camera module alignment</td>
<td>Adjust/align using static number plate. Test using static number plate. If focus is poor, contact PIPS Technology for advice.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera focus incorrectly set</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IR illuminator failure</td>
<td>View with a Camcorder. If illumination is not present, contact PIPS Technology for advice.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dirt on camera</td>
<td>Clean the front window.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Camera window covered with protective film</td>
<td>Remove protective film.</td>
</tr>
<tr>
<td>3</td>
<td>Complete System Failure</td>
<td>Power supply failure</td>
<td>Check integrity of supply and rectify as required.</td>
</tr>
</tbody>
</table>

Table 1 P372 Fault Finding Guide
Appendix 1  Mechanical and Electrical Specification for the P372

1.1 Mechanical

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Dimensions</td>
<td>210 mm long, 107mm diameter excluding head</td>
</tr>
<tr>
<td>Overall Weight</td>
<td>1.5kg</td>
</tr>
<tr>
<td>Casing Material</td>
<td>Aluminum anodized</td>
</tr>
</tbody>
</table>

1.2 Electronic

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>11.5 to 18 volts (at the camera connector)</td>
</tr>
<tr>
<td>Power Requirements Maximum</td>
<td>20 watts</td>
</tr>
<tr>
<td>Doze, LEDs off</td>
<td>14 watts</td>
</tr>
<tr>
<td>Doze, LEDs off, Camera off</td>
<td>6 watts</td>
</tr>
</tbody>
</table>

1.3 Environmental Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Storage)</td>
<td>-50, +50°C</td>
</tr>
<tr>
<td>Temperature (Working)</td>
<td>-20, +50°C</td>
</tr>
<tr>
<td>Sealing</td>
<td>To IP67</td>
</tr>
<tr>
<td>Vibration</td>
<td>(General Transport Specification)</td>
</tr>
<tr>
<td></td>
<td>Mil Std-810D Method 514</td>
</tr>
<tr>
<td>Shock</td>
<td>BS-EN 60068 2-27</td>
</tr>
</tbody>
</table>

1.4 Statutory and Regulatory Considerations

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC FCC Part 15, Subpart B, Class B (Digital Devices)</td>
<td>EN50081-1, EN50082-2</td>
</tr>
<tr>
<td>CE Low Voltage Directive</td>
<td></td>
</tr>
<tr>
<td>Transport environmental specification</td>
<td>TR1034</td>
</tr>
</tbody>
</table>
## Appendix 2  Connector pin outs

<table>
<thead>
<tr>
<th>Socket</th>
<th>19 way Binder</th>
<th>A350/33 Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pin</strong></td>
<td><strong>Connection</strong></td>
<td><strong>Cable wire color</strong></td>
</tr>
<tr>
<td>A</td>
<td>Ethernet XR-</td>
<td>Orange</td>
</tr>
<tr>
<td>B</td>
<td>Ethernet XR+</td>
<td>Yellow</td>
</tr>
<tr>
<td>C</td>
<td>Ethernet Screen</td>
<td>Drain Wire</td>
</tr>
<tr>
<td>D</td>
<td>Ethernet XT-</td>
<td>Green</td>
</tr>
<tr>
<td>E</td>
<td>Ethernet XT+</td>
<td>Blue</td>
</tr>
<tr>
<td>F</td>
<td>Camera 1</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Camera Screen</td>
<td>Grey</td>
</tr>
<tr>
<td>H</td>
<td>Camera 2</td>
<td>White</td>
</tr>
<tr>
<td>I</td>
<td>Battery -</td>
<td>Black</td>
</tr>
<tr>
<td>K</td>
<td>Battery +</td>
<td>Red</td>
</tr>
<tr>
<td>L</td>
<td>Screen</td>
<td>Screen</td>
</tr>
<tr>
<td>M</td>
<td>0 Volts</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>N/U</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>External LED Drive</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plug</th>
<th>19 way Binder</th>
<th>A350/33 Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pin</strong></td>
<td><strong>Connection</strong></td>
<td><strong>Cable wire color</strong></td>
</tr>
<tr>
<td>A</td>
<td>Ethernet XR-</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Ethernet XR+</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Ethernet/RJ232 Screen</td>
<td>Drain Wire</td>
</tr>
<tr>
<td>D</td>
<td>Ethernet XT-</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Ethernet XT+</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Camera 1</td>
<td>Red</td>
</tr>
<tr>
<td>G</td>
<td>Camera Screen</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Camera 2</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Battery -</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Battery +</td>
<td></td>
</tr>
</tbody>
</table>
P372 License Plate Recognition Camera User Manual

<table>
<thead>
<tr>
<th>L</th>
<th>Screen</th>
<th>Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Trigger 1 (Current out)</td>
<td>White</td>
</tr>
<tr>
<td>N</td>
<td>RS232 RXD</td>
<td>Orange</td>
</tr>
<tr>
<td>O</td>
<td>RS232 TXD</td>
<td>Yellow</td>
</tr>
<tr>
<td>P</td>
<td>External video</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Relay 1 (NO)</td>
<td>Green</td>
</tr>
<tr>
<td>S</td>
<td>Relay 2 (Common)</td>
<td>Black</td>
</tr>
<tr>
<td>T</td>
<td>Relay 3 (NC)</td>
<td>Blue</td>
</tr>
<tr>
<td>U</td>
<td>Trigger 2 (Current in)</td>
<td>Grey</td>
</tr>
</tbody>
</table>

Table A2.1 372 Connections

NOTE:

Signals are
RXD – Receive Data by P372
TXD – Transmit Data from P372

The 372 camera has an optically isolated trigger input. External current must be provided to enable correct operation. An example circuit is shown below.

![Circuit Diagram]

Appendix 3 P372 General Configuration

3.1 Overview

P372 system configuration information is stored on two places. Low level and system configuration information is stored within EEPROM. High level application information is stored within a file. This file may be located within any of the available file systems.

A small number of configuration options are accessible from the EPROM boot loader, as these configuration options must be set in order to start or to load software into the P372.

3.2 Connection & Control

Initial control and configuration of the P372 must be done via the engineering access serial port (the debug port). This serial port is a 3-wire connection and is by default configured for 19200bps, 8 databits, 1 stop bit, XON/XOFF protocol. Once basic network configuration is complete, then it is possible to perform configuration and control via a single TELNET connection over TCP/IP protocol.

The P372 will generate unsolicited monitor and debug messages on the engineering access port. The volume and detail of this information stream may be managed via various configuration options described below. In addition this data stream may also be monitored via a TELNET connection. This is described in further detail below.

Communication with the P372 control software is performed via a Command Line Interpreter (CLI). The CLI indicates that it is ready to accept further commands by means of a prompt.
3.3 EPROM configuration

(These options are duplicated within the application CLI)

<table>
<thead>
<tr>
<th>show boot</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>set boot dev (filespec)</td>
<td>Set program boot file and device device may be: ATE, prom, ftp or file</td>
</tr>
<tr>
<td>show date</td>
<td></td>
</tr>
<tr>
<td>set date dd-mmm-yyyy hh:mm:ss</td>
<td></td>
</tr>
<tr>
<td>show conf</td>
<td></td>
</tr>
<tr>
<td>set conf full_filespec</td>
<td>Set source for application configuration file</td>
</tr>
<tr>
<td>show server</td>
<td></td>
</tr>
<tr>
<td>set serial nnnn</td>
<td>Set the unit serial number. This entry requires a security code.</td>
</tr>
<tr>
<td>set ethernet aaaa bbbb cccc</td>
<td>Set the unit hardware Ethernet address. This entry requires a security code.</td>
</tr>
<tr>
<td>set server aaaa.bbbb.cccc.ddd</td>
<td>Set default ftp server IP address</td>
</tr>
<tr>
<td>set internet aaaa.bbbb.cccc.ddd</td>
<td>Set the IP address of the 372</td>
</tr>
<tr>
<td>set password</td>
<td></td>
</tr>
</tbody>
</table>

3.3.1 Boot device

<table>
<thead>
<tr>
<th>ATE</th>
<th>No application loaded. Minimal hardware configuration performed, network connection is not enabled.</th>
</tr>
</thead>
<tbody>
<tr>
<td>prom</td>
<td>No application loaded. Hardware configured. Network enabled.</td>
</tr>
<tr>
<td>ftp</td>
<td>Application will be loaded across network link via FTP protocol.</td>
</tr>
<tr>
<td>file</td>
<td>Application will be loaded from flash file system.</td>
</tr>
</tbody>
</table>

3.3.2 Examples

```bash
>>> show conf
config file: flash:/system.ini
>>> set conf mem:/system.ini
config file: mem:/system.ini

>>> show boot
boot mode is: FTP , default file: 372m1a.s00
>>> set boot file 372m1a.s00
```
3.4 Application configuration

Configuration information described herein is kept in the file named in the system config parameter. By default this would be flash;system.ini. But for development it will be mem;system.ini. Note use of colon and semicolon as the path descriptor separators.

<table>
<thead>
<tr>
<th>Capture show</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>capture set filter</td>
<td>This field is a numeric value either decimal or hex. In which each bit enables a filter to preselect plates.</td>
</tr>
<tr>
<td>0x0000</td>
<td>(no bits set) all plates rejected</td>
</tr>
<tr>
<td>0x0001</td>
<td>process images at maximum rate subject to the queue never having any pending images</td>
</tr>
<tr>
<td>0x0002</td>
<td>Images are captured on time expiry set by &quot;capture settme&quot;.</td>
</tr>
<tr>
<td>0x0004</td>
<td>Plate trigger must move a defined number of pixels (horizontal or vertical) before a new plate is accepted.</td>
</tr>
<tr>
<td>0x0008</td>
<td>Reject images if ALPR queue length exceeds set cap queue parameter.</td>
</tr>
<tr>
<td>0x0010</td>
<td>Accept all images, ignoring plate trigger.</td>
</tr>
<tr>
<td>0x0020</td>
<td>NY1 - select groups of images to encompass a complete exposure sequence</td>
</tr>
<tr>
<td>0x0040</td>
<td>In any series of images separated by a number of blank fields (set cap blanks) with no plate trigger, only forward the image with the best confidence figure for further processing.</td>
</tr>
<tr>
<td>0x0080</td>
<td>Only enable capture when fast trigger gate is open (see trigger below)</td>
</tr>
<tr>
<td>0x0100</td>
<td>Only enable capture on any camera when the detector for that channel shows that a vehicle is present</td>
</tr>
<tr>
<td>0x0200</td>
<td>Capture all images with a valid plate detect - beware can flood and stall</td>
</tr>
<tr>
<td>0x0400</td>
<td>Forward best image on completion of fast trigger gate. Requires 050 or 100 above.</td>
</tr>
<tr>
<td>0x0800</td>
<td>Images will be monitored according to other options set. However no image will be forwarded until after the completion of a trigger event.</td>
</tr>
<tr>
<td>capture set time nn</td>
<td>Set the minimum number of ms to elapse between image samples. Only used if filter bit 0x02 (filter_time) is set.</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>capture set vertical</td>
<td>Set the minimum number of lines the plate trigger must move before a new image is accepted. Only active if movement filter bit 0x04 is set. If set to 0, this filter is off.</td>
</tr>
<tr>
<td>capture set horizontal</td>
<td>Set the minimum number of horizontal pixels the plate trigger must move before a new image is accepted. If set to 0, this filter is off.</td>
</tr>
<tr>
<td>capture set queue</td>
<td>Set the maximum number of plate images permitted in the ALPR input queue. Reducing this figure will improve latency at the expense of lost images in a busy system.</td>
</tr>
<tr>
<td>capture set wide_field</td>
<td>Set parameter for the wide field detector (NYI);</td>
</tr>
<tr>
<td>capture set blanks nn</td>
<td>When filter_best is set, this value represents the number of blank fields used to detect the separation between vehicles.</td>
</tr>
<tr>
<td>capture set count nn</td>
<td>If a vehicle is stationary in front of the camera, no &quot;best&quot; plate can be detected until the vehicle has moved off. After this count has expired the &quot;best&quot; plate so far will be forwarded. Whilst the plate remains stationary, the count before the next forward is increased by count on each event.</td>
</tr>
<tr>
<td>capture set factor</td>
<td>Not in use.</td>
</tr>
<tr>
<td>capture set enable nn</td>
<td>0x0301 Default value.</td>
</tr>
<tr>
<td>capture set best</td>
<td>Not in use.</td>
</tr>
<tr>
<td>capture set upper_limit</td>
<td>mm Tell plate detector to ignore any trigger signal appearing outside this limit. Where nn is pixels from upper edge of field.</td>
</tr>
<tr>
<td>capture set lower_limit</td>
<td>mm Tell plate detector to ignore any trigger signal appearing outside this limit. Where nn is pixels from lower edge of field.</td>
</tr>
<tr>
<td>capture set left_limit</td>
<td>mm Tell plate detector to ignore any trigger signal appearing outside this limit. Where nn is pixels from left edge of field.</td>
</tr>
<tr>
<td>capture set right_limit</td>
<td>mm Tell plate detector to ignore any trigger signal appearing outside this limit. Where nn is pixels from right edge of field.</td>
</tr>
<tr>
<td>capture set debug</td>
<td>0xnn Set bits to turn on debug messages within capture system.</td>
</tr>
<tr>
<td>capture set age</td>
<td>mm When any of the &quot;capture best&quot; filters are enabled, any image older than nn ms will be discarded and replaced with a newer image.</td>
</tr>
<tr>
<td>capture set duplicates</td>
<td>n set n to 1 to reject successive plate events showing the same plate.</td>
</tr>
<tr>
<td>capture set age_bias</td>
<td>n set n to 0 to disable biasing of plates. Set to a positive number to bias toward the earlier plates in a sequence. Set to a negative number to bias toward the later plates in a sequence.</td>
</tr>
<tr>
<td>Parameter</td>
<td>Default</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>capture set direction</td>
<td>0x2m</td>
</tr>
<tr>
<td>capture set closeloop</td>
<td>n</td>
</tr>
<tr>
<td>htmlShow</td>
<td></td>
</tr>
<tr>
<td>html set rootiskerap</td>
<td></td>
</tr>
<tr>
<td>html set home fillepie</td>
<td></td>
</tr>
<tr>
<td>html set debug on</td>
<td>n=0</td>
</tr>
<tr>
<td>html set keep_open n</td>
<td>n=0</td>
</tr>
<tr>
<td></td>
<td>n=1</td>
</tr>
<tr>
<td>jpeg show</td>
<td></td>
</tr>
<tr>
<td>jpeg set host xxx.xxx.xxx</td>
<td></td>
</tr>
<tr>
<td>jpeg set account xxx</td>
<td></td>
</tr>
<tr>
<td>jpeg set password xxx</td>
<td></td>
</tr>
<tr>
<td>jpeg set separator</td>
<td></td>
</tr>
<tr>
<td>jpeg set list n</td>
<td>n=0</td>
</tr>
<tr>
<td></td>
<td>n=1</td>
</tr>
<tr>
<td>jpeg set time n</td>
<td></td>
</tr>
<tr>
<td>jpeg set name n</td>
<td>n=0</td>
</tr>
<tr>
<td></td>
<td>n=1</td>
</tr>
<tr>
<td>jpeg set quality n</td>
<td></td>
</tr>
<tr>
<td>jpeg set patch n</td>
<td></td>
</tr>
<tr>
<td>jpeg set box n</td>
<td></td>
</tr>
<tr>
<td>jpeg set dir size</td>
<td></td>
</tr>
</tbody>
</table>
## P372 License Plate Recognition Camera User Manual

### jpeg set aspect n
- **Default:** 1
- **Description:** Change the aspect ratio of jpeg images. NB PIPS Technology quotes performance for standard aspect ratio. This parameter does not affect patch images that are always unmodified.
  - **n=0**: Standard aspect ratio. A video field is compressed unmodified at an aspect ratio of 8x3
  - **n=1**: Horizontal data is subsampled 2:1 to give an image aspect ratio of 4x3
  - **n=2**: Vertical data is doubled to give an image aspect ratio of 4x3

### jpeg test
- **Default:** Capture JPEG test image

### show kermit

#### set kermit device devname
- **Default:**
- **Description:** The Kermit module needs to know which physical device is to be used for file transfers. Options are flash, or dosfile (the default).

#### set kermit debug nn
- **Default:**
- **Description:** If non zero enables Kermit debug facilities

### log show

#### log set mode uhhhhhhhh
- **Default:**
- **Description:** Log setting mode according to bits set in parameter:
  - **0x0100**: No data logged
  - **0x01000000**: Log plate result to file - summary information only
  - **0x01000001**: Log plate result to stderr - summary information only
  - **0x01080000**: Log all results to file
  - **0x01000008**: Log all results to stderr
  - **0x01040000**: Log timeout detection between plates to file
  - **0x01000004**: Log timeout detection between plates to stderr
  - **0x01200000**: Log plate detector output to file
  - **0x01000002**: Log plate detector output to stderr
  - **0x01010000**: Log any missed plates to file. A missed plate is an image which has generated a plate trigger but for which no plate can be found.
  - **0x01000001**: Log any missed plates (see above) to stderr.
  - **0x01000000**: When filter_best is in use, log to file the decision to forward a plate.
  - **0x01000002**: When filter_best is in use, log to stderr the decision to forward a plate
  - **0x01000004**: Generate brief format plate log to file
  - **0x01000000**: Generate brief format plate log to stderr
  - **0x01000000**: Log plate string to dos:/tmp/log if output Q becomes full.
  - **0x01000010**: ditto
<table>
<thead>
<tr>
<th>Key</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00000000</td>
<td>Enable logging to file of OEM specific debug messages</td>
<td></td>
</tr>
<tr>
<td>0x000000100</td>
<td>Enable printing of OEM specific debug messages</td>
<td></td>
</tr>
<tr>
<td>log set device path</td>
<td>Specify the device and (if relevant) directory in which the log files will be created. Do not use hash as a log device!</td>
<td></td>
</tr>
<tr>
<td>log set size mm</td>
<td>Set the maximum size for a log file. When this size is exceeded the current log file analysis.log will be renamed analyse.log and any existing analyse.log will be deleted.</td>
<td></td>
</tr>
<tr>
<td>log set slip mm</td>
<td>If this option is set non zero, the *.ink files created above will be zipped. A new zip file is created until mm is reached, at which time the oldest file will be overwritten.</td>
<td></td>
</tr>
<tr>
<td>show modem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>modem set type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gsm</td>
<td>Siemens M35 or M45 GSM modem</td>
<td></td>
</tr>
<tr>
<td>Hayes</td>
<td>Most Hay's compatible modems - tested with usRobotics</td>
<td></td>
</tr>
<tr>
<td>modem set init</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gsm</td>
<td>Set the modem initialisation string to gsm for example for a gsm modem this might be: ATSO=1&amp;OC:ifo=2.2</td>
<td></td>
</tr>
<tr>
<td>modem set pin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ppppp</td>
<td>A GSM modem requires a security pin to access the sim.</td>
<td></td>
</tr>
<tr>
<td>modem set format</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fffff</td>
<td>Set the communication format used by a GSM modem to fffff</td>
<td></td>
</tr>
<tr>
<td>modem set network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mmm</td>
<td>Set the GSM communications network specifier to mmm</td>
<td></td>
</tr>
<tr>
<td>modem set enable n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Modem disabled</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Modem enabled</td>
<td></td>
</tr>
<tr>
<td>modem set verbose n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No modem reports</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Minimal reporting of modem connection</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Report modem configuration process &amp; handshake changes</td>
<td></td>
</tr>
<tr>
<td>modem set net n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>No network connection, modem connects directly to a CLI</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>After connection the modem line is switched into a SLIP connection</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>After connection the modem line is switched into a PPP connection</td>
<td></td>
</tr>
<tr>
<td>modem set net_host</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.b.c.d</td>
<td>Set modem slip or ppp host address to a.b.c.d</td>
<td></td>
</tr>
<tr>
<td>modem set net.peer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.b.c.e</td>
<td>Set modem slip or ppp peer address to a.b.c.e</td>
<td></td>
</tr>
<tr>
<td>show raw</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### set raw patch n
Where n may be 0, indicating that the whole image must be saved or 1 to just save the plate patch.

### set raw dir_size
Raw files are placed in a subdirectory under top level directory raw. This directory is limited to nnn files, after which a new directory will be created. For reasonable efficiency this directory size should not exceed about 250 entries.

### set raw info n
If n=1, embed log data as a text string into the first video row of the image.

### set route xxxx
Sets the output route from analysis system. The actual processing routes available are system software build dependent. OEM systems may have specific routes enabled. The following routes are available on all systems:

<table>
<thead>
<tr>
<th>Route</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>null</td>
<td>Image is discarded</td>
</tr>
<tr>
<td>raw</td>
<td>Image is saved on disk in raw binary form</td>
</tr>
<tr>
<td>jpeg</td>
<td>Image is saved in JPEG format</td>
</tr>
<tr>
<td>bmp</td>
<td>Files are saved in BMP format</td>
</tr>
<tr>
<td>client</td>
<td>Plate patches and exposure information are passed to a TCP/IP client on a host system</td>
</tr>
</tbody>
</table>

### system show

### system set flex filespec
Specify the flex file to be loaded. A full file specification is required.

Example: set flex file flash:372aflex.x21

### system set exposure filespec
Name of file to use for exposure table. This is a machine readable file.

### system set startup filespec
Name of script file to run at startup.

### system set time_server
Specify the server IP address to be used for the internet "daytime client" and SNTP requests. Set this to 0 to turn off calls to a time server.

### system set daytime_port
Set the port number for the daytime server. This will default to 13, the usual daytime port number. However, if an OEM specific daytime server is in use, then the specific port number can be configured here.

### system set time_zone
Set the number of hours offset (+/-) from UTC time required. NB this offset must also take account of daylight saving if required. The 372 does not correct for daylight saving time.

### system set brownout nn
Set the number of ms during which power may be down as a result of a supply brownout

### system set powerdown nn
Set the number of ms the power fail system will wait for operations to complete before finally pulling the power

### system set plate_type nn
Set country code. This option selects for various system wide parameters that are country or
## P372 License Plate Recognition Camera User Manual

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>area specific eg plate aspect ratio.</td>
<td>00 UK type plates</td>
</tr>
<tr>
<td>system set camera_config</td>
<td>0 Default value</td>
</tr>
<tr>
<td>system set ftp_debug</td>
<td>00 ftp system operates silently</td>
</tr>
<tr>
<td>system set ts_timeout</td>
<td>mm Set telnet connection timeout in seconds</td>
</tr>
<tr>
<td>system set cc ended</td>
<td>0 Default value</td>
</tr>
<tr>
<td>system set reload</td>
<td>nm When set this options forces a periodic system software reload where nn is seconds</td>
</tr>
<tr>
<td>system set nmax</td>
<td>0 Default value</td>
</tr>
<tr>
<td>trigger set</td>
<td>trigger set mode nn Low byte controls fast trigger modes</td>
</tr>
<tr>
<td>0x000</td>
<td>Trigger not active</td>
</tr>
<tr>
<td>0x0001</td>
<td>Trigger on elapsed time after trailing edge of event</td>
</tr>
<tr>
<td>0x0002</td>
<td>Trigger on elapsed distance after trailing edge of event. distance is in mm. This is converted to a time by using speed measured through gate</td>
</tr>
<tr>
<td>0x0003</td>
<td>Event is rising edge on input</td>
</tr>
<tr>
<td>trigger set distance 5555</td>
<td>Set distance in mm between rising and falling edges of trigger timer. This can be used to measure speed through the &quot;gate&quot;</td>
</tr>
<tr>
<td>trigger set speed ss</td>
<td>Set threshold speed (mph) below which trigger events are ignored. If 0 then all events are accepted</td>
</tr>
<tr>
<td>trigger set delay nn</td>
<td>If mode is set to time then Set the number of ms to elapse between trailing edge of trigger event and action. Else if mode is set to distance then this is the delay in mm at measured speed through the gate</td>
</tr>
<tr>
<td>trigger set open nn</td>
<td>After delay has expired, capture will be enabled for the period (ms) or distance (mm) set here. For this to operate, use filter mode filter_on_trigger</td>
</tr>
<tr>
<td>trigger set nmode</td>
<td>Hi byte controls slow trigger modes</td>
</tr>
<tr>
<td>0x00</td>
<td>Enable detector on camera</td>
</tr>
<tr>
<td>0x100</td>
<td>Detector operates on lo going edge (default hi going)</td>
</tr>
<tr>
<td>trigger set debounce nn</td>
<td>After detecting an edge on any input, that input will be ignored for period nn ms. Note that the debounce only operates on the slow inputs</td>
</tr>
</tbody>
</table>
### 3.4.1 Mode and Sync

<table>
<thead>
<tr>
<th>Set mode</th>
<th>Default value</th>
<th>Set video sync rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>Default value</td>
<td></td>
</tr>
<tr>
<td>525</td>
<td>NTSC/EIA</td>
<td></td>
</tr>
<tr>
<td>426</td>
<td>PAL/CCIR</td>
<td></td>
</tr>
</tbody>
</table>

### 3.4.2 Camera exposure configuration

<table>
<thead>
<tr>
<th>Set cam n</th>
<th>Set illumination and exposure for camera 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Update is for table entry n</td>
</tr>
<tr>
<td></td>
<td>If this parameter is not present then it is assumed that the update is for table entry 1</td>
</tr>
<tr>
<td>p</td>
<td>This position is for camera type</td>
</tr>
<tr>
<td></td>
<td>0 - master mono</td>
</tr>
<tr>
<td></td>
<td>1 - slave mono</td>
</tr>
<tr>
<td></td>
<td>2 - master color</td>
</tr>
<tr>
<td></td>
<td>3 - slave color</td>
</tr>
<tr>
<td>v</td>
<td>Set view type</td>
</tr>
<tr>
<td></td>
<td>0 - plate view</td>
</tr>
<tr>
<td></td>
<td>1 - overview</td>
</tr>
<tr>
<td>m</td>
<td>Set multiple</td>
</tr>
<tr>
<td></td>
<td>This option sets the number of table entries cycled. It may take values 1-8</td>
</tr>
<tr>
<td>f</td>
<td>Set flash time. Valid entries are 0-7</td>
</tr>
<tr>
<td></td>
<td>0 – off (use for overview camera)</td>
</tr>
<tr>
<td></td>
<td>1 – 0.10 ms</td>
</tr>
<tr>
<td></td>
<td>2 – 0.13 ms</td>
</tr>
<tr>
<td></td>
<td>3 – 0.195 ms</td>
</tr>
<tr>
<td></td>
<td>4 – 0.260 ms</td>
</tr>
<tr>
<td></td>
<td>5 – 0.390 ms</td>
</tr>
<tr>
<td></td>
<td>6 – 0.580 ms</td>
</tr>
<tr>
<td></td>
<td>7 – 0.780 ms</td>
</tr>
</tbody>
</table>
### 3.4.3 Example exposure settings

For fast traffic, a suggested starting point would be:

<table>
<thead>
<tr>
<th>F</th>
<th>G</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0.1</td>
</tr>
</tbody>
</table>

System geometry would normally be set to give a plate size of about 25% of field of view. Typically this will mean a plate width of 220 pixels. A starting point for threshold would be about 43.

This should be implemented as a script (see below). The following would be the script fragment to configure camera 1 for the above:

```bash
* configure exposure
set cam 1 e:1 p:0 v:0 m:1 f:7 s:3 g:6 c:0 w:220 t:40
set cam 1 e:2 p:0 v:0 m:1 f:5 s:2 g:6 c:0 w:220 t:40
set cam 1 e:3 p:0 v:0 m:1 f:2 s:1 g:6 c:0 w:220 t:40
```

Current exposure settings may be examined from the CLI with:

```bash
>> cam script
```
3.4.4 direction selection

The P372 will normally accept all plates moving through the field of view (subject to selection filters). However, the system may be configured to accept plates from vehicles moving either toward or away from the camera. See option cap set direction above.

In order to determine direction the P372 observes the movement of a detected plate within the field of view. The P372 must therefore have at least two detection events for any plate. On high speed traffic under conditions of poor visibility and/or with a poor plate the P372 may only detect one plate from a single flash pattern and therefore will be unable to make a reliable determination of direction.

The direction parameter 0xnnn specifies which plates will be accepted as shown below. Bits are combined to select more complex arrangements.

<table>
<thead>
<tr>
<th>0xnn0</th>
<th>accept all plates on the camera – the default</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xnn1</td>
<td>accept vehicles moving toward the camera</td>
</tr>
<tr>
<td>0xnn2</td>
<td>accept vehicles moving away from the camera</td>
</tr>
<tr>
<td>0xnn4</td>
<td>accept vehicles when the system cannot determine reliably whether they are moving toward or away from the camera</td>
</tr>
</tbody>
</table>

Setting capture debug flag 0x0800 will report the direction of observed plates and will also report when a plate is dropped because in observed direction does not meet the required criteria.

3.4.5 closeloop

The closed loop algorithms in the P372 use the results of ANPR, and triggering to feedback into the system to adjust the camera parameters to try to capture more plates. These algorithms are only suitable for use on self-triggered systems (for example capture set filter 0x40), not on externally triggered systems.

In essence turning on these systems should lead to better capture rates, and means that (with both systems on) you do not need to set up the camera exposure tables and they will auto-adjust depending on the weather and lighting.

There are two parts to the system: threshold control and brightness control.
P372 License Plate Recognition Camera User Manual

Threshold control: This system only adjusts the threshold values of currently configured cameras (e.g. the part of set cam). It will adjust each individual flash setting individually and is best used on systems set up to do multiple flashes (e.g. m = 2). Turning on threshold control is safe to use with overview cameras in any configuration.

Brightness control: This system adjusts the whole of the camera table for each camera it is enabled on. It is possible to choose which cameras have this enabled. Therefore most of the set cam commands will no longer work properly (You will still need to set plate width and cable lengths). It will set up each camera to triple flash and will automatically adjust all of the flash, gain and shutter settings for you. It receives assistance from the threshold control system, so it is recommended to have that enabled as well as this system if you want to use brightness control.

Brightness control does not work with all camera configurations – it will only work properly on channels which have one camera on them, and that camera is not an overview.

None of the closeloop systems will operate unless "capture set closeloop 1".

<table>
<thead>
<tr>
<th>closeloop set</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>threshold_on 0</td>
<td>set to 0 to turn off threshold control</td>
</tr>
<tr>
<td>1</td>
<td>set to 1 (default) to enable threshold control</td>
</tr>
<tr>
<td>brightness_on 0</td>
<td>set to 0 to turn off threshold control</td>
</tr>
<tr>
<td>1</td>
<td>set to 1 (default) to enable brightness control</td>
</tr>
<tr>
<td>bright_mask</td>
<td>0x0001 Default value</td>
</tr>
<tr>
<td>bright_cutoff</td>
<td>180 This is a value used to control part of when the brightness control will try to make the image dimmer. If a plate image is overexposed with more than bright_cutoff number of pixels overexposed then we will think that this image should get dimmer.</td>
</tr>
<tr>
<td>bright_def</td>
<td>This option sets how bright the cameras will be set to at system startup. There isn’t really any need to adjust this as it does not affect long-term settings, just how long the system will take to settle after boot.</td>
</tr>
<tr>
<td></td>
<td>5 Start off at the dimmest setting</td>
</tr>
<tr>
<td></td>
<td>7 Start off at the brightest setting</td>
</tr>
<tr>
<td>debug</td>
<td>0x0000 Sets bits for debugging closedloop operation</td>
</tr>
<tr>
<td></td>
<td>0x001 – for threshold control</td>
</tr>
<tr>
<td></td>
<td>0x002 – for brightness control</td>
</tr>
</tbody>
</table>

3.4.6 ALPR configuration
(PIPS Technology AUTOPLATE specific)

<table>
<thead>
<tr>
<th>ALPR show</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>debug</td>
<td>set to 0 to turn off all internal debug messages within ALPR module</td>
</tr>
<tr>
<td>enable n</td>
<td>set to 0 to disable ALPR call in live analysis chain</td>
</tr>
<tr>
<td>1</td>
<td>set to 1 (default) to call ALPR system</td>
</tr>
<tr>
<td>retry n n</td>
<td>If plate ALPR confidence is &lt;= nn then retry ALPR using whole image. This facility is designed to capture some of those images where the trigger is taken off a light or</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ir_plate</td>
<td>0 = image is from standard camera, 1 = image is from IR camera (default)</td>
</tr>
<tr>
<td>detect</td>
<td>0 = simplest - fastest plate detection, 7 = intensive - slowest plate detection (bit options)</td>
</tr>
<tr>
<td>ap_debug</td>
<td>0 = autoplate internal debug control (default 0), 1 = internal debug control</td>
</tr>
<tr>
<td>plate_shape</td>
<td>0 = linear plate (default), 1 = square plates</td>
</tr>
<tr>
<td>whiteonblack</td>
<td>0 = plates are expected to be black on white, 1 = plates are expected to be white on black</td>
</tr>
<tr>
<td>multiple</td>
<td>0 = set number of approaches taken to locate and segment plate, 1 - 3 will vary from minimum to maximum</td>
</tr>
<tr>
<td>roi</td>
<td>0 = set image area as patch, 1 = image area is that reported by the hardware plate finder, 2 = the image area will be as reported by the anpr package so will be almost the exact size of the plate, 3 = the image area will be as 1 above but increase by 12.5% in each direction, 4 = the image width is increased sufficiently to allow for a superscript title area to be added above the image, 5 = when set to non zero enable software to locate hazard plates, NB: plate shape above must also be set to 1</td>
</tr>
</tbody>
</table>
### 3.5 Plate database

The P372 incorporates a real time fast access plate database. In its standard form this database may be used as a filter for plates either acting as a white list filter or as a black list filter.

A white list filter discards all plates found within the database. Such a facility might be used for example in a tolling application where the white list will contain all vehicles for which a toll has been paid. Thus only those plates which belong to potential violators would be forwarded for processing.

A black list filter discards all plates not found within the database. Such a facility might be used for example in a system searching traffic for stolen vehicles. Only plates found within the database will be forwarded for further processing.

OEM applications prepared by PIPS Technology for specific customers may include further data within the database. For example a security system might also carry vehicle make and color.

<table>
<thead>
<tr>
<th>pdb show</th>
<th>show current pdb configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>pdb set enable n</td>
<td>set the value of enable n</td>
</tr>
<tr>
<td>0x00</td>
<td>lists disabled – no lookup performed</td>
</tr>
<tr>
<td>0x01</td>
<td>blacklist – forward plate if found</td>
</tr>
<tr>
<td>0x02</td>
<td>whitelist – forward plate if not found</td>
</tr>
<tr>
<td>0x03</td>
<td>Always forward the plate. In this case the lookup is performed. Data returned from the lookup accompanies the plate to affect further processing. This option is only valid for specific OEM applications prepared by PIPS Technology</td>
</tr>
<tr>
<td>0x60</td>
<td>If this bit is set, then if a fast lookup fails, a detailed lookup is performed. WARNING: do not use this option if the list contains more than a few hundred entries.</td>
</tr>
<tr>
<td>pdb set file</td>
<td>set the default database filename</td>
</tr>
<tr>
<td>filespec</td>
<td></td>
</tr>
<tr>
<td>pdb set separator ss</td>
<td>set field separator to any character in string ss</td>
</tr>
<tr>
<td>pdb set info</td>
<td>not used</td>
</tr>
<tr>
<td>pdb set debug</td>
<td>set to non zero to enable debug</td>
</tr>
<tr>
<td>pdb set hashbase</td>
<td>set the size of the database hash table</td>
</tr>
<tr>
<td>pdb clear</td>
<td>clear all entries from current database</td>
</tr>
<tr>
<td>pdb load (filespec)</td>
<td>add file to current database. If filespec is given add this file, else load the default file. If the requested file is not found on the local disk the default ftp server will be asked for the file.</td>
</tr>
<tr>
<td>pdb save filespec</td>
<td>save current database to filespec</td>
</tr>
<tr>
<td>pdb lookup ppppp</td>
<td>test facility) search database for given plate ppppp</td>
</tr>
<tr>
<td>pdb insert ppppp</td>
<td>insert plate ppppp</td>
</tr>
<tr>
<td>pdb delete ppppp</td>
<td>delete plate ppppp</td>
</tr>
<tr>
<td>pdb amend ppppp</td>
<td>amend record for given plate ppppp (OEM specific)</td>
</tr>
</tbody>
</table>

When saving or restoring a database from disk, the file is stored in simple ASCII text with records delimited by newline. Fields within each record, if they exist, are by default delimited by ",". This is
done to permit comma or space delimited sub fields within each field, as for example with date and time. The first field in each record is always the plate. Subsequent records are application specific.

The default field separator may be changed. The separator specification is a string of possible characters, so multiple separators may be used. The separator list always includes space and newline. When a database file is saved to disk the first character in the specified string will be used as the field separator.

When a database is saved to disk it will be saved unordered. In its standard form the database stores nothing but the plate. Such a system is useful for simple white or black list matching. OEM specific implementations may store additional data with each plate.

The hash table size is a parameter that is only read at system start. Therefore, after changing this parameter it will be necessary to restart the unit for the change to take effect. This parameter should be approximately 1/20 of the expected worst case maximum database size. It must be a prime number. A suggested set of values are:

<table>
<thead>
<tr>
<th>hash table size</th>
<th>for database size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1009</td>
<td>1000 - 20,000</td>
</tr>
<tr>
<td>5003</td>
<td>5000 - 100,000</td>
</tr>
<tr>
<td>10007</td>
<td>10,000 - 200,000</td>
</tr>
<tr>
<td>500021</td>
<td>Default 50,000 - 1,000,000</td>
</tr>
<tr>
<td>100003</td>
<td>100,000 - 2,000,000 extra ram required</td>
</tr>
<tr>
<td>500009</td>
<td>500,000 - 10,000,000 extra ram required</td>
</tr>
</tbody>
</table>

### 3.5.1 Performance

The database is normally configured as an in memory system. Therefore the available size of the database is constrained by the amount of available memory. The standard system would probably have about 16Mbytes available memory, enough for perhaps 500,000 vehicles, depending upon the information to be associated with each vehicle.

By default only exact matches are accepted. No facilities exist for wild card (or any other form) of imprecise matching.

Search time per plate is insignificant (typically <75us) and is not substantially affected by the size of the database. Load time from local disk is approximately 15000 plates per second. Thus loading a database of 500,000 vehicles will take about 30 seconds. This does not include transfer time from a host system. Load time and search time will not be improved if the database is supplied ordered.

If bit 0x008 is set within the pbx enable configuration flag then the system will first use the fast match system and if this fails to locate the plate will then use an exhaustive substring match against all the records in the database. This approach is very slow. The plate database should be restricted to a few hundred vehicles. This approach is more appropriate for situations where many plates must be checked against a small list as for example in a controlled access situation.
3.6 Communication & file transfer facilities

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>kermit server</td>
<td></td>
</tr>
<tr>
<td>kermit send</td>
<td></td>
</tr>
<tr>
<td>kermit receive</td>
<td></td>
</tr>
<tr>
<td>ftp get filespec</td>
<td>Copies filespec from the server directory to an identical name in the current directory</td>
</tr>
<tr>
<td>ftp get fromfile tofile</td>
<td>Copies fromfile from the server to tofile, where tofile may be a full pathname</td>
</tr>
<tr>
<td>ftp put fromfile</td>
<td>Copies fromfile from the 372 to an identical name in the default server directory.</td>
</tr>
<tr>
<td>ftp put fromfile tofile</td>
<td>Copies fromfile from the P372 to tofile, where tofile may be a full pathname</td>
</tr>
<tr>
<td>ftp rm fromfile</td>
<td>fromfile may contain wildcards</td>
</tr>
<tr>
<td>ftp append fromfile tofile</td>
<td>Appends 372 fromfile to the end of tofile on the server.</td>
</tr>
<tr>
<td>ftp dir</td>
<td>list server current directory</td>
</tr>
<tr>
<td>ftp ren</td>
<td>rename file</td>
</tr>
<tr>
<td>ftp del</td>
<td>delete file</td>
</tr>
<tr>
<td>ftp mk</td>
<td>make directory</td>
</tr>
<tr>
<td>ftp rd</td>
<td>remove directory</td>
</tr>
</tbody>
</table>

NB: the kermit system cannot handle filesystem or directory specifiers. So by default it will read/write into the current directory. As it may be necessary to transfer files directly into flash, use:

```
>> set kermit device
```

(where device is flash; or dosfile:) to select the physical device to or from which transfers must be made.

The ftp subsystem provides a fairly complete client implementation. However, by design it is not interactive. Each invocation runs to completion, encompassing logon, transfer and disconnect. The ftp system uses the default system server and account details. All transfers are assumed to be hi image mode.

In addition, the 372 provides a minimal http server. An embedded home page allows for selection and interrogation of various data stores.
3.6.1 WEB management and reporting

![PIPS Technology ALPR Processors](image)

**Figure 3** Example home page for the P372

PIPS Technology ALPR processors are complete andbos processors for automatic license plate recognition (ALPR). They can take the input from PIPS Technology cameras, and when a vehicle passes through the field of view, output the exact plate information. How to set them up together will not be shown in this document, but if there is another similar system, you can use the special configuration settings to get a captured image. Your certificate must be valid.

This web interface will help you set up the ALPR processor for optimum performance. Simply, you should have obtained a copy of the License Plate Recognition Package from the manufacturer. This explains what the various configuration settings are for, and gives practical advice.

If the ALPR is available at all the configuration settings, just point the mouse at the label of each input label and click once. A pop-up window will appear with its default location.

If you have any comments or suggestions on how the system can improve the situation, will like to hear from you. Use the "Contact Us" option on this menu to choose an appropriate response number. It may!
3.7 Trigger system

The trigger detector system provides an input. This input is fed to the P372 processor so time measurements can be made. The trigger input can also be used to wake the P372 from its two doze modes.

The system can provide a longer latency detector designed for enabling a camera channel in response to an external vehicle detector as might for example be used at a car park barrier. This system is not designed for the detection and location of high speed vehicles. The input may be set to detect on low or high gong edges. The input may have a "dead time" (debounce) set during which further triggers are ignored.
### 3.8 BMP support

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>bmp show</code></td>
<td>Show current bmp settings.</td>
</tr>
<tr>
<td><code>bmp set host nnn.nnn.nnn.nnn</code></td>
<td>Set bmp ftp host. Use dotted decimal notation only eg 10.10.10.254</td>
</tr>
<tr>
<td><code>bmp set account account</code></td>
<td>Set bmp ftp server account name</td>
</tr>
<tr>
<td><code>bmp set password passwd</code></td>
<td>Set bmp ftp server account password</td>
</tr>
<tr>
<td><code>bmp set separator p</code></td>
<td>When long file names are generated by the bmp write process use this character as a field separator</td>
</tr>
<tr>
<td><code>bmp set timeout n</code></td>
<td>The bmp system will hold an ftp connection open between image writes until nn seconds without an image has passed. The ftp server should be set to time out connections at a period exceeding this number by about 10 seconds.</td>
</tr>
<tr>
<td><code>bmp set patch n</code></td>
<td>Set scope of image saved in ftp directory</td>
</tr>
<tr>
<td>n=0</td>
<td>Full image is saved</td>
</tr>
<tr>
<td>n=1</td>
<td>Plate patch only is saved</td>
</tr>
<tr>
<td>n=2</td>
<td>320x240 image centered on patch is saved</td>
</tr>
<tr>
<td><code>bmp set info n</code></td>
<td>No info saved</td>
</tr>
<tr>
<td>n=0</td>
<td>Plate tag is saved as string in image buffer</td>
</tr>
<tr>
<td>n=1</td>
<td>No debug messages</td>
</tr>
<tr>
<td><code>bmp set debug n</code></td>
<td>Use short image file names based on event number</td>
</tr>
<tr>
<td>n=0</td>
<td>Has no effect</td>
</tr>
<tr>
<td>n=1</td>
<td>Use long filename</td>
</tr>
<tr>
<td><code>bmp set dir_size n</code></td>
<td>Creates sub directories of the form Baaa each of which will have dir_size entries. aaaa will be event_id/dir_size</td>
</tr>
<tr>
<td>n=0</td>
<td>Not used</td>
</tr>
<tr>
<td><code>bmp set list filespec</code></td>
<td>If filespec exists, then a list of created bmp files (a log file) will be built in the specified local drive. Note that for performance reasons the list is not built on the ftp server. Set to 0 to disable.</td>
</tr>
<tr>
<td><code>bmp set flags</code></td>
<td>Not used</td>
</tr>
<tr>
<td><code>bmp set box n</code></td>
<td>If n is non zero and a full image is being saved, then a box will be drawn around the region of interest containing the plate patch</td>
</tr>
<tr>
<td><code>bmp anpr filespec</code></td>
<td>Read filespec from ftp server and process through ALPR engine</td>
</tr>
<tr>
<td><code>bmp list filespec outfile</code></td>
<td>Open file listfile and read list of images to process. Each image is fetched from the ftp server and is processed through the ALPR engine. The results are posted to file outfile. At completion of the list, the overall score is computed, comparing the file name with the read plate. If listfile cannot be found locally then the default ftp server will be searched. If the file is a remote...</td>
</tr>
</tbody>
</table>
3.8.1 Test system

This is a facility provided for testing the performance and behavior of the ALPR system. It provides the system with the capability of processing a set of BMP files and comparing the processed results with the correct number plate readings.

Reference files used for scoring and regression testing of the ALPR subsystem will be BMP format.

Files must be given a name of the form A123BCD.bmp. These files should be saved in the bmp account default ftp directory. Create a list of these files in the same directory, eg:

```
ls -al *.bmp > inlist
```

Then on the P372 process the files

```
>> bmp list inlist results
```

This will process each file, and record the result in in file "results".

The result plate string is compared with the file name to generate the score.

Each line has the form:

```
plate_name  anpr_result  time  score
```

eg

```
P512DEG  P5120EG  837ms  0
```

The "score" represents a percentage comparison between the input file name and the output from the ALPR engine, where 100 represents identical strings.

At the end of the run, total plates, total errors and mean processing time are reported.

These final statistics may be recreated by reprocesing the result file

```
>> bmp score results
```

an example score result follows:

```
902 plates processed, 820 correct, 82 wrong, score:904, mean time:156ms
0: >100 820 plates
1: > 95  4 plates
2: > 90  2 plates
3: > 80  20 plates
4: > 70  1 plate
5: > 0  58 plates
```

3.9 Batch processing

To assist in the configuration process there are two batch process commands available within the CLI. These are:

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>install list</code></td>
<td>If list does not exist, attempt to copy list from the ftp server into the current directory. Once list exists, open it, then attempt to copy each file in the list from the ftp server into the current directory.</td>
</tr>
<tr>
<td><code>script [-o] script_name</code></td>
<td>Execute CLI script script_name. The script must reside in the root of the ram disk. If the file script_name does not exist, then an</td>
</tr>
</tbody>
</table>
P372 License Plate Recognition Camera User Manual

attempt will be made to fetch the script from the ftp server. Once
the script exists, each line in script will be passed through the CLI
All CLI commands except those requiring interactive input may be
placed in the script file. If the script was loaded from a remote file
server, then after completion it will be deleted.
Empty lines are ignored. Comment lines start with #; or *
Option -q suppresses some of the messages.

bmp script
Some command blocks have the ability to prepare a script by listing
current settings, as though they were set commands. The example
shown will produce set of commands to recreate the current BMP
settings.

dump script
This facility dumps all of the systems current configuration settings
to the terminal screen.

At system start the 372 will attempt to execute a startup script file. This startup script may be local
or on the ftp server as described above. The filename used is defined as a system parameter.
If a script filename contains ":" it is assumed to be local and will not be requested from the ftp
server.

3.10 Network support
The P372 has a fairly complete TCP/IP stack. Communication links may be made either via
100/10baseT Ethernet or via SLIP or PPP on the modem port.
SLIP & PPP support direct connections. No facility exists to allocate (or accept allocated) IP
numbers. Header compression is not supported. No authentication protocols are supported.
Network management and test facilities may be accessed via the net command set (though ping
may be accessed directly):

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>net gateway a.b.c.d</td>
<td>Set system default gateway address</td>
</tr>
<tr>
<td>net mask</td>
<td>Set system default network mask</td>
</tr>
<tr>
<td>net broadcast</td>
<td>Set system default broadcast address</td>
</tr>
<tr>
<td>net show</td>
<td></td>
</tr>
<tr>
<td>net set script scriptfile</td>
<td>Network configuration script file run automatically at system start</td>
</tr>
<tr>
<td>net con!</td>
<td>Display network configuration</td>
</tr>
<tr>
<td>net route gateway route_ip gateway_ip</td>
<td>Set gateway for route_ip to gateway_ip. Both route and gateway are IP addresses in dotted decimal notation. Route may be either a single address or may be a class of addresses.</td>
</tr>
<tr>
<td>net route mask address</td>
<td>Set the default mask to address where address is an IP address in dotted decimal notation</td>
</tr>
<tr>
<td>net route add</td>
<td>NYI</td>
</tr>
<tr>
<td>net route delete</td>
<td>NYI</td>
</tr>
<tr>
<td>net ping (options) address</td>
<td>See below</td>
</tr>
<tr>
<td>ping (options) address</td>
<td></td>
</tr>
<tr>
<td>net slip</td>
<td>NYI</td>
</tr>
<tr>
<td>net ppp</td>
<td>NYI</td>
</tr>
</tbody>
</table>

3.10.1 Ping
In order to help debug network connections both the EPROM implementation and the
application provide full responses to ICMP messages. In addition, the application provides a
fairly complete implementation of ping. For a full description refer to any UNIX or LINUX documentation, but briefly the options to ping are:

```
ping (options) target
net ping (options) target
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-c count</td>
<td>stop after sending (and receiving) count echo response packets</td>
</tr>
<tr>
<td>-d</td>
<td>set SQ_DEBUG option on socket</td>
</tr>
<tr>
<td>-i wait</td>
<td>wait wait ms between sending each packet (default 500ms)</td>
</tr>
<tr>
<td>-n</td>
<td>numeric address only</td>
</tr>
<tr>
<td>-q</td>
<td>quiet output</td>
</tr>
<tr>
<td>-r</td>
<td>bypass routing tables</td>
</tr>
<tr>
<td>-s packetsize</td>
<td>use packets of size packetsize, default 56</td>
</tr>
<tr>
<td>-v verbose</td>
<td>list other ICMP packets received (useful for debugging routing issues)</td>
</tr>
<tr>
<td>-R</td>
<td>set the IP record route option (NYI)</td>
</tr>
</tbody>
</table>

If no target is given, ping will access the default server address.

3.10.2 Telnet

The P372 supports a telnet interface on the standard telnet port 23. Concurrent telnet sessions are not supported. The telnet connection may be set to automatically time out on no input activity. This is advisable when the system is configured for dial up connections.

```
>> system set tn_timeout nn
```

where nn is timeout in seconds. Setting nn to zero will turn off the timeout option.

3.10.3 Debug

The P372 may generate a stream of informational and debug messages. These messages will appear on the engineering port. In addition this information stream may be monitored over a network connection. This connection may be made via a TELNET connection to port 3577.

NB: Any error messages related to network operation failure or any messages generated before a network connection has been made cannot of course appear on this network port.

All EPROM messages (ie informational text, errors and configuration dialog) and the application initial start up messages will fall into this latter group. In addition, the TELNET connection must be made before any messages can be seen. This will normally require manual intervention within the TELNET program.

3.10.4 Mail

Where the 372 is connected to an IP network, the system may send email automatically. It is envisaged that this facility will be integrated with the automatic data logging applications in specific OEM applications.

```
mail show
mail set host a.b.c.d set address of SMFT mail server at destination
mail set address see set destination address, this should be the full internet address
mail set sender Set the name used as the originator of the
```
3.10.5 FTP

The 372 provides an ftp client. No ftp server is yet available. See above for command syntax.

3.10.6 HTTP

A fairly simple single thread http server provides access to a debug & diagnostic facilities.

3.10.7 PPP

PPP is supported over the modem connection port. However at this time the support is minimal with no IP address assignment, authentication or packet compression.

3.10.8 Time services

By default the 372 will attempt to interrogate an IP network time server 15 seconds after startup, and thereafter, every 5 minutes. The IP address for the time server is in the system configuration table ie:

```
>> show system

>> system set time_server n.n.n.n
```

If the time server IP address is set to 0 then this facility is turned off.

See section on time synchronization for further details.

3.11 Gzip & Gunzip

Files may be compressed or uncompressed at the command line using LINUX compatible utilities:

```
>> gzip fromfile tofile

Compresses fromfile into tofile. It is recommended that if the files are to be decompressed on a PC, then extension .gz is used, since this will mean that WINZIP can automatically recognize the format.

>> gunzip fromfile

Will expand fromfile to its original name.

There are no options available to manage the compression process. These utilities use internal defaults.

A PC version of these utilities (gzip.exe) is commonly available.
```
3.12 Storage subsystem support

The 372 supports two distinct data storage systems:

Flash file system

DOS style ram disk

3.12.1 Flash file system

The flash file system is used for primary program store. The flash system may not become the current working directory.

When accessing a flash file the prefix flash; must be used to indicate this file system. Note use of semicolon. eg:

```
>> copy system.ini flash;system.ini
```

Will copy the configuration file from the current directory to the flash file system.

There is a single flat directory structure. A maximum of 12 files may exist. Each file uses a minimum of 64k of flash store space. Each file name has an 8.3 format. However the 3 portion of the file name is used for version identity and plays no part in the name matching process. CLI support for management of the flash file system is available.

Flash file commands are preceded by fs, eg:

```
>> fs format

>> fs dir

>> fs del fspec
```
3.12.2 DOS file system

The P372 provides local non volatile storage in an area of battery backed ram configured as a ram disk.

The ram disk system has a DOS 3.3 style file system. This limits file naming conventions to the DOS 3.3 format. The ram disk has a default capacity of 2 Mbyte. The maximum number of files is 64k (again, the maximum for a DOS 3.3 filesystem).

The file system type is dosfile and may be used as a prefix (as shown above for flash). However this is rarely required as this is the default file system type.

Media type is indicated by a prefix followed by a colon as with PC files system A: C: etc.

<table>
<thead>
<tr>
<th>media</th>
<th>prefix</th>
<th>desc</th>
</tr>
</thead>
<tbody>
<tr>
<td>mem:</td>
<td></td>
<td>A small 2 Mbyte RAM disk is provided for fast data and event log storage. In addition it provides a useful place in which to keep configuration files whilst they are under development.</td>
</tr>
</tbody>
</table>

eg:

```plaintext
>> type mem:/system.ini
```

Types a file of the same name in the ram disk.

A number of conventional commands are available to manipulate files within the DOS file systems.

<table>
<thead>
<tr>
<th>command</th>
<th>argument</th>
<th>desc</th>
</tr>
</thead>
<tbody>
<tr>
<td>ls</td>
<td>[spec]</td>
<td>List current directory (or named directory)</td>
</tr>
<tr>
<td>dir</td>
<td></td>
<td>Ditto</td>
</tr>
<tr>
<td>md</td>
<td>spec</td>
<td>Create named directory in current directory</td>
</tr>
<tr>
<td>rd</td>
<td>spec</td>
<td>Remove named directory</td>
</tr>
<tr>
<td>rm</td>
<td>(-r) spec</td>
<td>Del file spec (wildcards accepted) option -r recursive delete</td>
</tr>
<tr>
<td>del</td>
<td></td>
<td>Ditto</td>
</tr>
<tr>
<td>ren</td>
<td>from to</td>
<td>Rename from to</td>
</tr>
<tr>
<td>cd</td>
<td>spec</td>
<td>Change to directory</td>
</tr>
<tr>
<td>copy</td>
<td>from to</td>
<td></td>
</tr>
<tr>
<td>cmp</td>
<td>spec_a spec_b</td>
<td>Compare files a.b</td>
</tr>
<tr>
<td>tail</td>
<td>(-n)m spec</td>
<td>Type the last n lines (default 10) of file spec</td>
</tr>
<tr>
<td>type</td>
<td>spec</td>
<td>Type file</td>
</tr>
<tr>
<td>dump</td>
<td>spec</td>
<td>Hex dump file</td>
</tr>
<tr>
<td>create</td>
<td>spec size</td>
<td>Create test file of size blocks - time the disk activity</td>
</tr>
</tbody>
</table>
3.13 Time synchronisation

In many applications it is necessary to provide time stamps on images or plates. Often these time stamps will be used to match the event capture with an external situation or event. Under these circumstances it is necessary that the P372 time reference be synchronized in some way with the external systems.

The P372 has an internal clock/calendar chip. This is used to set the system time on initial power up.

The time on this clock can be set manually via the set date or set time CLI commands. However this clock cannot be expected to maintain accurate synchronization with the external world. Drift rate will be several seconds per day.

There are a number of mechanisms by which the 372 may be synchronized to an external time standard.

<table>
<thead>
<tr>
<th>CLI interface command</th>
<th>These commands could be generated automatically via an interface to an external system. Precision is likely to be +/- 1 second</th>
</tr>
</thead>
<tbody>
<tr>
<td>set date or set time</td>
<td>network &quot;daytime&quot; server</td>
</tr>
<tr>
<td></td>
<td>Precision is likely to be +/- 1 second</td>
</tr>
<tr>
<td></td>
<td>network SNTP server</td>
</tr>
<tr>
<td></td>
<td>Precision will be of the order of 10ms giving time resolution to better than 100ms. NB. The 372 SNTP client does not take account of leap seconds.</td>
</tr>
<tr>
<td></td>
<td>optional GPS interface</td>
</tr>
<tr>
<td></td>
<td>This method will require an internal GPS receiver with NMEA output. Without a dedicated hardware interface for the 1 sec pulse, precision is +/- 1 second</td>
</tr>
</tbody>
</table>

Where possible, the optimal mechanism is to provide access to an SNTP server.

Whenever any external time synchronization event occurs, the internal clock/calendar chip is updated with the correct time. This will permit the 372 to free run if access to the external time source is temporarily lost, albeit with time drift relative to the external system.

The P372 internal time is (by default) UTC time. File and event timestamps may be generated in local time format. Local time is defined as P372 internal UTC time + time_zone offset. The time zone offset can be any number of whole hours (+ve or -ve).

The P372 does not automatically track changes in daylight saving time.
Appendix 4   Vehicle logging software notes

4.1 Overview
This document describes a system for logging vehicle license plate numbers together with the plate
pictures. The data is collected via an Ethernet connection to a server running FTP. One server will
be able to support many P372 data collection points. The exact number being dependant upon the
capabilities of the sever.
This document describes the OEM portion of the software on the P372 specifically prepared for this
purpose together with a suggested configuration scheme.

4.2 General configuration
All 372 configuration options are set or modified via a command line interface (CLI). Commands
to the CLI may originate either via serial or telnet connections or via script files. The system may
be configured to run a script file automatically at startup. This script file may be kept locally or
may be copied automatically from the default FTP server. PIPS Technology suggests that site
specific configuration scripts are prepared and stored both locally on the site ftp server and at the
central control point.
The 372 maintains a system event log reporting key system behavior and may if required
maintain a data log file (analyse.log) tracking image events. These files may be viewed via the
CLI or transferred to a host system via ftp.

4.3 Example functional specification
The system extends the evaluation of ALPR equipment and associated communication links. The
installed system will initially comprise:
At the outstation site:
- Two P372 cameras installed on an appropriate pole.
- Ethernet communication links from camera site to instation site or GPRS modems as an
  option.
At the instation
- PC running Microsoft Windows2000 sp4 or connected via Ethernet to P372 to provide data
capture and storage. PIPS Technology can assist in the configuration and testing of the PC.
The objective is for the PC to make available log files providing a time stamped ALPR record for
each vehicle observed by the camera. In addition, for each vehicle a JPEG compressed license
plate patch may be stored on the PC.

4.4 OEM specific configuration
A set of dedicated CLI options has been added to configure the OEM specific interface. The full
CLI interface may be accessed either via:
The debug serial port
A standard TELNET connection on port 23
The debug serial port will generate unsolicited messages reporting system behavior. The exact
messages generated will depend on various system configuration, logging and debug options.
We therefore recommend that access to this port be available during the trial for system
configuration and for system software maintenance.
The serial port operates as a 3-wire connection, 19200bps, 8data, 1stop, XON/XOFF protocol.
The TELNET interface will time out on no input, closing the connection. The actual timeout period
may be configured.

```
lcc show                     Show current lcc specific configuration options
```
### P372 License Plate Recognition Camera User Manual

<table>
<thead>
<tr>
<th>ICC set</th>
<th>Set a specific ICC configuration parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>host</td>
<td>Set IP address of ICC host system</td>
</tr>
<tr>
<td>account</td>
<td>Set account name used by ICC software to transfer data to host system</td>
</tr>
<tr>
<td>password</td>
<td>Set the password for the above account</td>
</tr>
<tr>
<td>separator</td>
<td>Set the separator used to separate field in ICC specific log files and file names. By default this will be comma making the files CSV format</td>
</tr>
<tr>
<td>device</td>
<td>Set the storage device used on the P372 to store log files. By default this will be mem. However if a hard disk is available this could be changed to dos/ allowing for larger log files</td>
</tr>
<tr>
<td>name</td>
<td>Set the root file name used for log file names on the P372. By default this will be ICC.</td>
</tr>
<tr>
<td>host_path</td>
<td>Set the path used from the FTP account home directory on the host system on to which the log files will be placed.</td>
</tr>
<tr>
<td>size nnnn</td>
<td>Set the maximum size a log file will be allowed to reach before it is queued for transfer to the host system. Where nnn is the maximum size of the file in bytes.</td>
</tr>
<tr>
<td>count nnn</td>
<td>Set the number of plate records covered by one log file. (this parameter is ignored if set to 0)</td>
</tr>
<tr>
<td>time</td>
<td>Set the time interval one log file will be used before it is closed and queued for transfer to the host system. Where nnn is the number of minutes for which a log file is active. (this parameter is ignored if set to 0)</td>
</tr>
<tr>
<td>debug</td>
<td>Set to non zero to enable debug messages</td>
</tr>
<tr>
<td>threshold</td>
<td>Set the ALPR confidence threshold below which license plate reads will not be accepted by the system</td>
</tr>
<tr>
<td>b/og</td>
<td>Set the number of temporary log files the P372 will maintain in a queue for transfer to the host system</td>
</tr>
<tr>
<td>image</td>
<td>If set to 0, no image will be transferred to the host system. If set to 1 JPEG images will be transferred to the host system for each license plate detected. Refer to the JPEG configuration options for details.</td>
</tr>
</tbody>
</table>

In the suggested configuration, when the P372 detects a license plate, the number will be read and an entry will be placed in a log file within the P372. Optionally a JPEG compressed copy of the plate patch image will be transferred to the host system. The log file will grow until the first of three possible limits is reached:

<table>
<thead>
<tr>
<th>size</th>
<th>If the log file exceeds the configured size (ICC set size nnn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>count</td>
<td>If the count of plates processed (ICC set count nnn)</td>
</tr>
<tr>
<td>time</td>
<td>If the current log file has been running for the given number of minutes (ICC set time nnn). NB: the count is not started from system start, but rather runs until the time is a multiple of the given count eg if count were set to 60, then data would be transferred on every hour.</td>
</tr>
</tbody>
</table>

When the limit is reached, the log file is renamed, and a new log file is created. The renamed log file is then queued for transfer via ftp to the host system. It is possible for a number of log files to be waiting for transfer to the host system. This might happen if for example the connection to the host system is lost as the PC is restarted. The exact number of files waiting cannot exceed that in...
P372 License Plate Recognition Camera User Manual

4.5 Data format

The OEM specific software provides two data streams: One stream is the log of all plates detected and read. The other and optional data stream is a JPEG compressed patch showing a picture of each license plate.

4.5.1 Log files

As described above the P372 generates a log file with a record for each license plate detected and read. Log files are created within the P372 and transferred on either time or size overflow. The P372 is not limited to providing batch transfers, but could transfer the data in real time to a suitable accepting application if this were available and appropriate.

Each record has the format:

```
mmdhhmmstn,PPPPP,cc
```

where:

- mm: month
- dd: day
- hh: hour
- mmm: minute
- ss: second
- t: tenth second
- n: camera number (0-3)
- PPPP: license plate
- cc: % confidence in read

eg

0326,1456108,0,W202MAK,94

would indicate:

- 29 March, 14:56 pm 10.8 seconds
- image collected from camera 1
- Plate: W202MAK read with confidence 94%

With the default field separator of comma these records form a CSV format file which may easily be imported into many data processing applications.

When a log file is transferred to the host system it will have a name giving the time stamp of the first record in the file. eg a log file might have the name:

0326,1456099.csv

Would indicate that the first record in this log file was captured on 29 March at 14:56pm 9.9 seconds. The file name extension is set to CSV so that it is readily identified by processing applications such as MS EXCEL.

4.5.2 Patch files

The P372 can optionally transfer plate patch files to the host PC if required. This is enabled with configuration option loc set image 1. There are a number of configuration options used to manage the transfer of these images. As there are potentially very many
of these image files the P372 will break the storage of the images into a number of separate directories with a configurable maximum number of files in each directory. Each image file is given a name based on the same format as the log file record:

eg:

```plaintext
p0329,1221465,0,W202MAK,98.jpg
```

The prefix p indicates that this is a patch file.

4.5.3 File locations

If the suggested PC configuration is followed then the files will appear in a directory tree as illustrated below:

```plaintext
/Dinetpub/cpoot/loc_test
   | J00000
   |  | p0329,1255110,2,0773RLD,80.jpg
   |  | p0329,1255112,0,W782EB,06.jpg
   |  | p0329,1255118,0,R453ORW,94.jpg
   |  | p0329,7802332,0,T875MAB,98.jpg
   |  | ...
   | J00001
   |  | p0329,1529610,0,R823KDB,98.jpg
   |  | p0329,1529610,2,R823KDB,98.jpg
   |  | p0329,1529524,2,LD78FL,82.jpg
   |  | p0329,1529537,0,D256HBF,94.jpg
   |  | ...
   | log
   | 0329,1220127.csv
   | 0329,1226537.csv
   | 0329,1230045.csv
   | 0329,1244598.csv
   | 0329,1300034.csv
   | 0329,1456069.csv
   | 0329,1529164.csv
```

4.6 Time Synchronisation

The P372 system will attempt to maintain local time and date via a connection to the SOD / UNIX style SNTP (preferred) or daytime server on a specified host machine at port 13. Most UNIX and RIT systems will provide this service or can load a service to do so. This service call may be disabled by setting the time service host IP address to 0. If this service is disabled, then the 372 internal clock / calendar will drift with respect to external time. Note that event log message timestamps are also taken from the calendar.

4.7 PC configuration

This section describes the configuration required for host PC running MS Windows2000 sp4. However it should be understood that the host system could run any operating system which runs TCP/IP protocols and supports FTP. Further, one host system will support many 372 ALPR camera units since all the host is providing is a repository for the results.
P372 License Plate Recognition Camera User Manual

For demonstration and test purposes PIPS Technology have suggested that the host server is configured to run the MG FTP server. You will need to allocate a directory with adequate space to the FTP server. This directory should be on a NTFS partition.

The ftp server will need a suitable account configured. The P372 needs to know the account name and password. The name should be short (<10 characters), lower case, and containing no punctuation.

The ftp server should be set up to accept this account for UNIK mode file read and write. If you do not wish to use the ftp default directory for file storage then you will need to specify the desired directory as an alias directory for this account.

In addition you may need to change the software or configuration files on the P372. To do this you will need to add a further account to the PC system:

account name: ftp_boot
password: ftp_boot

This account should have at least read permission in the ftp default directory (\inetpub\ftproot). For a test system it might also be useful to have write permission granted as well. The ftp server must accept this account.

ftp timeouts should be set to 120 seconds.

4.8 System connection

This describes the connection of one P372 system for trial purposes

4.8.1 Initial connection

Connect a serial debug lead between the PC and the serial debug connector on the P372 breakout box. Configure a terminal emulator on the development PC to run 19200bps, 8 data, 1 stop, XON/XOFF protocol. We use KEAterm as this has many useful features. However hyperterm distributed with windows is adequate.

Connect power to the P372

Turn on the P372.

4.8.2 Network configuration

Connect the P372 to your network hub via a normal 100/10baseT cable (not provided). Plugging it into the RJ45 connector on the breakout box.

Ensure that your development PC has TCP/IP configured. You will need to know the IP address of the PC.

Ensure that the development PC has a FTP server operating. The P372 will require this server at the very minimum to download configuration scripts and any software updates. You may also configure the P372 to save images via the ftp server. You will need to ensure that the FTP system recognizes at least one account for both read and write. This account will have:

account name: ftp_boot
password: ftp_boot

You will need to know the default directory for this account.

The following table shows the address map I am running, so that the examples below may be understood:

<table>
<thead>
<tr>
<th>machine</th>
<th>my address</th>
<th>your address</th>
</tr>
</thead>
<tbody>
<tr>
<td>trial PC</td>
<td>195.40.28.131</td>
<td></td>
</tr>
<tr>
<td>1st P372</td>
<td>195.40.28.139</td>
<td></td>
</tr>
<tr>
<td>SNTP server</td>
<td>195.40.28.131</td>
<td></td>
</tr>
<tr>
<td>jpeg server</td>
<td>195.40.28.131</td>
<td></td>
</tr>
</tbody>
</table>
P372 License Plate Recognition Camera User Manual

If you wish to use a network time server ensure that your network has an SNTP server running. You will need to know the IP address of this server.

Allocate IP addresses for the P372 units within your local domain. The P372 defaults to a mask of 255.255.255.0

Turn on the P372. When the chevron prompt appears, configure the network addresses within the P372:

the P372s own IP address:

```
>> set internet 195.40.28.139
system serial number: 10
ethernet hardware address: 0800 372b 0013
internet address: 195.40.28.139
server address: 195.40.28.121
```

the P372s default FTP server:

```
>> set server 195.40.28.121
system serial number: 10
ethernet hardware address: 0800 372b 0013
internet address: 195.40.28.139
server address: 195.40.28.121
```

You will need to reset the P372 for these changes to take effect

```
>> reset
```

Once the system has returned to the chevron prompt, test that the network connections are operating.

Test the link to the host PC:

```
>> ping 195.40.28.131
PING 195.40.28.131 (195.40.28.131): 56 data bytes
64 bytes from 195.40.28.131: icmp_seq=0 ttl=128 time=2 ms
64 bytes from 195.40.28.131: icmp_seq=1 ttl=128 time=1 ms
64 bytes from 195.40.28.131: icmp_seq=2 ttl=128 time=1 ms
64 bytes from 195.40.28.131: icmp_seq=3 ttl=128 time=1 ms

--- 195.40.28.131 ping statistics ---
4 packets transmitted, 4 packets received, 0% packet loss
round-trip min/avg/max = 1/1/2 ms
```

Unpack the zip file containing configuration scripts into the directory on the development system for account ftp_boot. Confirm that the ftp client on the P372 can "see" this directory:

```
>> ftp dir
--------- 1 owner group
         2562 Mar 2 17:50 lccmftp1.acr
--------- 1 owner group
         150 Mar 3 12:33 lccudp.acr
```

© PIPS Technology Ltd
P372 License Plate Recognition Camera User Manual

You may have other files, depending upon the exact files shipped.

If you have troubles with the ftp connection you can turn on debug messages for the ftp client:

```
>> sys set ftp_debug 0
```

You will now see reports indicating the stages of the connection. As an example, on my machine I request ftp transfer of file seq from the P372 to the PC:

```
>>sys set ftp_debug 0
>>ftp put seq
220 gawpc Microsoft FTP Service (Version 3.0)
user ftp_boot
331 Password required for ftp_boot.
pass ftp_boot
230-GNFC ftp server
230 User ftp_boot logged in.
type I
200 Type set to I.
pasv
stor seq
125 Data connection already open; Transfer starting.
226 Transfer complete.
seq copied
quit
221
```

Running the same example with write permission removed at the PC gives:

```
>>sys set ftp_debug 0
>>ftp put seq
220 gawpc Microsoft FTP Service (Version 3.0).
user ftp_boot
331 Password required for ftp_boot.
pass ftp_boot
230-GNFC ftp server
230 User ftp_boot logged in.
type I
200 Type set to I.
pasv
stor seq
550 seq: Access is denied.
quit
221
```
Ensure that once the connection is ok you disable debug on the ftp connection as shown at the end of the above examples. The debug messages can lead to connection disruption.
## OEM Journey time system

### 5.1 Journey time system specific configuration

This document describes the additional facilities provided as part of the TCP/IP network based OEM journey time system.

A set of dedicated CLI options have been added to configure the journey time specific interface.

The full CLI interface may be accessed either via:

- The debug serial port
- A standard TELNET connection on port 23

The debug serial port will generate unsolicited messages reporting system behavior. The exact messages generated will depend on various system configuration, logging and debug options.

We therefore recommend that access be available for system configuration and for system software maintenance.

The serial port operates as 3-wire connections, 19200bps, 8data, 1stop, XON/XOFF protocol.

The TELNET interface will timeout on no input, closing the connection. The actual timeout period may be configured.

<table>
<thead>
<tr>
<th>CLI show</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>set</td>
<td>Show current ojt specific configuration options</td>
</tr>
<tr>
<td>host</td>
<td>Set a specific ojt configuration parameter</td>
</tr>
<tr>
<td>host</td>
<td>Set IP address of ojt journey time host system</td>
</tr>
<tr>
<td>bb_host</td>
<td>Set IP address of ojt heartbeat host system (heartbeat may be turned off by setting this address to 0)</td>
</tr>
<tr>
<td>station</td>
<td>Unique station identification string. This may be any alphanumeric up to 8 characters, but should not contain space or punctuation.</td>
</tr>
<tr>
<td>port</td>
<td>Set the port number for the process receiving vehicle tag information</td>
</tr>
<tr>
<td>bb_port</td>
<td>Set the port number for the process expecting heartbeat messages</td>
</tr>
<tr>
<td>keep_alive</td>
<td>Period in seconds between heartbeat messages. Also, the journey time connection will close if no data is sent for half of this period. If set to 0: no heartbeat messages will be sent and the journey time connection will close after 20 seconds</td>
</tr>
<tr>
<td>not_alive</td>
<td>If the heartbeat process is running (i.e. keep_alive &gt; 0) then if the heartbeat fails to send its message (i.e. unable to establish connection) for this many attempts, then the 372 will attempt recovery action</td>
</tr>
<tr>
<td>timeout</td>
<td>If no plate image is received on a camera for this number of seconds then a bit will be set in the status register. This may indicate a possible system failure e.g. camera fault or, may indicate that a lane is closed</td>
</tr>
<tr>
<td>debug</td>
<td>Set to non zero to turn on ojt specific debug messages 0x01 - tag message reports 0x02 - heartbeat message reports</td>
</tr>
<tr>
<td>hash</td>
<td>Set plate hash function modes 0x00 - plate is forwarded unchanged 0x01 - reduce ambiguous characters</td>
</tr>
</tbody>
</table>
5.2 Vehicle tag message

On detection of a vehicle, the P372 will send a message to the host system comprising time stamp and tag details. The connection to the host is opened on the first plate and thereafter maintained open until no vehicles have been detected for a period, at which time the connection will be closed. The period will be half of keep_alive, or if this is set to 0 then will default to 20s. On transmission failure (e.g. lost connection) the P372 will retry the connection and transmission.

5.2.1 Format of tag message

Each number plate record will comprise:

- time stamp
- station identifier
- Camera channel
- ALPR plate string
- Confidence factor

The record will be comma delimited and terminated by newline.

```
yyyy-mm-dd:hh:mm:ss:aa,ssss,n,ttttt,cc
```

where

<table>
<thead>
<tr>
<th>YYYY</th>
<th>year</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>month</td>
</tr>
<tr>
<td>dd</td>
<td>day</td>
</tr>
<tr>
<td>hh</td>
<td>hour</td>
</tr>
<tr>
<td>mm</td>
<td>minutes</td>
</tr>
<tr>
<td>ss</td>
<td>seconds</td>
</tr>
<tr>
<td>aa</td>
<td>1/100 seconds</td>
</tr>
<tr>
<td>ssss</td>
<td>station identifier string as entered in configuration</td>
</tr>
<tr>
<td>n</td>
<td>camera number</td>
</tr>
<tr>
<td>ttttt</td>
<td>vehicle tag – exact length will depend upon plate format.</td>
</tr>
<tr>
<td>cc</td>
<td>read confidence 0 - 99</td>
</tr>
</tbody>
</table>

5.3 Heartbeat message

If option keep_alive is set to non zero, then, on every "keep_alive" seconds the P372 will open a connection to the host system and send a heartbeat message. The connection will be closed after transmission.

Heartbeat may also be disabled by setting the heartbeat host address to 0. This may be required if keep_alive is set non zero to maintain the tag link for a period other than 20 seconds.

5.3.1 Format of heartbeat message

```
1111,ssss,bbb,f\n```

where:

| 1111 | Station identifier – this can be any string of letters and numbers up to eight characters in length. The string should not include punctuation |

© PIPS Technology Ltd
5.4 Time synchronisation

This application requires that the tags captured by a P372 be matched with events detected by other P372 systems. This is managed by time stamping captured images. These time stamps may then be compared to estimate journey time between capture. For this to work the two systems must share a common clock.

The P372 system will attempt to maintain local time and date via a connection to the BSD / UNIX style GNTP (preferred) or daytime server on a specified host machine at port 10. Most Unix and NT systems will provide this service or can load a service to do so. This service call may be disabled by setting the time service host IP address to 0. If this service is disabled, then the P372
P372 License Plate Recognition Camera User Manual

Internal clock / calendar will drift with respect to external time. Note also that event log message timestamps are taken from the calendar.

A modification has been added to the daytime server to enable transfer of time information to a higher resolution. An example of the normal daytime string is:

Thu May 10 10:18:06 2001

The P372 software will parse this as normal. However the P372 will look for an extra parameter at the end of the string:

Thu May 10 10:18:06 2001 33

This parameter is the sub second time, measured in units of 0.01 seconds. This modification permits normal daytime servers to be used unchanged. However a specific daytime server may be written to provide this extra subsecond information. The normal daytime server responds on port 13. If a non-standard daytime server is incorporated into the host system then it should be assigned a proprietary port number.
Appendix 6  P372 Application Notes

This section reviews a number of example configurations, showing how the P372 might be used to solve typical problems. These examples are shown as case studies. The software and functionality described may not be available as standard on the P372. It is usually the case that a specific application or configuration will require specific software to be implemented. These case studies show how that might be done by describing the required system configuration and hypothetical software specification. Each of these case studies is based on actual systems and software installed by PIPS Technology.

6.1 Tolling system

The customer is implementing a free flowing road tolling operation. Vehicles contain transponders. When a vehicle passes through the tolling plaza the transponder is interrogated and a charge made against the customers account. There are no barriers at the plaza in the automatic lanes. Therefore a system is required to identify violators. Road loops are used to detect vehicles passing the tolling point and trigger the transponder system. In order to provide adequate enforcement the customer requires:

- An overview of the road showing as much of the offending vehicle as possible. This image should be in color.
- A patch image of the vehicle license plate.
- An ALPR read of the vehicle license plate.

PIPS Technology P372 ALPR cameras are mounted on a gantry to view the road at the position of the road loop. The color overview camera will give a 3/4 view of the loop area. These cameras have wide-angle lenses. Automatic switch on illumination is provided for night operation.

As traffic is running at high speed through the plaza, one P372 is required for each pair of lanes. The P372 equipment is connected to the tolling equipment via Ethernet and TCP/IP protocols.

The tolling loop trigger is connected to the external trigger input on the P372.

When a vehicle passes through the plaza the loop trigger causes the P372 to initiate a capture sequence. The P372 ALPR system will observe the vehicle for a configurable period of time usually 90-200ms. The P372 will save the best license plate image captured during this period together with the first captured overview image from the color camera. Each of these images will be time stamped. The image set is stored in a circular buffer within the P372.

Should the vehicle be a violator, the tolling system will send a message to the P372 indicating the time at which the vehicle entered the loop. The P372 will match this time with an image set within its internal buffer and forward the image set to the tolling system. Should no request be made for an image set within a configurable period, typically 10 seconds, the image set is discarded.

The image sets are forwarded to tolling system by means of the ftp protocol. The tolling host system runs an ftp server. The P372 opens a connection and transfers the required image set. On completion of an image set transfer the P372 sends a message via a separate channel to indicate that the transmission is complete.

6.1.1 File formats

The overview image is a color JPEG image. The vehicle plate image may either be BMP format or JPEG format. Image files are identified by their name ie

SCmmssss, LLLLLL, G.ext

where

S  image source: w for wideangle, p for plate patch
C  camera (a,b,c,d)
mm minutes
ss seconds
ft ticks
LLLL vehicle license plate tag
G  confidence of license plate read
ext extension indicating image type (jpg or bmp)
6.1.2 Time stamps

This application requires that the images captured by the 372 be matched with events detected by the main tolling system. This is managed by time stamping captured images. These time stamps may then be compared with the known tolling event time to select the correct image set for transfer. For this to work the two systems must share a common clock.

In this application the customer decided that the common clock would run for 60 minutes in 10 ms increments. The P372 runs an internal ms counter. To generate the P372 variant of this clock this internal counter is taken \(96(90 \times 60 \times 1000)\). This is synchronized to the tolling system by adding an offset computed from the time as returned from the tolling system. At P372 system start the internal counter will start at zero, and the offset will be zero. Therefore the two clocks are unlikely to be in sync until after the first time update.

The host system will provide a TCP/IP server listening on a defined port. Upon receiving a connection it will return a simple text string indicating host system current time then close the connection. The actual server address and port are configurable.

The time message will be in the format

\[
\text{mm ss tt}
\]

where

- \(\text{mm}\) minutes
- \(\text{ss}\) seconds
- \(\text{tt}\) ticks (1/100 second)

As it is captured images that are time stamped, the actual images selected will never have the exact time stamp of the tolling event, but will be delayed as the video system runs asynchronously at normal video rates. An exposure sequence is usually four fields. By default, the image set time stamp is that of the overview image. As the exposure sequence is asynchronous to the triggered input, latency between a trigger event and the capture of an overview image will be less than four fields (<100ms Europe, <90ms USA). Thus when requesting an image set, a time window may be specified within which an image will be accepted.

An alternative mechanism would be to use a standard calendar timestamp eg the

\[
\text{minutes, seconds, ticks from a normal clock}
\]

The P372 system will maintain local time and date via a connection to the SSD / UNIX style S/FTP (preferred) or daytime server on a specified host machine at port 13. Most Unix and NT systems will provide this service or can load a service to do so. This service can be enabled by setting the time service host IP address to 0. If this service is disabled, then the P372 internal calendar will drift with respect to external time. Event log message timestamps are taken from the calendar.

6.1.3 Command channel

The tolling host system opens a connection to the P372 to issue requests for image sets or for system status. The connection is a network virtual terminal (NVT) is a telnet like connection, but without any handshake to manage echo and line edit configuration. The connection port used is a configurable parameter. Each command issued on this connection is a simple text string terminated with newline. The connection will be closed automatically after a configurable period without any commands.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{find}</td>
<td>Find and forward a stored image set for lane 1 at time mmsst within window www ms. If window parameter is not given then the configurable default will be used. The successful reply to this command will be: OK I mm ss tt MM SS TT nwms</td>
</tr>
</tbody>
</table>

© PIPS Technology Ltd
<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>trigger</td>
<td>Simulate a trigger on lane 1 - valid lanes a-d. This mechanism may be used to force the system to grab a wide-angle image. Once this command is issued, the 372 will behave as though a trigger event had occurred on the relevant camera trigger input.</td>
</tr>
</tbody>
</table>
| list | List content of store buffer. The list shown will be in the form: 

```
s l mm ss tt
s - slot
l - lane (a-d)
mm - minutes
ss - seconds
tt - ticks
```

| status | Indicates: 

- Current status of the ftp link to the host system,
- Last link error if any.
- Current consumption of each camera channel. |
| reset | Force the 372 to perform a complete software reset. All current IP connections will be lost, and all current image sets will be discarded. |
| logout | Close the connection, wait for a new connection |

### 6.1.4 Message channel

A message channel is available, providing progress and status messages for the file transfer operations. This message channel appears on a separate configurable TCP/IP port. There will be no effect on system behavior if the port is left unconnected. Messages will be strictly formatted to facilitate machine reading. Messages will:

- be ASCII text
- be newline terminated
- start with a message specific identifier of the form:
where L is an upper case letter, one of:

M  progress message
W  warning message
E  error message
P  panic message

nnn is a unique numeric message identifier

eg

P123 PANIC & 0x1123abcd widget failed

This is an extensible system. In practice the only messages implemented for this application are:

<table>
<thead>
<tr>
<th>M000 n keep alive</th>
<th>Keep alive message transmitted every 30 seconds. n is a decimal numeral incrementing on every transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>M001 filespec</td>
<td>Indicates that transmission of filespec is complete</td>
</tr>
<tr>
<td>M002 l mmsst npwm</td>
<td>Indicates that transmission of image set for lane l at timestamp mmsst containing images npwm is complete</td>
</tr>
</tbody>
</table>

example messages from the message channel

M000 002 keep alive
M001 wc451556.jpg
M002 c 451556 __w_
M001 wc451556.jpg
M002 a 451556 __w_
M001 pc451808.jpg
M001 wc451808.jpg
M002 c 451808 __npw_

6.1.5 Keep alive

It is desirable that in the event of any system failure, the system should as far as is possible perform automatic recovery, whether that failure is internal or external to the P372.

As part of this mechanism, the time client process may act as a "keep alive" monitor. If no replies have been received for a configurable time, then the system will restart.

In addition, the message channel will transmit a periodic message if no other messages have been sent for the configurable period msg_timeout seconds. The host system may use the presence of data on this service as an indication that the P372 is operational.

6.1.6 Error codes

The tolling specific CLI interface returns either OK or ERR nnn on completion of any command.

<table>
<thead>
<tr>
<th>err code</th>
<th>command</th>
<th>reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>n/a</td>
<td>command not recognized</td>
</tr>
<tr>
<td>01</td>
<td>set</td>
<td>parameter not matched</td>
</tr>
</tbody>
</table>
### 6.1.7 Status report

The status request will always return OK. Exact status of system is conveyed via subsequent parameters in the reply message.

```
OK nvt.n ftp.n msg.n clk.n
```

where:
- `n` is state of communication channel
- `nvt` channel state: 6
- `ftp` channel state: 1
- `msg` channel state: 1
- `clock` state: 1

#### 6.1.8 Tolling specific configuration options

The tolling system has a number of application specific configuration options in addition to those described in the main configuration notes.

<table>
<thead>
<tr>
<th>Host</th>
<th>Set host ftp server IP address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Account</td>
<td>Host ftp server account name</td>
</tr>
<tr>
<td>Password</td>
<td>Host ftp server password</td>
</tr>
<tr>
<td>sim_host</td>
<td>Set simulation ftp server IP address</td>
</tr>
<tr>
<td>sim_account</td>
<td>Simulation ftp server account name</td>
</tr>
<tr>
<td>sim_password</td>
<td>Simulation ftp server password</td>
</tr>
<tr>
<td>ftp_timeout</td>
<td>Period in seconds ftp connection will remain open with no data to transfer</td>
</tr>
<tr>
<td>nvt_port</td>
<td>Set the local TCP/IP port used by nvt command channel. A system restart will be required after this has been changed.</td>
</tr>
<tr>
<td>msg_port</td>
<td>Set the local TCP/IP port used by the message channel. A system restart will be required after this</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>time_host</code></td>
<td>Set host system IP address providing time services</td>
</tr>
<tr>
<td><code>time_port</code></td>
<td>Set the host system TCP port providing the proprietary time service. (0 disables client)</td>
</tr>
<tr>
<td><code>time_poll</code></td>
<td>Period in seconds between polls of host for time service (0 disables client)</td>
</tr>
<tr>
<td><code>keep_alive</code></td>
<td>n: If no time service replies have been received for this number of polls, then the 372 will perform an automatic restart. 0 disables this facility.</td>
</tr>
<tr>
<td><code>debug</code></td>
<td>0x00: Debug all off</td>
</tr>
<tr>
<td></td>
<td>0x10: Monitor nvt interface</td>
</tr>
<tr>
<td></td>
<td>0x01: CLI interface functions, buffer functions</td>
</tr>
<tr>
<td></td>
<td>0x08: Time system functions</td>
</tr>
<tr>
<td></td>
<td>0x04: nvt states</td>
</tr>
<tr>
<td></td>
<td>0x02: nvt timing</td>
</tr>
<tr>
<td></td>
<td>0x20: Push processor</td>
</tr>
<tr>
<td></td>
<td>0x40: Message channel</td>
</tr>
<tr>
<td><code>max_age</code></td>
<td>Age in seconds for which images are maintained in the history table. NB: images will be discarded oldest first despite this setting when the table becomes full.</td>
</tr>
<tr>
<td><code>window</code></td>
<td>Default time window (ms) within which to match requested image</td>
</tr>
<tr>
<td><code>nvt_timeout</code></td>
<td>Telling system control nvt will close after timeout seconds of inactivity</td>
</tr>
<tr>
<td><code>jpeg</code></td>
<td>0nm: Output images may be windows BMP format or JPEG format. Set bits in this parameter to define the format for each image. (use jpeg quality nn to set the compression level)</td>
</tr>
<tr>
<td></td>
<td>0x01: Set to save plate patch in jpeg format, clear to save in BMP format</td>
</tr>
<tr>
<td></td>
<td>0x02: Set to save full plate image in JPEG format, clear to save in BMP format</td>
</tr>
<tr>
<td></td>
<td>0x04: Set to save overview tile in JPEG format, clear to save in BMP format</td>
</tr>
<tr>
<td><code>msg_timeout</code></td>
<td>mm: If no messages have been sent on the message channel for mm seconds, then a message M00 is sent.</td>
</tr>
<tr>
<td><code>simulate</code></td>
<td>0x0n: Set to force transfer of triggered images to the simulation ftp server. This option has been added to facilitate testing without access to the tolling control system. Images of all vehicles for which triggers have been generated will be copied to the ftp server. (see note 1)</td>
</tr>
<tr>
<td></td>
<td>0x01: Transfer patch</td>
</tr>
<tr>
<td></td>
<td>0x02: Transfer full plate image</td>
</tr>
<tr>
<td></td>
<td>0x04: Transfer overview image</td>
</tr>
</tbody>
</table>
6.2 Security monitoring system

The customer operates a secure site. The requirement is for a system to provide image and ALPR records of all vehicles entering the site. This system will run independently of the manual processing of vehicles as they enter or leave the site.

The site has barriers at entrances. Loops are available indicating when a vehicle is waiting at the barrier.

For each lane entering the site, one P372 camera is mounted on a pole viewing the area before the barrier.

A central system stores the images and vehicle tags in a database.

The P372 systems are coupled to the central system via Ethernet carried over fiber.

When a vehicle crosses the loop a trigger is forwarded to the P372. The P372 will observe the vehicle for a configurable period, typically 150-300ms. During this period, one overview and the best license plate image will be saved.

6.3 Car parking

The car park has two entry lanes and one exit lane. The latter has a payment booth. One of the entry lanes and the exit lane are to be monitored by automatic license plate reading system (ALPR). Each of the lanes will be monitored by one P372 camera. This will feed data to the parking system.

Front or rear plates?

The site is located in the US, however there is a requirement to recognize plates from adjoining states. Initial information from a website indicates two of these states do not require front plates thus the system must look at rear plates.

Location of capture point

In general the P372 camera can collect images suitable for ALPR with an image capture point at any distance between 12 feet and 60 feet from the camera. This distance does however have to be pre-selected, and the appropriate lens and illuminator fitted to the camera at the factory.

As rear plates are to be captured, the stopping point of the rear plate may vary considerably depending on the length of the vehicle (e.g. mobile homes, trailers, stretch limos etc). It is important to decide the rear plate stopping point of the longest vehicle envisaged. The capture point must be at this point, or before. For many vehicles, the vehicle will stop with the plate not within the field of view. This means that for most vehicles, the plate will have to be read as the vehicle approaches the barrier, and the data stored until requested by the parking system.

The capture point also has to be located where the lateral position of the vehicle is constrained so that the license plate will always pass through the field of view. Clearly the capture point must also be located where cameras can be practically mounted to have a clear field of view (see below)

Location of P372 relative to the capture point

Set against these points are the considerations of practical camera location, and minimizing obscuration by following (or tailgating) vehicles.

In practice, many car park operators use a relatively short distance between the camera and capture point, typically 12 to 32 feet. The camera is usually mounted over the lane or as close as possible to the side of the lane.

Other considerations

It is important that there are not any other reflective surfaces within the field of view. These could be fixed or moving barriers, an operator’s coat, parked vehicles, signs etc.

Strong sunlight either directly in the field of view, or behind the camera in a direct line from the target through the camera are worth avoiding as even with the P372’s ability to suppress sunlight, there may be a loss of data for certain times of the day.
P372 License Plate Recognition Camera User Manual

If front plates are to be captured then usually it is necessary to have the camera in front of the barrier either looking above or below the barrier.

The mounting of the camera also needs consideration. Typically cameras in car parks are mounted within bollards, on posts or mounted from roofs or walls etc. Clearly they must be in a position such that they will not be hit by vehicles, and will not be too prone to vandalism.
Appendix 7  High level commands at the CLI Interface

These commands are entered at the command line interface (CLI) on the P372. The function of these commands is described in Appendix 3.

1 - capture
Available Commands are
  0 - set
  1 - show
  2 - script
  3 - clear
  4 - stats

2 - dump
Available Commands are
  0 - ram
  1 - cpu
  2 - eeprom
  3 - line
  4 - file
  5 - script

3 - show
Available Commands are
  0 - stack
  1 - profile
  2 - history
  3 - queues
  4 - files
  5 - port
  6 - date
  7 - time
  8 - trigger
  9 - serial
  10 - bit
  11 - boot
  12 - config
  13 - counters
  14 - itab
  15 - image
  16 - analyse
  17 - site
  18 - jpeg
  19 - raw
  20 - capture
P372 License Plate Recognition Camera User Manual

21 - log
22 - anpr
23 - system
24 - kermit
25 - carpark
26 - client
27 - tl
28 - sync

4 - set
Available Commands are
0 - date
1 - inter
2 - server
3 - serial
4 - ether
5 - boot
6 - password
7 - itab
8 - eam
9 - mode
10 - thresh
11 - width
12 - trigger
13 - cache
14 - config
15 - site
16 - route
17 - capture
18 - jpeg
19 - raw
20 - log
21 - anpr
22 - system
23 - kermit
24 - carpark
25 - client
26 - tl
27 - sync

5 - clear
Available Commands are
0 - image
P372 License Plate Recognition Camera User Manual

1 - analyse
6 - help

7 - install

8 - test
Available Commands are
0 - text
1 - read
2 - write
3 - many
4 - ini
5 - uart
6 - seive
7 - whel
8 - dhry
9 - dma
10 - copy
11 - match
12 - snip
13 - oo
14 - cam

0 - kermit
Available Commands are
0 - receive
1 - server
2 - send
3 - set
4 - show
5 - script

10 - ftp
Available Commands are
0 - nlist
1 - dir
2 - ls
3 - get
4 - put
5 - mput
6 - append
7 - mkdir
8 - md
P372 License Plate Recognition Camera User Manual

11 - pdb
Available Commands are
0 - set
1 - show
2 - script
3 - load
4 - lookup
5 - ammend
6 - insert
7 - delete
8 - clear
9 - save

12 - reset
13 - shutdown
14 - exit
15 - flash
Available Commands are
0 - write
1 - erase

16 - flex
Available Commands are
0 - load
1 - reset
2 - version

17 - fs

18 - snap

19 - jpeg
Available Commands are
0 - test
1 - set
2 - show
3 - script
Available Commands are

1 - start
2 - show
3 - script
4 - queue
5 - release

Available Commands are

1 - test
2 - set
4 - show
5 - info
6 - hangup
7 - power
8 - command

Available Commands are

0 - show
1 - set

Available Commands are

0 - set
1 - show
2 - script
3 - count
4 - test

Available Commands are

0 - set
1 - show
P372 License Plate Recognition Camera User Manual

2 - script
3 - prepare
4 - delete

28 - bmp
Available Commands are
0 - test
1 - set
2 - show
3 - html
4 - ALPR
5 - list
6 - soope
7 - script

29 - net
Available Commands are
0 - mask
1 - broadcast
2 - gateway
3 - set
4 - show
5 - config
6 - ping
7 - blast!
8 - route
9 - getit
10 - slip
11 - ppp
12 - info

30 - ping

32 - convert
Appendix 8  Customer comment proforma

This proforma should be retained in this publication. When required for use, reproduce (photocopy) locally.

To:  PIPS Technology Ltd
     York House
     School Lane
     Eastleigh
     Hants  SO53 4DG

From:  

Tel No:  

Senders Reference:  

Date:  

Title of Publication: P372 License Plate Recognition Camera User Manual – Issue 1

USER COMMENT (Use a separate sheet of paper if necessary.)

Signed  Name

To:  

From:  PIPS Technology Ltd
     York House
     School Lane
     Eastleigh
     Hants  SO53 4DG

Thank you for commenting on: P372 License Plate Recognition Camera User Manual – Issue 1
Action is being taken to:

1. Revise the publication
2. Amend the publication
3. No action is considered necessary for the following reasons:

* Delete as necessary

Signed  Name