Final Report
For
CRADA Number ORNL 95-0364

ADVANCED WEIGH-IN-MOTION
SYSTEM FOR WEIGHING
VEHICLES AT HIGH SPEED

D. L. Beshears
J. D. Muhs
M. B. Scudiere
L. D. Marlin0
Oak Ridge National Laboratory

B. W. Taylor
A. J. Pratt
R. J. Koenderink
International Road Dynamics

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Prepared by the
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Oak Ridge, Tennessee 37831
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FINAL REPORT

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D. L. Beshears  
J. D. Muhs  
M. B. Scudiere  
L. D. Marlino  
Oak Ridge National Laboratory  

and  

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Prepared for the  
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Facility and Technology Management Division  
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International Road Dynamics  
Saskatchewan, Canada
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ABSTRACT

A state-of-the-art, Advanced Weigh-In-Motion (WIM) system has been designed, installed, and tested on the west bound side of Interstate I-75/I-40 near the Knox County Weigh Station. The project is a Cooperative Research and Development Agreement (CRADA) between Oak Ridge National Laboratory (ORNL) and International Road Dynamics, Inc. (IRD) sponsored by the Office of Uranium Programs, Facility and Technology Management Division of the Department of Energy under CRADA No. ORNL95-0364. ORNL, IRD, the Federal Highway Administration, the Tennessee Department of Safety and the Tennessee Department of Transportation have developed a National High Speed WIM Test Facility for test and evaluation of high-speed WIM systems. The WIM system under evaluation includes a Single Load Cell WIM scale system supplied and installed by IRD. ORNL developed a stand-alone, custom data acquisition system, which acquires the raw signals from IRD’s in-ground single load cell transducers. Under a separate contract with the Federal Highway Administration, ORNL designed and constructed a laboratory scale house for data collection, analysis and algorithm development. An initial advanced weight-determining algorithm has been developed. The new advanced WIM system provides improved accuracy and can reduce overall system variability by up to 30% over the existing high accuracy commercial WIM system.
BACKGROUND

Project

In recent years, considerable attention from both government and private industry has been given to the demand for a vehicle weigh-in-motion (WIM) system capable of accurately measuring the weight of vehicles at high speeds. Although WIM technologies exist today, commercially available devices are used for screening and monitoring purposes only while the ticketing for enforcement applications are only issued using static scales. The benefits of such a technological innovation are both indisputable and wide-ranging in the transportation arena. Most weight enforcement systems today use static weighing scales which are calibrated regularly to maintain a measurement error of approximately 1-3% and require each vehicle being weighed to come to a complete stop on the transducer platform.

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 Specifications E 1318-94. Because the dynamic vehicle weight, as defined in the ASTM standard, is by definition, an estimate of the static vehicle weight, the accuracy and variability of the estimate depends on how well the WIM system is able to compensate for the physical phenomena acting on the vehicle during the instance the tire is in contact with the transducer. The difficulty with weigh-in-motion systems lies in predicting the static weight of a vehicle from varying dynamic weight. Eliminating or minimizing the effects of these system dependent variables at high speeds is the challenge of this project.

Many system dependent variables are inherent to all WIM systems and can be broadly classified into four basic categories, listed in Table I.

<table>
<thead>
<tr>
<th>Vehicle-Dependent</th>
<th>Environmental-Dependent</th>
<th>System-Dependent</th>
<th>Roadway-Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire Characteristics</td>
<td>Temperature gradients</td>
<td>Vertical height</td>
<td>Pavement</td>
</tr>
<tr>
<td>- Mass</td>
<td>- Impulse forces</td>
<td>- Rigidity</td>
<td></td>
</tr>
<tr>
<td>- Temperature</td>
<td>- Torque</td>
<td>- Smoothness</td>
<td></td>
</tr>
<tr>
<td>- Air pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Diameter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tread pattern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Width &amp; location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Balance quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspension system</td>
<td>Wind</td>
<td>Algorithm accuracy</td>
<td>Obstructions</td>
</tr>
<tr>
<td>- Load</td>
<td></td>
<td>- Potholes</td>
<td></td>
</tr>
<tr>
<td>- Type</td>
<td></td>
<td>- Debris</td>
<td></td>
</tr>
<tr>
<td>Aerodynamic lift</td>
<td>Ice</td>
<td>Hysteresis</td>
<td>Ice build up</td>
</tr>
<tr>
<td>Velocity &amp; Acceleration</td>
<td>Snow</td>
<td>Lateral uniformity</td>
<td>Pavement contour</td>
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<tr>
<td></td>
<td>Rain</td>
<td>Electronic noise</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sampling rate</td>
<td></td>
</tr>
</tbody>
</table>

Weigh-in-motion is not as straightforward as one might perceive it to be at first glance. Although commercial weigh-in-motion systems are available, there is considerable room for improvement in accuracy and variability. In this project, understanding the sources of error and their causes has
allowed the project team to quantify sources of error, and design hardware to reduce, eliminate, or compensate for these errors. Coupled with advanced algorithms, we have found that the accuracy can be increased and the variability can be reduced significantly.

Oak Ridge National Laboratory

In 1989, Oak Ridge National Laboratory (ORNL) began work on WIM systems by developing a fiber optic WIM system for the Department of Energy Defense Nuclear Agency. The Army Corp of Engineers Waterways Experimental Station (WES) tested this system in 1992-1993. WES results indicated the ORNL WIM system performed better than a piezo electric WIM system supplied by the Texas Transportation Institute. In partnership with the Tennessee Air National Guard, ORNL developed, tested, and evaluated a WIM system for the United States Air Force to weigh and determine the center of balance of military vehicles in motion for rapid deployment. Ms. Cara Clark of the U. S. Air Force Productivity, Reliability, Availability, and Maintainability Office sponsored the work. The system referred to as the Automated Vehicle Data Acquisition system is a portable weigh-in-motion system developed for the purpose of accurately and efficiently manifesting cargo onto aircraft during military deployments. This development effort resulted in a self-zeroing, user-friendly system capable of weighing a wide range of military vehicles in any random order. The control system is based on the STANDARD (STD) bus and incorporates a custom-designed data acquisition system with hardware controlled by a PC-based single-board computer. The user interface is written in "C" language to display number of axles, axle weight, axle spacing, gross weight, and center-of-balance. The weighing algorithm developed functions with any linear weight sensor and a set of four axle switches per sensor. This system and its development are described in some detail in two ORNL reports. ORNL continues to work with the military on other WIM programs such as the present Defense Advance Research and Development Administration program where ORNL is working with the Advanced Logistics Program to develop WIM systems for military assets characterization.

International Road Dynamics

International Road Dynamics Inc. (IRD), incorporated in Saskatchewan, Canada, in 1980, is a publicly owned highway traffic management products and systems technology company operating in the worldwide Intelligent Transportation Systems (ITS) industry. IRD has its corporate headquarters in Saskatoon, Saskatchewan with other Canadian offices in Mississauga and Toronto, United States offices in Colorado, Oregon, Indiana, Minnesota, Virginia, California, and Arizona, and one office in the United Kingdom. IRD also has a division called IRD Teleride, which is responsible for Fleet Management and Automatic Vehicle Location (AVL) activities. In addition to its own operations, IRD is represented worldwide by various local distributors.

IRD is a multi-discipline high-tech company that specializes in advanced WIM technologies, with the expertise to integrate complementary ITS technologies in systems designed to solve unique and challenging transportation problems. IRD’s engineers are experts in designing and supplying automated truck weigh station systems, advanced traffic data collection, and traffic control systems, freeway management systems, WIM systems, automatic vehicle location (AVL), and real-time dispatch systems based on GPS technology and wireless communications. IRD has used and is using integration and speed factors in WIM system algorithms."

ITS is the application of technology to improve the movement of people and goods. The goal is safer, quicker, more efficient travel. It means:

• Improved trucking management
• Faster freight deliveries
• Reduced congestion
• Improved traffic flow
• Quicker emergency response
• Better travel information
• Improved energy efficiency
• Money saved
• High returns on investments

IRD is a recognized leader in the design and installation of customized solutions in the ITS industry. IRD is the one source company that can offer multi-systems solutions by integrating a number of different technologies to achieve the desired functionality. IRD’s main product areas include:

• Commercial Vehicle Operations
• Safety Systems and Specialized Traffic Applications
• Traffic Data Collection (AVC)
• Toll Roads, Freeway Management, Traffic Management and Control Systems (ETTM, FMS, AVI)
• Real-Time Automatic Vehicle Location (AVL) utilizing GPS satellite information and wireless dispatch system (APTS, TWC)
• Advanced systems integration and design,
• Service maintenance and support

ID is registered with the ISO 9000 Quality control program and is committed to "Total Quality" in all areas of expertise, from design and development to manufacturing and installation, to long-term service. IRD's "Total Quality Commitment" focuses on the customer, striving to exceed customer requirements: "It is the policy of IRD to provide consistent, reliable, and high quality products and service at all times, meeting or exceeding our customer's needs and expectations. Our goal is to continuously improve in all areas of our business environment and to deliver excellence to our customers."

OBJECTIVES

The goal of this project is to develop an understanding of and establish methods for reducing the sources of error in WIM systems for high-speed weight monitoring applications. IRD’s objective in participating in the Cooperative Research and Development Agreement (CRADA) is to provide the best product possible to our customers. As part of IRD’s commitment to its Total Quality Program, the company is always looking for ways and innovations to improve IRD products. In order to meet these specific objectives the planned activities included: 1) IRD installs a standard mainline Single Load Cell Transducer WIM system as a part of the Advantage 1-75 program, 2) IRD installs an improved Strain Gage Transducer WIM System with additional peripheral sensors and adds additional sensors to the standard mainline Single Load Cell Transducer WIM system, 3) ORNL develops an improved data acquisition system for acquiring and processing data from the WIM hardware, 4) ORNL installs a laboratory scale house for data collection, analysis, and algorithm development, 5) ORNL develops initial advanced weight determining algorithm, and 6) ORNL evaluates the advanced WIM system against existing commercial mainline system.

BENEFITS

The benefits of an improved accuracy and variability of WIM systems can be summarized in four major areas: benefits to the United States Department of Energy, benefits to the motor carrier industry, benefits to the state and local enforcement agencies, and benefits to the United States public.
Benefits to the United States Department of Energy

The average weigh station stop for a motor vehicle carrier is five minutes. During that five minutes the motor carrier is consuming nonrenewable energy and accomplishing nothing toward their end goal of delivering goods and services. These vehicles are also operating at reduced efficiency in terms of fuel consumption as well as producing pollutants that adversely affect the air quality. Given that over 500,000 carriers are on our nation’s highways traveling through an average of four weigh stations each day, it is easy to see that reducing the motor carrier stops at weigh stations will result in a substantial reduction in nonrenewable energy consumption and pollution by motor carriers.

Benefits to Motor Carrier Industry

The average cost of operating a semi truck today is approximately $1.50 per minute and, as indicated above, the average weigh station stop five minutes. Consequently, the potential economic benefit to carriers of the proposed system is approximately $7.50 per vehicle for each weigh station stop. Given that there are over 500,000 carriers on the nation’s highways traveling through an average four weigh stations each day, the projected cost-savings for the motor carrier industry alone is estimated to be over $15M daily. It is anticipated that the major portion of these savings will be passed on to the consumer.

Benefits to the State and Local Enforcement Agencies

Weight enforcement activities are slow and cumbersome causing substantial overcrowding at weigh stations. Law enforcement officials are forced to either create unsafe conditions by allowing vehicles to backup in long lines near the weigh station entrance ramps or allow carriers to bypass weigh stations completely. The successful implementation of the increased accuracy and reduced variability high speed WIM system will allow weight enforcement officials to screen all carriers and require only those exceeding weight limits to stop at weigh stations, thereby increasing productivity and operational efficiency.

Benefits to the United States Public

The benefits to the United States public are twofold: 1) fewer serious motor carrier accidents and injuries due to unsafe, overloaded trucks (these vehicles will no longer be able to by-pass busy scales), and 2) lower costs of transporting goods (this will be accomplished by lowering the cost of enforcing transportation regulations and reducing accidents and injuries).

TECHNICAL DISCUSSION OF WORK PERFORMED BY ALL PARTIES

As with any major innovation project, there are many activities that must take place in preparation for the actual development effort. In the case of developing an advanced weigh-in-motion system for weighing vehicles at high speed, several agencies and organizations have teamed together to contribute to the overall program. A project of this magnitude requires in-ground certified scales for calibration and test certification, installation of WIM imbedded transducers and peripheral sensors, roadside electronics, a laboratory facility for data collection, and a means of transmitting data to the laboratory facility. This project required that all these systems be located, developed and/or fabricated before the actual development and evaluation of the improved high speed WIM system could take place. As part of this project, ORNL, IRD, the Federal Highway Administration (FHWA), the Tennessee Department of Transportation (TNDOT), and the Tennessee Department of Safety (TNDOS) have developed a National High Speed WIM Test Facility for test and evaluation of high-speed WIM systems. The Tennessee Department of Safety/Transportation provided static scales used for calibration and test certification. The National High Speed WIM Test Facility includes an on-site, state-of-the-art laboratory with data...
acquisition system and computer hardware linked to highway imbedded WIM hardware and environmentally secured roadside electronics box via 6 fiber optic cables and 25 twisted pair data transmission cables. The Tennessee Department of Safety/Transportation provided not only the use of their static scale facility but personnel and assistance to make the National High Speed WIM Test Facility a reality which allowed this project to be successfully undertaken.

Installation of the National High Speed Test Facility

Although not formally a part of this CRADA, ORNL leveraged interest in the project and funds from FHWA, TNDOS, and TNDOT to design and install a new 14' X 40' permanent laboratory at the Knox County Weigh Station. This facility, described below, houses much of the data acquisition/signal processing hardware used by the project team. A schematic depicting the National High Speed WIM Test Facility is shown in Figure 1. The facility presently consists of a standard IRD Single Load Cell Transducer configuration installed as part of the Advantage I-75 Program; electronics housed in a roadside box; both fiber optic and standard twisted pair cable sets for data transmission; and a laboratory building which houses collection, recording and monitoring equipment used to collect and analyze data used to develop advanced weight determining algorithms. The laboratory facility is also linked directly to the Tennessee Department of Safety/Transportation weigh station scales to provide direct static scale readings for system calibration and certification. The IRD inground sensors, shown in the outside west bound lane Figure 1, consist of two inductive loops, a single Dynax™ switch, and a single load cell transducer. The roadside box houses both the standard IRD data collection and analysis electronics as well as the custom designed ORNL data acquisition/analysis system. A general layout and some details of the roadside box electronics are shown in Figures 2 and 3. Figure 4 shows a schematic of the laboratory facility electronics including two computers, fiber optic and twisted pair links to the roadside box, a weather station for correlating weather effects with system performance, direct feed from weigh station static scales, and a direct ORNL Ethernet link to the ORNL computer network.
Figure 1. Schematic of National High Speed Weigh-in-Motion Test Facility

National High Speed WIM Test Facility

Figure 2. Details of Roadside Box Electronics

IRD WIM Electronics 1065

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Additional hardware purchased but not yet fully installed includes a video camera and PC overlay card, an optical storage disc drive, and a Schwartz Electro-Optic Autosense II unit. The color video camera and PC overlay card is a wireless video system which is to be mounted on a roadside pole to provide video images of trucks as they pass over the WIM transducer. The video unit was received, configured, and tested in a series of laboratory tests. The overlay card allows live video to be displayed on a VGA monitor. Video images can also be overlaid with computer graphics. Positioning and scaling of the video image on the output display can be used to provide information on vehicle dynamics, which can potentially be used to improve algorithm accuracy.

The 2.6 GB SCSI optical hard drive was received, configured and tested. It will be utilized to store video images from the Autosense II unit with overlay data or data from the video camera. It will be invaluable in archiving data and storing images for later evaluation and analysis.

The Schwartz Electro-Optics Autosense II unit is designed to be mounted directly above the inground WIM transducer. It was received, configured and tested in a series of laboratory tests. This unit will allow remote vehicle classification and detection of vehicle spacing, speed, height, length, width, and lane position data for incorporation into the advanced algorithm. The Autosense II unit provides processed data along with either a 2D or 3D image of the vehicle as it moves through the Autosense scan. This unit, along with the video camera, will be used in the future to obtain additional data on both vehicle dynamics
and aerodynamics as it passes over the WIM scales. The algorithm can then incorporate this information and adjust for lateral sensitivity of the sensor as well as provide a first order correction for aerodynamic lift.

**Installation of Mainline High-Speed Weigh-In-Motion System Hardware**

One (1) lane of an *IRD Single Load Cell Weigh-In-Motion (WIM) Scale* was installed in the west bound, right-hand lane of Interstate 1-75 / I-40 near the Knox County Weigh Station along with IRD’s 1065 System Electronics to provide WIM Information as part of the Advantage I-75 Project. This system operates on a continuous basis, collecting data on axle weights, vehicle classification, and vehicle speed.

The IRD Single Load Cell WIM System consists of the following main components:

- IRD 1065 WIM Interface and Data Collection Electronics
- IRD Single Load Cell WIM Scales
- IRD AS-406 DYNAX™ Axle Sensor
- Inductive Loops
- Remote Communication Modem
- Operational Software
- Roadside Controller Cabinet (Information not included)

Some of the above outlined equipment is described in detail in the following appendices:

- Appendix 1 – IRD 1065 WIM Electronics Technical Specifications
- Appendix 2 – IRD Single Load Cell WIM Scales Technical Specifications
- Appendix 3 – IRD Single Load Cell WIM System Technical Specifications
- Appendix 4 – IRD AS-406 DYNAX™ Sensor Technical Specifications

**Development of Improved Data Acquisition System for the Roadside Box**

ORNL designed and fabricated two custom data acquisition cards for the advanced high speed WIM system. One card, the accumulator, handles the two analog channels from the IRD WIM transducer. It converts the analog signal to 12-bit digital at 50 kHz and then sums the resultant digital signal to maintain a running accumulation of the input. This reduces the volume of data being processed by the host processor by several orders of magnitude without loss of required information and minimizes data transmission time. The second card handles all digital inputs that include the switches and loop sensors. It records a 24-bit time from an 800 kHz clock which is synchronized with the accumulator card and buffers the results until the host computer is able to read it.

**Development of Initial Advanced Weight Determining Algorithm**

The basis of the algorithm used here is that utilized in the low-speed WIM systems developed for the United States Air Force under Patent Serial Number 08/1815,107. The algorithm is the mathematical representation of the actual physics of a tire rolling over a sensor, which is known mathematically as a "convolution". In addition to this basic processing, there is a lot of preprocessing to determine valid sections of data as well as determining the baseline for auto zeroing. This preliminary testing did not incorporate any algorithms for separating axles or determining axle spacing – all of which were included in the low-speed WIM but were not included here. This was due in part to not needing this information for the preliminary testing and in part to funding levels.
Comparison of Improved Mainline High-Speed Weigh-In-Motion System To Existing State-of-the-Art Commercial High-Speed Weigh-In-Motion System

Some 20,000 vehicle passes were accumulated from which more than 5,000 waveforms have been stored and used in the development and evaluation of the initial algorithm. This section will evaluate two specific tests 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 IRD standard commercial WIM systems. All pertinent information was recorded from the Advanced WIM System, the IRD standard commercial WIM system, and the static scales. The raw scale outputs were feed into IRD’s commercial system computer and in parallel into the Advanced WIM System data acquisition system. A typical output waveform from inground transducer for a standard 18-wheel semi showed severe ringing or signal oscillations that had to be accounted for in the weight-determining algorithm. Also the non-linearity in the left sensor waveform as well as the very different time constant of the ringing created system errors which could not be easily accounted for. Some mechanical adjustment to the inground transducer may help to reduce or eliminate some of system errors we encountered. The raw data from the two tests are shown in Tables II and III. Results of the two tests are summarized in Table IV. The first test was used as a calibration of the Advanced WIM System while both tests were used to compare of the two systems to determine the degree of improvement demonstrated by the Advanced WIM system.

Table II. Calibration results - Test I

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Static Weight</th>
<th>IRD Weight</th>
<th>Advanced WIM Weight</th>
<th>IRD %Error</th>
<th>Advanced WIM %Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi</td>
<td>79.2</td>
<td>84.8</td>
<td>76.5</td>
<td>7.1</td>
<td>-3.4</td>
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<tr>
<td>Car carrier</td>
<td>41.3</td>
<td>48.2</td>
<td>43.6</td>
<td>16.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Tyson</td>
<td>48.4</td>
<td>56.0</td>
<td>49.3</td>
<td>15.7</td>
<td>1.7</td>
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<tr>
<td>Semi</td>
<td>75.3</td>
<td>86.4</td>
<td>75.9</td>
<td>14.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Semi</td>
<td>31.9</td>
<td>38.2</td>
<td>32.4</td>
<td>19.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Semi</td>
<td>32.1</td>
<td>37.4</td>
<td>32.2</td>
<td>16.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Flat bed</td>
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<td>81.5</td>
<td>76.9</td>
<td>6.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Towed bus</td>
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<td>42.9</td>
<td>38.5</td>
<td>13.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Semi</td>
<td>79.4</td>
<td>86.1</td>
<td>80.6</td>
<td>8.5</td>
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<td>Wal-Mart</td>
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<tr>
<td>Semi</td>
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<td>17.6</td>
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<td>9.1</td>
<td>-2.0</td>
</tr>
<tr>
<td>Semi</td>
<td>51.6</td>
<td>55.1</td>
<td>50.9</td>
<td>6.9</td>
<td>-1.3</td>
</tr>
<tr>
<td>Semi</td>
<td>53.5</td>
<td>61.8</td>
<td>54.6</td>
<td>15.6</td>
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<tr>
<td>Semi</td>
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<td>59.2</td>
<td>51.1</td>
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<td>49.5</td>
<td>4.9</td>
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<td>Semi</td>
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<td>Average</td>
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<td>56.0</td>
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<tr>
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<td>18.2</td>
<td>18.7</td>
<td>17.8</td>
<td>4.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Table III. Final results – Test II

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Static Weight</th>
<th>IRD Weight</th>
<th>Advanced WIM Weight</th>
<th>IRD % Error</th>
<th>Advanced WIM % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi</td>
<td>74.8</td>
<td>78.7</td>
<td>70.8</td>
<td>5.2</td>
<td>-5.3</td>
</tr>
<tr>
<td>Semi</td>
<td>67.3</td>
<td>76.6</td>
<td>65.3</td>
<td>13.8</td>
<td>-3.1</td>
</tr>
<tr>
<td>Semi</td>
<td>70.2</td>
<td>76.3</td>
<td>70.0</td>
<td>8.7</td>
<td>-0.3</td>
</tr>
<tr>
<td>Car carrier</td>
<td>69.6</td>
<td>72.0</td>
<td>69.5</td>
<td>12.0</td>
<td>-0.1</td>
</tr>
<tr>
<td>Semi</td>
<td>29.0</td>
<td>33.3</td>
<td>29.1</td>
<td>14.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Semi</td>
<td>69.4</td>
<td>78.6</td>
<td>68.3</td>
<td>13.2</td>
<td>-1.6</td>
</tr>
<tr>
<td>Semi</td>
<td>76.8</td>
<td>82.9</td>
<td>73.1</td>
<td>7.9</td>
<td>-4.8</td>
</tr>
<tr>
<td>Semi</td>
<td>56.6</td>
<td>62.7</td>
<td>56.1</td>
<td>10.7</td>
<td>-0.9</td>
</tr>
<tr>
<td>Flatbed</td>
<td>90.2</td>
<td>93.9</td>
<td>84.9</td>
<td>4.1</td>
<td>-5.9</td>
</tr>
<tr>
<td>Semi</td>
<td>41.2</td>
<td>49.2</td>
<td>43.7</td>
<td>19.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Semi</td>
<td>76.6</td>
<td>85.4</td>
<td>76.0</td>
<td>11.4</td>
<td>-0.8</td>
</tr>
<tr>
<td>Semi</td>
<td>49.6</td>
<td>57.7</td>
<td>49.5</td>
<td>16.3</td>
<td>-0.2</td>
</tr>
<tr>
<td>Semi</td>
<td>76.0</td>
<td>83.3</td>
<td>73.1</td>
<td>9.7</td>
<td>-3.8</td>
</tr>
<tr>
<td>Semi</td>
<td>45.7</td>
<td>52.0</td>
<td>45.9</td>
<td>13.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Semi</td>
<td>75.5</td>
<td>82.1</td>
<td>72.4</td>
<td>8.7</td>
<td>-4.1</td>
</tr>
<tr>
<td>Semi</td>
<td>33.3</td>
<td>37.8</td>
<td>33.7</td>
<td>13.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Semi</td>
<td>77.5</td>
<td>85.7</td>
<td>73.9</td>
<td>10.6</td>
<td>-4.7</td>
</tr>
<tr>
<td>Semi</td>
<td>32.2</td>
<td>38.0</td>
<td>33.0</td>
<td>18.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Semi</td>
<td>76.3</td>
<td>84.6</td>
<td>76.6</td>
<td>10.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Semi</td>
<td>46.3</td>
<td>53.3</td>
<td>47.3</td>
<td>15.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Semi</td>
<td>78.0</td>
<td>86.5</td>
<td>77.3</td>
<td>10.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>Flatbed</td>
<td>65.7</td>
<td>74.3</td>
<td>65.9</td>
<td>13.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Car carrier</td>
<td>69.7</td>
<td>77.6</td>
<td>71.8</td>
<td>11.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Average</td>
<td>62.9</td>
<td>69.9</td>
<td>62.1</td>
<td>11.9</td>
<td>-0.9</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>17.4</td>
<td>17.9</td>
<td>16.2</td>
<td>3.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

From this table one can see a significant improvement in the Advanced WIM System over the standard commercial WIM system. While the average error in the IRD standard commercial WIM system is high, it could be corrected by adjusting the calibration factor. The average deviation, which is a function of the overall systems repeatability, will remain unchanged. Tests indicate average variation in the Advanced WIM System has reduced errors by 30% over the current IRD standard commercial WIM system.

Table IV. High-Speed Weigh-in-Motion Data

<table>
<thead>
<tr>
<th></th>
<th>Average Error</th>
<th>Standard Deviation</th>
<th>Number Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRD Standard</td>
<td>12.1%</td>
<td>4.7%</td>
<td>18 – test I</td>
</tr>
<tr>
<td>Commercial System</td>
<td>11.7%</td>
<td>3.7%</td>
<td>23 – test II</td>
</tr>
<tr>
<td>12.0%</td>
<td>4.2%</td>
<td>41 - combined</td>
<td></td>
</tr>
<tr>
<td>Advanced WIM System</td>
<td>-0.9%</td>
<td>3.0%</td>
<td>23 – test II</td>
</tr>
<tr>
<td>-0.5%</td>
<td>2.8%</td>
<td>41 - combined</td>
<td></td>
</tr>
</tbody>
</table>
The error results as a function of weight are shown in Figure 5. Here both systems are “recalibrated” for perfect fits in order to illustrate the variabilities of the errors. The limits for one standard deviation for the ORNL data are indicated by the dashed lines. Notice the general reduction of error using Advanced WIM system.

![Errors vs Weight](image)

**Figure 5. Error as a Function of Weight for Ideal Calibration**

The States’ Successful Practices Weigh-in-Motion Handbook\(^{(10)}\) indicated that for many high-speed WIM systems there is a correlation between vehicle speed and WIM system error. In Figure 6, the errors are plotted as a function of speed. Here we see no indication that speed has any influence on the result.

![Error vs Speed](image)

**Figure 6. Errors versus Speed**
Figure 7 shows a comparison of the two analysis systems. One can see from this that, if the weight bias in the IRD commercial calibration were corrected, then the two systems would agree to approximately 1% standard deviation. By comparing the 2% Advanced WIM System standard deviation and IRD’s commercial 4% standard deviation which could be reduced to about 3% with a correction for the weight bias, we can deduce that 2% of the error is a result of the vehicle’s dynamics. The 2% dynamic error is unique to the individual site as the dynamic effects are very site specific. If this is accurate for this site, then a “perfect analysis system” could only determine weights to approximately 2% standard deviation using these scales in the present configuration. The 2% dynamic error is unique to each site as the dynamic effects are very site specific.

![Figure 7. Ratio of Advanced Weigh-in-Motion System/IRD Commercial System Weights](image)

**IRD’S INVESTIGATION OF THE FEASIBILITY OF USING AN INTEGRATION TECHNIQUE IN SLC WIM SYSTEM**

Research data gathered from an IRD site in Umatilla, Oregon, was used for this investigation. The following is a description of how the data was gathered.

The WIM electronics were interfaced with a data acquisition system. The setup was similar to the ORNL configuration where the data acquisition system ran in parallel with the normal operation of the scale. The tests were performed using a scale truck. The truck configuration was 3-axle truck loaded with calibrated weights. During the test period, five passes were gathered in the morning and five passes in the afternoon.
The test results showed a larger than expected mean error between morning and afternoon. Normally, the scales do not show an error due to time of day. As part of this investigation into the error at this particular site, the sample data was manually analyzed using the integration algorithm and compared with the standard algorithm. The integration algorithm gave about 30% improvement in the standard deviation results. However, it did not significantly change the mean error.

Based on IRD's experience, the majority of this type of error is site dependent and related to site conditions. This particular site has the scale located right after a bridge. The bridge has a significant downgrade prior to the scale. The test speeds were different between the morning and afternoon runs. Based on other sites, if the site has a large dynamic component in the weights, then the dynamic effect is quite repeatable for the same vehicle at the same speed, even though the difference in weight can be quite large at another speed.

In summary, the integration technique did not solve IRD's problem at this particular site. Indicators are that, an integration technique can improve the overall accuracy by reducing the standard deviation.

INVENTIONS

No inventions were made or reported as a result of the work performed on this CRADA.

COMMERCIALIZATION POSSIBILITIES

By improving the accuracy and reliability of WIM systems, the market will find new applications. Weigh-in-motion is already a rapidly growing market place. The benefits include improved economics and competitiveness issues for the transportation industry. Without a doubt, the ability to accurately weigh vehicles in motion provides tremendous cost savings as well as tremendous spin-off technologies due to the advantages of the WIM systems.

Currently the domestic market place is estimated at $10M to $30M. This market place is just emerging and is still in its infancy. It is expected that markets will more than double in the next two years and expand to an excess of $50M within the next five years. The off shore markets are even larger. IRD estimates these at $60M to $80M over the next five years. The markets listed are the current known markets. With improved accuracy and reliability of WIM systems, it is anticipated the new applications/markets will more than double these market estimates.

PLANS FOR THE FUTURE

The algorithm is expected to be expanded to include such things as a more robust auto-zero determination, individual axle weights, axle spacing, and center-of-balance. It is our desire to incorporate both the existing Autosense II profilometer and the video imaging into the advanced WIM system in order to obtain additional data on both the vehicle dynamics and its aerodynamics as it passes over the WIM scales. The algorithm will then incorporate this information to adjust for lateral sensitivity of the sensors as well as provide a first order correction for aerodynamic lift. The latter can be done through a form of neural network. The prototype data acquisition system will be reduced to a printed circuit card for greater robustness and better noise immunity. The overall system will be reduced in size and cost for reproduction. In addition, the entire analysis system could be incorporated into a single compact unit if desired.

CONCLUSIONS

There are ways to improve accuracy in the current approach to the high-speed WIM system as well as reduce the overall size of an analysis system. The prototype Advance WIM System has shown a 30%
reduction in error over the standard commercial WIM system, which agrees with IRD’s earlier test results. Since the Advanced WIM System variation is approximately equal to the sensor’s capability, any further improvement in the analysis system is not likely to improve overall accuracy. Therefore, further improvements beyond the Advanced WIM System will have to come from better sensor design and installation or the inclusion of additional peripheral sensors. As always, site preparation is critical to the overall results.
REFERENCES


10. Center for Transportation Research and Education Iowa State University, States Successful Practices Weigh-In-Motion Handbook, Iowa State University, September 1, 1997.
Appendix 1

IRD 1065 WIM Electronics Technical Specifications
GENERAL

The Weigh-In-Motion (WIM) Electronics must contain the interface and signal conditioning for the inroad sensors, a process computer, and an integral power supply within a single chassis. All material necessary for setup and operation of the system must be provided including all cords and cabling. The system must be provided with the required software pre-loaded so that it will automatically execute when the system is powered up. The electronics must be modular in design to facilitate easy maintenance, troubleshooting and in-field servicing. The computer, power supply and the interface electronics must meet the following requirements.

COMPUTER DETAILS

| RAM Memory | - 32 Mb minimum |
| Processor  | - Pentium or better |
| Minimum Processor Speed | - 133 MHz minimum |
| Peripherals | - 1 - 3.5" 1.44 Mb Floppy Disk Drive |
| | - Non-volatile storage for vehicle information to prevent data loss during power outages (i.e.: hard disk drive, battery backed RAM or Flash Drive) |
| | - 2 Async RS232-C Serial Ports |
| | - 1 Parallel Centronics Interface |
| | - Expansion bays for CD-ROM, Tape Drives, one half height 3.5" drive, two half height 5.25" drives can be added with front access |
| Expansion Slots | - 2 ISA card slots, 2 PCI card slots, one shared ISA/PCI slot |
| Keyboard | - Separate 104 style keyboard with 12 programmable function keys |
| Monitor | - Separate monitor |
| | - Minimum monochrome VGA |
Casing
- Shelf or 19" rack mount
- Powder coated aluminum panels
- Shelf dimensions: 44.5 cm high x 48.4 cm wide x 27.8 cm deep (17 1/2 in. x 19 in. x 11 in.)

Power Supply
- 110 VAC 60Hz, or 220 VAC 50Hz operation
- 80 watt supply
- Optional 130 watt supply

COMPUTER INTERFACE CARDS

Analog Input Card
- 16 single-ended analog input channels
- Industry standard 12 bit successive approximation A/D converter
- Minimum sampling rate 47 KHz - Must sample each analog input at no less than 1600 Hz
- On board programmable timer for A/D clock

Digital Input/Output
- 16 Digital Inputs
- 16 Digital Outputs
- 72 Programmable Input/Output Lines

Custom cards are used for the WIM Mat and Slow Speed WIM (SSWIM).

SENSOR INTERFACE

The system must provide for at least the following sensor interfaces:

Sixteen (16) Analog Input Channels, capable of interfacing with a combination of up to 16 sensors as follows:

- Temperature Sensor (up to 2)
- Voltage Sensor (up to 1)
- Current Sensor (up to 1)
- Piezoelectric WIM Sensor (up to 16)
- Bending Plate™ WIM Sensors (up to 16)
- Single Load Cell WIM Scales (up to 16)

The custom cards used for the WIM Mats and Slow Speed WIM are capable of interfacing to up to two (2) Capacitive WIM Mats and one (1) Slow Speed WIM Scale.

16 Digital (Interrupt) Input channels capable of interfacing with a combination of up to 16 loops and axle sensors.
SENSOR INTERFACE con’t

16 Digital (Polled) Input channels capable of interfacing with a combination of up to 16 devices such as offscale detectors and overheight detectors.

16 Digital output channels for control of lights, cameras or other externally triggered devices.

32 additional Digital Input/Output channels for future applications.

Operating System:  
- MS-DOS 6.22 or later
- SCO UNIXWARE V2.1 or later

Software:  
- Diagnostics programs
- WIM operating programs
Appendix 2

IRD Single Load Cell WIM Scales Technical Specifications
TECHNICAL DETAILS

The IRD Single Load Cell Weigh-In-Motion (WIM) Scales are a highly accurate, load cell based in-motion scale designed for weighing at all speeds. Two 0.965 m x 1.83 m (3.17 ft x 6 ft) scales are used per lane giving a total weighing surface of 3.43 m x 0.660 m (11.25 ft x 2.17 ft). IRD Single Load Cell scales incorporate the following features:

- Each scale platform is a self-contained weighing unit, with the weighing element consisting of a Single Load Cell. The scale mechanism incorporates patented load transfer torque tubes which effectively transfer all loading on the weighing surface to the load cell, which is mounted centrally in the scale.

- Each scale incorporates a Single Load Cell located in the center of the weighing surface. The load cell is serviceable from the surface of the road, without the need for removal of the entire mechanism contained in the platform.

- Each scale incorporates a rubber seal around the edge of the weighing surface, effectively sealing all internal components of the scale from debris and moisture.

- "O"-ring seals located at the base of the scale platform seal the scale to the in-road frame, preventing any moisture from entering the load cell wiring compartment.

- "O"-ring seals at the top of the load cell cover complete the sealing of the scale to the road, making the IRD Single Load Cell Scale the only fully sealed scale design in the world.

- Each scale incorporates two offscale detectors at the outside edge of the weighing surface. This allows wheels that are potentially overhanging the weighing surface to be identified. The offscale detectors are field replaceable, and are based on IRD DYNAX® technology.

- The scales are mounted in frames which are installed in a 865 mm (34 in.) deep concrete vault, providing a solid foundation for long life, and a reliable installation.

- The scales and scale frames are grounded and protected from lightning using ground rods and lightning protection modules.

- All top surface mounting bolt and service holes are sealed with expansion plugs.
ACCURACY AND PERFORMANCE

IRD Single Load Cell Scales will typically provide the following performance in good installations based on the calibration procedure as noted:

<table>
<thead>
<tr>
<th>SPEED</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 10 mph</td>
<td>Single Axle +/- 2% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle +/- 1.5% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 1% of applied</td>
</tr>
<tr>
<td>11-25 mph</td>
<td>Single Axle +/- 4% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle +/- 3% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 2% of applied</td>
</tr>
<tr>
<td>25-45 mph</td>
<td>Single Axle +/- 5% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle +/- 4% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 3% of applied</td>
</tr>
<tr>
<td>46 + mph</td>
<td>Single Axle +/- 6% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle +/- 5% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 4% of applied</td>
</tr>
</tbody>
</table>

The above accuracy specifications are to be based on a minimum sample of 50 vehicles, loaded to within 75% of the legal allowable limit. Vehicles that traverse the scale with more than a 10% speed variation, live loads, or liquid loads shall not be considered. The accuracies will be based on a one standard deviation confidence level.

The above accuracies are contingent upon specific site conditions. The site conditions must, as a minimum, meet the roads specification identified in ASTM E1318-94.
GENERAL SPECIFICATIONS

The WIM Scales will be located in the traffic lane and shall consist of two in-line scale platforms per lane.

The WIM Scales must weigh both the left and right side of each axle simultaneously. Each scale will operate as an independent weighing unit, with the axle weight being obtained by summing of left and right weights by the WIM Electronics.

Each weighing surface will incorporate a single load cell, to provide increased accuracy. The load cell must be serviceable, with a replaceable pressure transducer. To minimize road closure time, the scale design should be such that the load cell can be removed from the scale without removal of the scale mechanism from the road surface. The load cell complete with the transducer should be sealed, and durable, with an operating temperature range of -45°C to 70°C (-50°F to +160°F).

The scale platforms must be placed in a metal frame installed in the road surface. The scale platforms must be of a totally sealed design to prevent intrusion by water, salt, dirt and other debris. The scale platforms must be anchored to the in-road frames, and must be flush with road surface so not to be damaged by road maintenance such as sweeping and snow removal.

Offscale detectors shall be integrated into the scale assembly to sense any vehicle off the weighing surface of the scales. The offscale detectors must be of a durable and robust design, and should be replaceable without removing the scale mechanism from the in-road frame.
Appendix 3

IRD Single Load Cell WIM System Technical Specifications
GENERAL

It is the intent of these specifications to describe the details and operation of a *Weigh-In-Motion (WIM) Data Collection System*. The system will utilize Single Load Cell technology. The scales must be site repairable, allowing for repairs and parts replacement in the field. The system will operate on a continuous basis, collecting data on axle weights, vehicle classification (based on the number and spacing of axles), and vehicle speed. The system must be accessible remotely using a standard telephone communication modem and personal computer for system monitoring, setup and data collection.

The successful vendor must show that they have been involved in the Weigh-In-Motion field for at least 5 years. The vendor must also provide a reference list of people who currently use the proposed equipment. The references should include the name of a contact person who can be interviewed as to the performance of equipment similar to that being proposed.

OPERATIONAL OVERVIEW

The system supplied must be a stand alone Data Collection System, which will be utilized to meet a portion of the Agency's traffic data collection needs. The system must operate reliably in all weather conditions. The system must utilize Single Load Cell scale platforms that are installed in the travelled lanes of the highway.

*The system should incorporate the following operational features:*

- The WIM data collection system should operate such that RAW data is collected for certain selected vehicle classifications. For vehicle classes not selected, tabular data will be stored showing the number of vehicles in each unselected class per lane. The RAW records and tables will be stored on a fixed on-site storage system in hourly files. The storage system must be nonvolatile (i.e., no data is lost in the event the system shuts down due to a low power state).

- The data collection system should allow at least 30 days of continuous RAW data storage with a four lane installation and must be capable of storing over 500,000 vehicle records. The data must be stored in a compressed format, to facilitate efficient data transfer.
The site data collection system must be accessible via a telephone modem communication link with an office computer. The user must be able to operate the WIM system remotely via this link, including data transfer and analysis. The system should contain at least 3 levels of password protection.

The system must contain a self (auto) calibration system which monitors both the effects of daily temperature effects, and long term seasonal pavement variations. The system should incorporate an expert system which continuously and automatically adjusts the calibration of the system to epitomise the weight accuracy based on user input parameters.

The system must allow the user to create or modify classification schemes based on the number and spacing of axles. The system should allow at least 24 vehicle types (classifications) to be defined. The system should be able to store up to 10 different classification schemes, and allow the user to select a particular classification scheme. The FHWA classification scheme "F" should be provided as default.

**SYSTEM REQUIREMENTS**

As a minimum, the data collection system must contain the following components:

a) Single Load Cell WIM Scales  
b) WIM Interface And Data Collection Computer  
c) Remote Communication Modem  
d) Operational Software

**a) Single Load Cell WIM Scales**

The WIM Scales will be located in the station access lanes and shall consist of two in-line scale platforms per lane.

The WIM Scales must weigh both the left and right side of each axle simultaneously. Each scale will operate as an independent weighing unit, with the axle weight being obtained by summing of left and right weights by the WIM Computer.

Each weighing surface will incorporate a single load cell, to provide increased accuracy. The load cell must be serviceable, with a replaceable pressure transducer. To minimize road closure time, the scale design should be such that the load cell and pressure transducer can be removed from the scale without removal of the scale mechanism from the road surface. The load cell complete with the transducer should be sealed, and durable, with an operating temperature range of -50°F to +160°F.
The scale platforms must be placed in a metal frame installed in the road surface. The scale platforms must be of a totally sealed design to prevent intrusion by water, salt, dirt and other debris. The scale platforms must be anchored to the in-road frames, and must be flush with road surface so not to be damaged by road maintenance such as sweeping and snow removal.

Offscale detectors shall be integrated into the scale assembly to sense any vehicle off the weighing surface of the scales. The offscale detectors must be of a durable and robust design, and should be replaceable without removing the scale mechanism from the in-road frame.

At least one inductive loop and one axle sensor shall be utilized with the Single Load Cell scale system in each lane. The loop shall be placed upstream of the WIM scale, such that vehicles travelling in the lane will pass over the loop before the scale. The axle sensor shall be installed downstream of the WIM Scale.

b) WIM Interface and Data Collection Computer

The electronics must be of modular and integrative design with the capability of multiple sensors (Single Load Cell scale, Single Load Cell, piezo WIM, and/or classification) interfacing and operating concurrently from the same electronics. This modularity shall be accomplished by the insertion of interface cards into a slot on the electronics system.

This modularity provides the system with the capability of sorting in the entry ramp, while at the same time weighing or classifying in the main lane(s) adjacent to the Weigh Station, without an additional computer processor package. The system will therefore, provide a means for diversion studies with only a minimal increase in sources.

The WIM interface and Data Collection Computer must be a stand alone system with the capability to collect and interpret the signals from the WIM Scale. The interface and data collection system must facilitate easy maintenance and in-field servicing. The electronics should contain the necessary interfaces for the scales, piezoelectric axle sensor, temperature sensor, and inductive loop. All electronic components must be adequately surge and lightning protected.

The WIM Computer must at a minimum be driven by an 80486SX microprocessor at a minimum speed of 25Mhz. Analog speeds must be sampled at a rate of at least 1,500 samples per second per analog channel. The WIM Computer must have a minimum of 1Mb of random access memory and all operating parameters must be stored in non-volatile memory.
The WIM electronics must be capable of collecting data from a minimum of six lanes of scales and sensors (4 lanes of weight and classification and 2 lanes of classification only). The system must include a data extraction system to allow data to be retrieved in the field. The system must be compatible with automatic vehicle identification (AVI) equipment, as specified by the Heavy Vehicle Electronic License Plate (HELP) project, including communications ports and software.

c) Remote Communication Modem

The system must contain a telephone communication modem. The modem should be at least 1200 bps and operate on a standard telephone communication service line. The modem will facilitate remote data collection and system monitoring of the data collection system. The modem must be compatible with the AT (HAYES) command set, and be auto answer.

d) Operating Software

The system must be supplied with operational software which includes software for data communication and data analysis. The supplied communication and analysis software must operate on any IBM or compatible personal computer (XT, AT, or PS2) under MS-DOS or OS/2 operating systems. The communication software must allow user friendly communication with the site system and feature autodialing, and user menus. The office analysis software must allow reports to be generated on collected raw vehicle record files. The software shall be similar in operation to the report generation feature on the site system.

The overall system operational software will interpret the signals from the WIM scale and sensors, and generate the vehicle record. The algorithm used to interpret the signals should directly compensate the determined weights based on vehicle speed.

**Raw vehicle records must include the following data:**

- Site Identification
- Time and Date of Passage
- Lane Number
- Vehicle Sequence Number
- Vehicle Speed
- Classification
- Weight of all Axles or Axle Groups
- Code for Invalid Measurement
- Optional Graphic Configuration
- Equivalent Single Axle Load (ESAL) value
While connected to the site system via a telephone link, the user should be able to perform as a minimum the following tasks:

- Real time vehicle viewing selectable by lane (with optional graphical output).
- Resetting of the system clock (including date).
- Monitor system memory in terms of storage remaining.
- Setup and initiate the generation of summary reports on data previously collected by the system.
- View generated summary reports.
- Generate and view error reports including time down, system access, auto-calibration and improperly completed records.
- Transfer selected raw data files or generated reports from the site system to the office host computer.
- Purge old data files from the system.

The real time viewing option should provide both graphical or tabular display formats as follows:

**Graphical Format**

NORMAL DISPLAY FORMAT WITH GRAPHICAL DISPLAY MODE (Metric):

4) LANE #1 TYPE 12 GVW 39.1 tonnes LENGTH 2284 cm
18-K ESAL 1.681 SPEED 104 kph Sat Jul 1 15:45:40 1989

```
<------------------- 21.3 ------------->
0   0   0   0   0   0   0
5.9 5.4 5.6 5.7 5.1 6.3 5.1
```

The length from axle to axle is shown on a linear scale with axle weights plotted below the scale line. The report operates in a scroll mode.

**Tabular Format**

NORMAL DISPLAY FORMAT WITH TEXT DISPLAY MODE (Metric):

4) LANE #1 TYPE 12 GVW 39.1 tonnes LENGTH 2284 cm
18-K ESAL 1.681 SPEED 104 kph Sat Jul 1 15:45:40 1989

<table>
<thead>
<tr>
<th>UNIT (cm)</th>
<th>SEPARATION WEIGHT (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5082</td>
</tr>
<tr>
<td>2</td>
<td>6325</td>
</tr>
<tr>
<td>3</td>
<td>5133</td>
</tr>
<tr>
<td>4</td>
<td>5713</td>
</tr>
<tr>
<td>5</td>
<td>5562</td>
</tr>
<tr>
<td>6</td>
<td>5408</td>
</tr>
<tr>
<td>7</td>
<td>5905</td>
</tr>
</tbody>
</table>
The system must be capable of generating output in the FHWA's TMG Card Format. The operator shall be provided with capability to define and generate a wide range of user-defined reports and tables.

The site system and the office computer running the office analysis software must be able to perform as a minimum the following report generation options:

Summary reports based on user input values of:

- Daily, Weekly, Monthly, or Continuous Summaries in hourly increments by:
  - Vehicle Speed (Minimum 16 User Defined Bins)
  - Classification (Minimum 24 User Defined Classes)
  - Equivalent Single Axle Load (ESAL) Value by table or formula
  - Daily, Weekly, Monthly, or Continuous Weight Summaries (both violating and non-violating) per vehicle class for:
    - Steering Axles
    - Single Axles
    - Tandem Axles
    - Tridem Axles
    - Quad Axles
    - Gross Vehicle Weights
    - ERROR Reports
    - Autocalibration Report
    - Site History Report
    - Calibration History Report

**ACCURACY AND CALIBRATION**

The Single Load Cell system must meet the following accuracy criteria:

<table>
<thead>
<tr>
<th>SPEED</th>
<th>ACCURACY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 10 mph</td>
<td>Single Axle  +/- 2% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle  +/- 1.5% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 1% of applied</td>
</tr>
<tr>
<td>11-25 mph</td>
<td>Single Axle  +/- 4% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle  +/- 3% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 2% of applied</td>
</tr>
<tr>
<td>26-45 mph</td>
<td>Single Axle  +/- 5% of applied</td>
</tr>
<tr>
<td></td>
<td>Tandem Axle  +/- 4% of applied</td>
</tr>
<tr>
<td></td>
<td>Gross Weight +/- 3% of applied</td>
</tr>
<tr>
<td>Speed</td>
<td>Axle Spacing</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------</td>
</tr>
<tr>
<td>46 + mph</td>
<td>+/- 6% of applied</td>
</tr>
<tr>
<td>Single Axle</td>
<td>+/- 5% of applied</td>
</tr>
<tr>
<td>Tandem Axle</td>
<td>+/- 4% of applied</td>
</tr>
<tr>
<td>Gross Weight</td>
<td>+/- 4% of applied</td>
</tr>
</tbody>
</table>

The above accuracy specifications are to be based on a minimum sample of 50 vehicles, loaded to within 75% of the legal allowable limit. Vehicles that traverse the scale with more than a 10% speed variation shall not be considered. The accuracies will be based on a one standard deviation confidence level. This assumes that the errors are normally distributed, and subsequently, 68% of all samples fall within the above quoted limits.

The above accuracies are contingent upon specific site conditions. The site conditions must as a minimum meet the following site specifications.

Weigh-In-Motion (WIM) systems are extremely sensitive to the conditions at a specific site. The WIM system performance can vary due to these site specific conditions. Some of the items that can be effected are:

- Accuracy of axle, axle group and gross vehicle weights.
- Accuracy of speed, axle spacing, and overall vehicle length.
- The ability of the system to accurately classify the vehicles passing over the site.
- The longevity of the in-road sensors, and the variation of sensor performance over the sensor life.

Note that the above mentioned items do not usually suffer in performance independently, and one item will effect others. For instance, the accurate determination of speed is vital, as speed is used in weight, axle spacing, and vehicle length calculations, which in turn enables the system to classify vehicles.

The site requirements can be broken into two classes, those dealing with the general site location, and those dealing with pavement conditions specific to a site. The following is a list of site conditions, and recommended limits for each item.

**OVERALL SITE LOCATION**

a) The WIM site should be located on a straight section of road, of uniform horizontal and vertical alignment. Sites located on curves, or on hills will not perform as well as sites on straight flat stretches. The travelled lanes should not have any superelevation, and the cross slope should be no more than 3% from the lane centre line to the lane shoulder (ideally, less than 2%). The horizontal elevation should not vary by more than 2% for 300 feet up and down stream of the sensors.
b) The WIM site should not be located immediately adjacent to areas where vehicles are changing speeds (accelerating, or decelerating). Areas to avoid are those within 1.5 miles of traffic control lights, or major intersection entrance or exit lanes. System performance will suffer if individual vehicles change speed by more than 1% over the site sensors.

c) For multiple lane systems where vehicles are being weighed in both travelled directions, the site should be selected where the median between the travelled ways is as short as possible. This distance should be less than 200 feet, and ideally less than 100 feet.

d) The site should be easily accessible for electrical power, and telephone services. Most WIM systems will require regular line service power, and remotely operated systems require telephone.

Pavement Conditions

All WIM sensors must be installed in either asphalt concrete, or portland cement concrete pavements. The pavements should ideally be relatively new and smooth. One of the major sources of variation in a WIM system is due to pavement roughness. Pavement conditions at the site should meet the following criteria

a) Asphalt concrete pavements should not be shoving, ravelling, heaving, spalling, or in a major distressed condition (ie: heavily fatigue cracked, or have severe compressional rutting). Portland concrete pavements should not have heaved or open joints.

b) The pavement structure should not exhibit excessive deflection during vehicle passage. The maximum deflection of the pavement using Benkelman Beam Deflection apparatus should be less than 0.030 inches.

c) A grid of the site should be established for an area of at least 145 feet before, and 80 feet after the sensor locations. The grid shall be at 3 foot intervals both longitudinally, and laterally (longitudinal meaning in the direction of vehicle travel, and lateral meaning perpendicular to vehicle travel). The following tolerances should be observed:

- Within 60 feet upstream, and 40 feet downstream of the sensors, the deviation (either lateral or longitudinal) over any 3 foot interval should be less that 3/16 inch. Over any 9 foot interval, the variation in the surface profile should be less than 3/8 inch.

- From 60 to 145 foot upstream, and 40 to 80 feet downstream of the sensors, the deviation (either lateral or longitudinal) over any 3 foot interval should be less that 1/4 inch. Over any 9 foot interval, the variation in the surface profile should be less than 9/16 inch.
Appendix 4

IRD AS-406 DYNAX® Sensor Technical Specifications
TECHNICAL DETAILS

The IRD DYNAX® Model AS406 system is an 8 foot long, 1 strip replaceable sensor system designed to hold one replaceable DYNAX® Model AS407 axle sensor per lane, to be employed for axle detection on a roadway regardless of vehicle speed. The AS407 sensor is installed into the Model AS406 installation frame. This system must incorporate the following features:

- The dimensions of the AS406 system shall be 25.4 mm (1 in.) thick, 2498.8 mm (98.375 in.) long, and 181 mm (7 1/6 in.) wide.

- The DYNAX® Model AS407 sensor must be an inverted “T” shape in cross-section. Its dimensions will be 20 mm (0.78 in.) high, 2476.5 mm (97.5 in.) long, 35 mm (1.375 in.) wide at the top and 48 mm (1.875 in.) wide at the bottom of the sensor. Machined ASTM A36/CSA C44W Steel clamp bars shall secure each sensor in place. These removable clamp bars shall be held in place with SAE Grade 8 centerlock nuts on B7 studs which shall be embedded into the roadway. This method will allow for rapid removal of the clamp bars when sensor replacement is necessary. The recessed nuts must be protected by expansion plugs.

- All DYNAX® sensors must be weatherproof and field replaceable. Each sensor must be constructed using Force Sensing Resistive (FSR) elements and sealed in black, UV-resistant polyurethane. The sensors must be very wear resistant with a minimum of Shore D hardness of 80.

- The sensor lead cable must consist of an 18 gauge, twisted, individually shielded, stranded and tinned copper pair wire with a polyethylene jacket and a length of 30 m (100 ft). The connection to the sensor element must be sealed during the molding process.

- A horizontal 3/4 in. NPT connection will be provided for routing the signal cable through from the sensors to the electrical box.

- The DYNAX® Model AS406 installation frame can be mounted in existing pavements (provided it exceeds 228.6 mm (9 in.) in thickness and has sufficient structural integrity). When mounting into existing pavements, the frame must be secured using chemical anchors. It shall be surrounded with high strength epoxy grout and supported with vertical epoxy anchors. Alternately, a shallow vault installation may be employed which will utilize concrete to provide the necessary support around the frame.
• The AS406 frame must be constructed from ASTM A36/CSA C44W Steel, then commercially sandblasted to SSPC-10. For corrosion protection, the frame shall be primed with zinc-rich paint and then top coated with black epoxy paint.

• The complete Model AS406 treadle system must be flush mounted to allow normal snow removal and road cleaning to be carried out, therefore no component of the system (i.e. frame, clamping bars, or sensor) will be elevated above the surface of the roadway.

• Multiple interface cards shall be available to connect the DYNAX@ Treadle System to a variety of electronics for different applications such as Toll Roads, Weigh-In-Motion, etc.

**ACCURACY AND PERFORMANCE**

• The DYNAX® Sensor must have a temperature operating range of -29°C to +71°C (-20°F to 160°F).

• The DYNAX® Sensor will typically achieve an operating life of 2 million axles or two years in 80% of all cases.

• To replace a DYNAX® Axle Sensor in a frame, the MTTR (Mean Time To Repair) shall be 1/2 hour.

• The Treadle Frame shall have a MTBF of 15 years and a MTTR of 48 hours.

• The DYNAX® Interface shall have a MTBF of three (3) years and a MTTR of 1/2 hour.

• The IRD Treadle and Interface board, in a typical installation, shall have an accuracy of better than 99.9%.

• The IRD Treadle system must withstand the action of single axle loads of up to 30,000 Ib., provided the treadle is installed correctly and the roadway base has adequate strength to support this load.

** The MTTR values listed above assume that the appropriate equipment, parts, tools, and trained personnel are on site and available.
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