Weigh-Pad-Based Portable Weigh-In-Motion System

USER MANUAL

MINNESOTA DEPARTMENT OF TRANSPORTATION

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BOARD

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16. Abstract (Limit: 250 words)

Weigh-in-motion (WIM) systems provide traffic load information that is vital to pavement design and management. While installing and maintaining permanent WIM stations may be justified for Interstate and trunk highways with heavy traffic, they are cost-prohibitive for local roadways. But monitoring the volume of heavy truck traffic on rural roads is necessary to ensure the service lives of these roadways. Researchers have developed a low-cost, portable WIM (PWIM) system that can be used for short durations to collect WIM data on two-lane highways. The PWIM system includes durable weigh-pads that can withstand the forces of heavy truck traffic. When attached securely to the pavement surface, these sensors resist vibration and ensure accurate readings. A battery-operated controller allows the system to collect data for several days. This user manual provides road crews and field office staff with a simple and effective procedure for installing weigh-pads on rural roads.

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Weigh-Pad-Based Portable Weigh-in-Motion System User Manual

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Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADC	analog-to-digital converter
CSV	comma separated values (format)
EALF	equivalent axle load factor
ESAL	equivalent single axle load
GUI	graphical user interface
GVW	gross vehicle weight
PWIM	portable weigh-in-motion (system)
WIM	weigh-in-motion (system)

1 Introduction

Weigh-in-motion (WIM) systems provide traffic load information that is vital to pavement design and management. While installing and maintaining permanent WIM stations may be justified for Interstate and trunk highways with heavy traffic, they are cost-prohibitive for local roadways. But monitoring the volume of heavy truck traffic on rural roads is necessary to ensure the service lives of these roadways.

Researchers have developed a low-cost, portable WIM (PWIM) system that can be used for short durations to collect WIM data on two-lane highways. The PWIM system includes durable weigh-pads that can withstand the forces of heavy truck traffic. When attached securely to the pavement surface, these sensors resist vibration and ensure accurate readings. A battery-operated controller allows the system to collect data for several days.

This user manual provides road crews and field office staff with a simple and effective procedure for installing weigh-pads on rural roads. Section 2 describes the key components of a PWIM system: a pair of weigh-pads, a controller and system batteries. In Section 3, step-by-step instructions are given for installing the weigh-pads and controller on a two-lane highway. Included in these instructions are recommended tools and equipment needed for the installation. Procedures for programming the controller are given in Section 4 along with guidance for collecting data. Section 5 provides recommended procedures for calibrating the system while Section 6 offers additional information about the functionality of the PWIM controller, including details about some of the system settings and a brief discussion about the data files produced.

2 Components of a PWIM System

This section describes the two essential components of a PWIM system (as shown in Figure 1):

- A pair of weigh-pads (one for upstream and one for downstream traffic).
- A controller, which translates raw load signals to WIM data.

Figure 1: Components of a PWIM System: A Pair of Weigh-Pads and the PWIM Controller

2.1 Weigh-Pads

The weigh-pads in this system are two Roadtrax BL (Brass Linguini) Class-1 piezoelectric axle sensors (referred to as BL sensors in this manual), manufactured by Measurement Specialties, Inc. These sensors are embedded within a flat rubber material that is used in industrial conveyer belts. Each weigh-pad is 1 foot wide by 24 feet long and covers two lanes of a highway.

To accommodate the temperature sensitivity of these sensors, researchers developed a special charge amplifier in the controller. This circuit removes thermally generated charge signals by detecting a slowly changing rate in charge signals. In general, pavement temperatures change slowly (a few degrees in several minutes), while axle signals change rapidly (a few milliseconds).

2.2 Controller

The PWIM system controller is a battery-operated, Windows-embedded PC OS (XP or 7) that is equipped with an SVGA LCD monitor (800 x 600 pixels). An easy-to-use graphical user interface (GUI) was developed to operate the PWIM system using this monitor.

The controller has four ports to connect to the two weigh-pads: an upstream and a downstream connection for each lane.

The PWIM system also includes a thermocouple that records pavement temperature data. This temperature data may be used for calibration if further temperature compensation is needed.

2.2.1 PWIM System Batteries

The PWIM system has an internal battery stored within the controller and an external battery pack to extend system operation. When fully charged, the internal battery lasts about 45 hours; the external battery pack adds seven days to system operation.

The external battery pack (Figure 2) contains two 6-volt deep cycle AGM batteries (model PVX-2240T) in a well-insulated enclosure. The batteries are connected in series to produce 12 volts and hold a maximum capacity of 224 ampere-hours (for a combined total energy of 2,688 watt-hours).

> *Caution:* The battery pack weighs about 145 pounds. Always use caution when lifting it.

The cable supplied with the external battery pack has special military-type connectors that must be used to connect to the PWIM controller. Because the external battery pack was designed as “hot-swappable,” the power pack can be plugged in or unplugged without turning the PWIM system on or off.

2.2.2 Battery Storage

After using the PWIM system, both the internal battery and the external battery pack must be charged to a near fully charged state before storing. Storing batteries without charging them can significantly shortened the life of the batteries.

- **Internal battery:** The charger for the internal battery, located on the right side of the controller, is a trickle-down slow charger. Fully charging the internal battery can take a couple of days. Since this charger has an automatic charge controller, it will stop charging once the battery is fully charged, so plugging it in an AC outlet for several days will not damage the battery.
- **External battery pack:** The external battery pack requires a charger that is appropriate for a 12-volt deep cycle AGM battery. The Schumacher SE-70MA battery charger (Figure 2) that is supplied with the external battery pack is recommended.

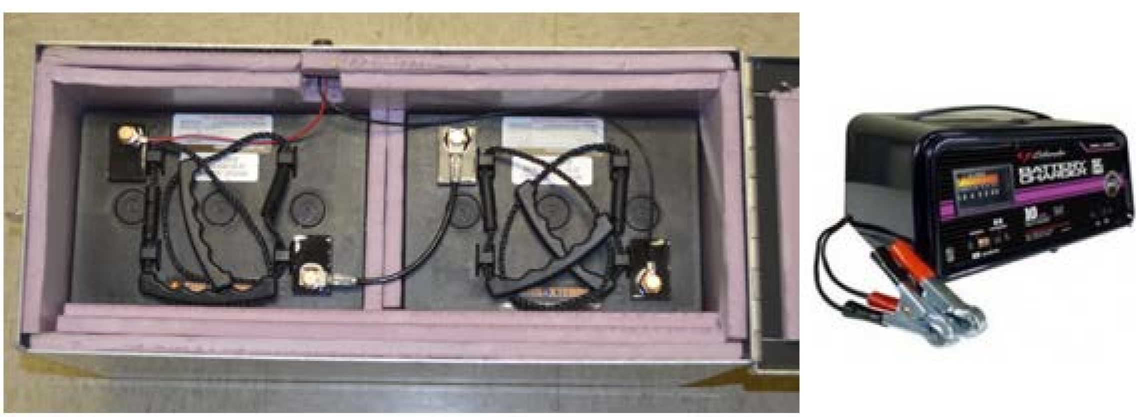

Figure 2: External Battery Pack and Battery Charger

3 Getting Started: Weigh-Pad and Controller Installation

Proper weigh-pad installation is key to collecting accurate, high-quality data with a PWIM system. Any movement in weigh-pad positions caused by weak attachment or vibration will not only decrease the accuracy of PWIM data, but will shorten the life of the weigh-pad and increase traffic safety risks.

This section provides the instructions for installing a PWIM system on a two-lane highway, including:

- Tools and equipment needed to install the weigh-pads.
- Instructions for installing the weigh-pads.
- Instructions for connecting the weigh-pads to the controller.

3.1 Tools and Equipment

Installing weigh-pads on bituminous pavement requires minimal tools and materials, all readily available online or at most hardware stores. These required tools and materials are listed below. (See Figure 3 for illustrations of some of these tools and materials.)

- Hammer drill and drill bits (¼ inch in diameter and 6 inches long).
- ¼-inch x 2¼-inch threshold sleeve anchor screws (ITW Red Head TH-1420, available at Home Depot; or ITW Red Head FS-1420, available online at amazon.com, $20 for 100 pieces).
- ¼-inch flat washer.
- Hammer.
- Screwdriver.
- Strong bonding utility tape (preferably black).
- Carpet tape or any double-sided tape (optional).

	Hammer drill and ¼" diameter , 6" long drill bits
	Strong bonding utility table - black color (black Gorilla tape was used)
	Sleeve Anchor, ¼ " diameter, 2-1/4" length (**ITW Red Head TH-1420 or ITW Red Head FS-1420**)
	¼" flat washer

Figure 3: Tools for Weigh-Pad Installation

3.2 Weigh-Pad Installation

Installing two 24-foot weigh-pads across a two-lane highway takes about 30 minutes (15 minutes for each lane). Removal is easier and takes about half of the installation time (Table 1).

Table 1: Weigh-Pad Installation and Removal Time

	Installation	**Removal**
Single lane (Two 12-ft weigh-pads)	15 minutes	7 minutes
Two lanes (Two 24-ft weigh-pads	30 minutes	14 minutes

Weigh-pad installation requires closing one lane of traffic at a time. Always exercise caution when working near traffic.

To install the weigh-pads:

1. Determine where the controller will be placed.
    - Weigh-pad installation will begin in the lane closest to the controller.
    - Placing the controller in a dry, stable area alongside this lane is recommended.
2. Begin flagging operations in the lane closest to the controller and close this lane of traffic.
3. Sweep the pavement area in the first lane where the weigh-pads will be placed.
4. Space the weigh-pads 15 feet apart.
5. Unroll one of the weigh-pads up to the centerline of the first lane (Figure 4).
    - To ensure a secure fit and avoid wrinkles in the weigh-pads, lay the sensor strip flat along the pavement surface, then stretch and pull the strips tight before installing the sleeve anchors.
    - *Optional:* To strengthen the bond between the weigh-pad and the pavement, attach carpet tape or any double-sided tape underneath the strip before installing the sleeve anchors.

Figure 4: Crew Installing a Weigh-Pad along Trunk Highway 53 in Cotton, Minnesota

6. Mark off every 2 feet along the weigh-pad.
   - Install sleeve anchor screws at approximately 2-foot intervals along each weigh-pad (24 sleeve anchors required to install a pair of weigh-pads).
   - To ensure the weigh-pad is fastened securely, use additional sleeve anchor screws at each end of the strip.
7. To install the sleeve anchor screws:
   a. At the first 2-foot mark, use a hammer drill to drill a ¼-inch diameter hole through the weigh-pad and pavement for a total depth of 2¼ inches.
   b. Insert a sleeve anchor screw and a ¼-inch washer through the hole in the weigh-pad, and place the anchor and washer in the drilled hole. Carefully tap the anchor in place using a hammer.
   c. Turn the sleeve anchor screw clockwise to expand the sleeve, which will fasten the pad to the pavement.
   d. Insert the remaining sleeve anchor screws every 2 feet along the length of each weigh-pad.
8. Once all the sleeve anchor screws are installed, tape the leading and trailing edges of the weigh-pad to the pavement using a strong bonding utility tape, such as a Gorilla tape (Figure 3).
   - Taping prevents the pad edges from lifting as a result of air drag or rolling resistance generated by wheels. It also reduces air trapping beneath the pads.

9. Repeat Steps 5 through 8 with the second weigh-pad in the first lane.
10. Close the second lane of traffic and reopen the first lane of traffic.
11. Sweep the pavement area in the second lane of traffic where the weigh-pads will be placed.
12. Unroll the first weigh-pad across the centerline and the second lane. Lay the sensor strip flat along the pavement surface, stretching and pulling it tight before installing the sleeve anchors.
13. Repeat Steps 6 through 8 for the first weigh-pad.
14. Unroll the second weigh-pad across the centerline and the second lane.
15. Repeat Steps 6 through 8 for the second weigh-pad.
16. Reopen the second lane of traffic.

Figure 5 shows a segment of a properly installed weigh-pad, with sleeve anchor screws spaced at 2-foot intervals and tape placed along both edges of the weigh-pad.

Figure 5: Segment of a Properly Installed Weigh-Pad

Figure 6 shows an improperly installed weigh-pad after one day of operation. This weigh-pad was not stretched and tightened before the sleeve anchor screws and tape were installed. As a result, wrinkles formed and the pad edges ripped out of the tape, creating a space between the pavement and weigh-pad.

Figure 6: Improperly Installed Weigh-Pad

3.3 Controller Installation

After the weigh-pads have been fastened to the pavement surface, they must be connected to the PWIM system controller. Inside each weigh-pad are two BL sensor strips connected to two coaxial cables that are terminated with BNC female connectors. The controller enclosure has four male BNC connectors—an upstream connection and a downstream connection for each lane:

- Lane 1 upstream.
- Lane 1 downstream.
- Lane 2 upstream.
- Lane 2 downstream.

To collect accurate data from the weigh-pads, the sensor location on the highway and the lane assignment in the controller must match. A typical two-lane configuration is shown in Figure 7. In this example, the controller is located on the left side of the diagram (not shown). The lane closest to the controller is labeled Lane 1; the other lane is labeled Lane 2. Upstream or downstream is determined based on the lane traffic direction.

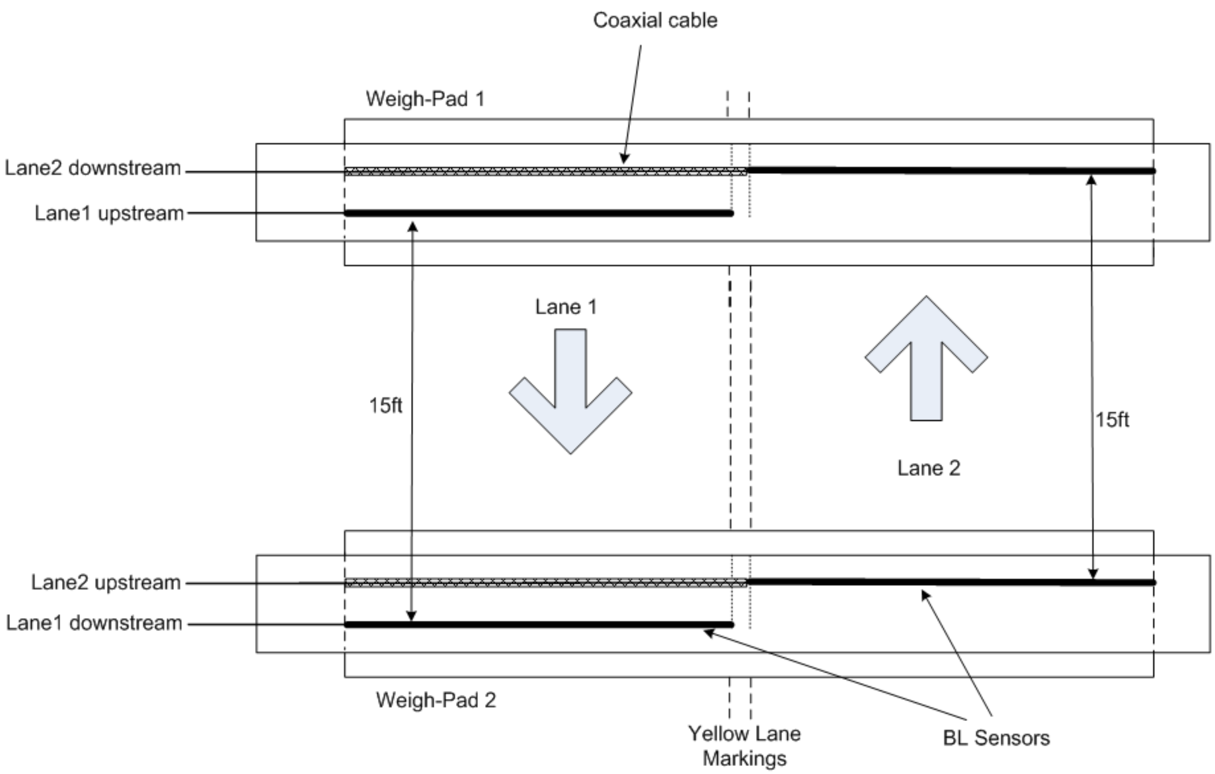

Figure 7: Weigh-Pad Location and Lane Assignment

To connect the weigh-pads to the controller:

1. Assign lane numbers for the PWIM system.
    - Lane 1 is the lane closest to the controller.

2. Choose the Lane 1 upstream cable and the Lane 1 downstream cable of the weigh-pads based on the direction of traffic flow (see Figure 7).
3. Connect the Lane 1 upstream cable of the weigh-pad to the Lane 1 upstream port in the controller.
4. Connect the Lane 1 downstream cable to the Lane 1 downstream port in the controller.
5. Connect the Lane 2 upstream cable to the Lane 2 upstream port in the controller.
6. Connect the Lane 2 downstream cable to the Lane 2 downstream port in the controller.

4 PWIM System Setup and Data Collection

This section provides step-by-step instructions for programming a PWIM system after installing the weigh-pads and controller. Before operation, the following functions must be programmed (available from the **Settings** drop-down menu of the **Bulldog WeighPad** screen):

- Site ID and lane setup.
- Axle sensor spacing setup.
- Parameter limits.
- Initial speed setup.
- Lane speed reference setup.
- Calibration setup.
- Signal threshold setup.
- Data collection.

In addition to these settings, a calibration is required, which is described in Section 5.

All setup parameters must be saved before closing the setup screen. All parameters related to real-time computation, such as calibration factors, equivalent single axle load (ESAL) setup, limit parameters and speed reference, are activated from the **Activate Settings** item in the **Settings** drop-down menu (Figure 8). However, this command cannot activate the parameters in the **Site Setup** screen. Alternatively, restarting the PWIM program will activate all parameters, including the parameters in the **Site Setup** screen. To restart the PWIM program, select **Restart** from the **File** drop-down menu.

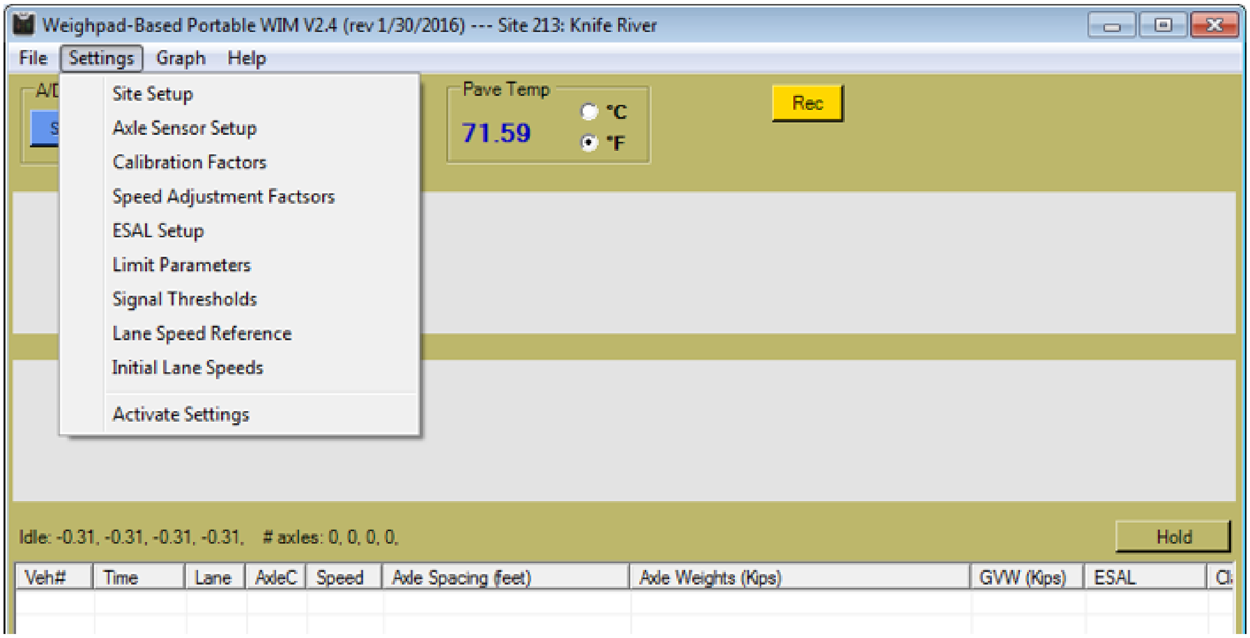

Figure 8: Settings Drop-Down Menu

4.1 Step 1: Power-On Sequence

To start the controller:

1. Turn on the master switch.
2. Press the PC reset switch using a wooden stick.
    - Because this system uses a USB monitor, the boot process takes longer (approximately 1 minute, 40 seconds for Windows 7). The PWIM program is loaded in 13 seconds.

4.2 Step 2: PWIM Controller Program Startup

After the PWIM program has loaded, three icons appear on the controller desktop screen: **weighpad WIM, keepAlive** and **Wpad-Plot** (Figure 9).

Weighpad WIM is the main program that runs the PWIM controller; **keepAlive** and **Wpad-Plot** are utility programs. This section provides information about the **weighpad WIM** and **keepAlive** programs; more information about the **Wpad-Plot** utility is provided in Section 6.1.

To start the PWIM controller program:

1. Double-click on the **weighpad WIM** icon or the **keepAlive** icon. If the **weighpad WIM** program does not automatically start, double-click on the **keepAlive** icon.
    - Running the **keepAlive** program is more reliable since it monitors and starts the **weighpad WIM** program. Every 30 seconds, the **keepAlive** program automatically checks whether the **weighpad WIM** program is running. It also restarts the **weighpad WIM** program if it is accidentally ended.
    - The **weighpad WIM** executable file is located in the following drive:

C:\WIM_development\WeighPad-V2.2\WIMdata\weighpadWim.exe.

Figure 9: PWIM Controller Icons: weighpad WIM, keepAlive and Wpad-Plot

4.3 Step 3: Site ID and Lane Setup

All settings in the **Site Setup** screen are required for system startup and must be set before data collection can begin.

Note: Only the **Site ID**, **Location**, **Lane Direction** and **Arrow Display** must be set. The **Vehicle Classification Definition File** and **WIM Root Data Folder** locations will already be set to their proper locations when the PWIM system is delivered.

To start the PWIM controller program:

1. From the **Settings** drop-down menu on the **Bulldog WeighPad** screen (Figure 8), select **Site Setup**.
2. From the **Site Setup** screen (Figure 10), enter the site's three-digit number in **ID**.
    - PWIM data filenames consist of the date and site ID. The site ID is critical because it determines the data directory and filenames of PWIM data.
    - The data directory for the site shown in Figure 10 is created in C:\WIM_development\WeighPad-V2.2.\WIMdata\Site_213\. Since the Site ID is 213, all data files are named "yyyymmdd.213.csv," where yyyymmdd is an eight-digit year/month/day text string.

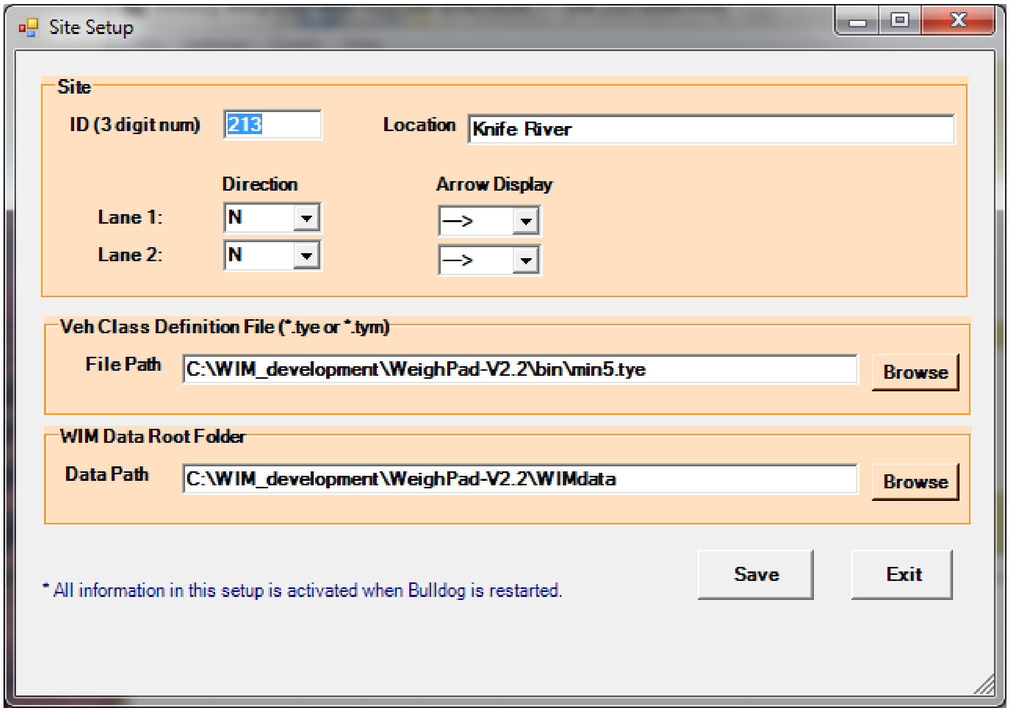

Figure 10: Site Setup Screen

3. Enter the location name in **Location**.
    - The location name can be any text, including numbers and symbols, that describes the site. It will appear in the heading of the PWIM controller screen.

4. From the list below **Direction**, select the lane direction corresponding to the physical lane direction of Lane 1 and Lane 2.
5. From the list below **Arrow Display**, select the arrow that matches the direction of traffic flow for each lane.
    - In Figure 10, both lanes (driving and passing) are in the north direction, and the arrow displays point to right, thus the PWIM controller is located on the east side of the road.
    - The lane and arrow display determine the lane direction and traffic flow direction, respectively, displayed in the corresponding vehicle display model (i.e., vehShow control). It only affects the screen display and does not affect the vehicle records saved.
6. In **Veh** C**lass Definition File**, use **Browse** to navigate the files and select a class definition file.
    - The PWIM controller uses the same vehicle classification algorithm and software components as the BullConverter or BullReporter [1] program, which requires a class definition file.
    - The system accepts either a metric (.tym) or English (.tye) unit definition file.
7. In **WIM Data Root Folder**, use **Browse** to navigate the folders and select a valid root directory for collecting and storing WIM data.
    - Data files are stored in a subdirectory named Site**_###**, where ### is the three-digit site ID.
    - The date directory is created in "yyyymmdd" format and stores the data files in that directory.
    - The user is only responsible for setting the root folder for the WIM data. The site and date directories are automatically created by the PWIM controller program.
8. Click **Save** to save all entries.
    - If **Exit** is clicked without saving, all new entries entered will be lost.
9. Click **Exit** to return to the PWIM main screen.
10. Activate the new settings by selecting **Restart** from the **File** drop-down menu.

4.4 Step 4: Axle Sensor Spacing Setup

To compute vehicle speeds, the distance between the upstream and downstream weigh-pads must be known. These values affect speed, axle spacing and weight computations.

Sensor-to-sensor distance values can be set using both feet and/or inches, but the final value is always converted and stored in feet, and the inch entry is left 0. The inch entry is only provided for convenience to convert inches to feet in the field. For example:

- If 14.2 is entered in the **feet** box and 6 in the **inch** box of the **Axle Sensor Setup Parameters screen**, the system will translate the values as 14.7 feet internally. The next time the information is displayed, the values will be 14.7 in the **feet** box and 0 in the **inch** box.
- If 0 is entered in the **feet** box and 176.4 in the **inch** box, the next time the information is displayed, the values will be 14.7 in the **feet** box and 0 in the **inch** box.

To enter the sensor-to-sensor distance values:

1. From the **Settings** drop-down menu, select **Axle Sensor Setup** to access the **Axle Sensor Setup Parameters** screen (Figure 11).
2. In **Axle Sensor Spacings**, enter the distance between the weigh-pads (in feet and inches) for each lane.
    - The recommended distance between the upstream and downstream weigh-pads is 15 feet, as shown in Figure 11.
    - For accurate data collection, the feet and inch values must match the actual distance between the weigh-pads.
3. In **WIM Sensor Sensitivity**, use the default settings for the upstream and downstream values of both lanes.
    - The sensor manufacturer supplies the sensor sensitivity settings.
    - The default sensitivity value of BL sensors used in the PWIM system is 6.25 (as shown in Figure 11).
4. Select one of the items under **Thermocouple Type**.
    - The PWIM system currently supports Type J and Type K thermocouples.
5. Click **Save Changes** to save the new entries.
6. Click **Exit** to return to the PWIM main screen.
7. Activate the new settings by selecting **Restart** in the **File** drop-down menu or **Activate Settings** in the **Settings** drop-down menu.

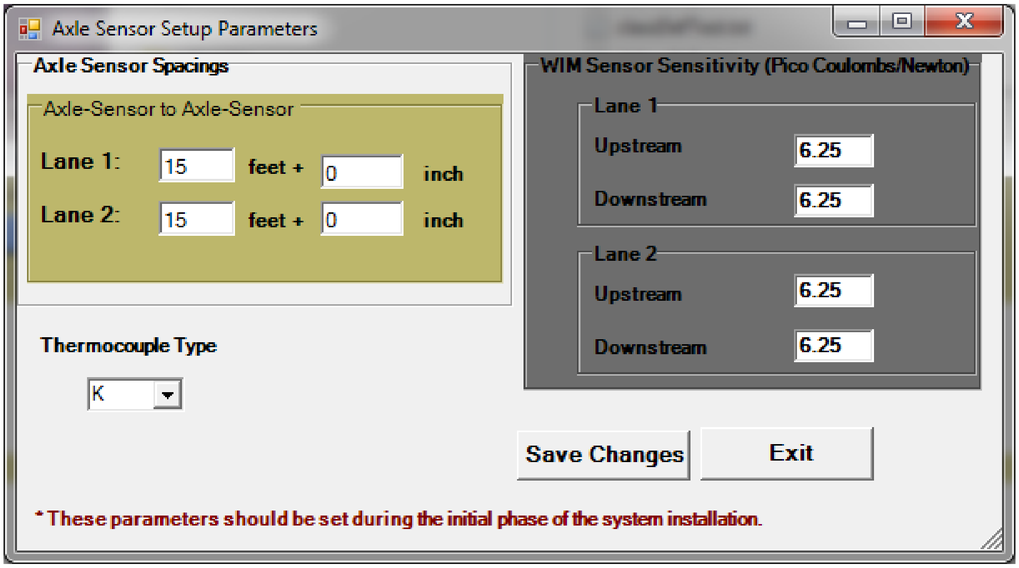

Figure 11: Axle Sensor Setup Parameters Screen

4.5 Step 5: Parameter Limits

Only two parameters in this screen should be adjusted according to the local traffic speed range:

- **Low possible speed on this road**.
- **High possible speed on this road**.

Use the default settings for the remaining limit parameters or modify them if local conditions demand. For more information about these limit parameters, see Section 6.2.4.

To enter the low and high speed parameters:

1. From the **Settings** drop-down menu (Figure 8), select **Limit Parameters** to access the **Parameter Limits** screen (Figure 12).

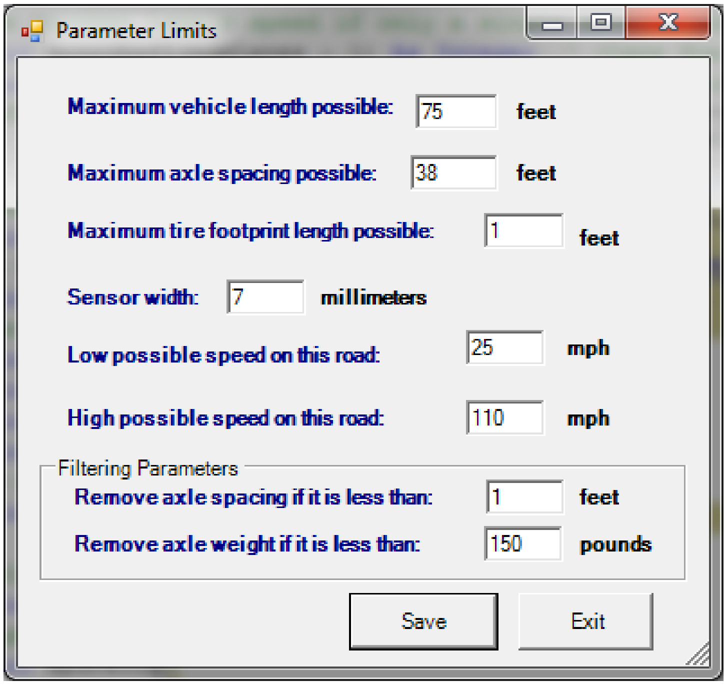

Figure 12: Parameter Limits Screen

2. In **Low possible speed on this road**, enter the low speed limit value of the highway.
    - This value is used to compute a potential maximum time spacing between the upstream and downstream axle signals or channel-to-channel axle signals. Channel-to-channel axle spacing is limited by the low possible speed of the road. If this spacing is larger than the low limit set, it indicates that the two axles are not from the same vehicle.
    - This value should never be set to 0 mph. A 0 mph setting will lead to a channel-to-channel axle spacing limit of infinity. It would take an infinite amount of time for a low-speed vehicle to cross two axle sensors.
3. In **High possible speed on this road**, enter the high speed limit value.
    - This value is used to compute a potential minimum time spacing between the upstream and downstream axle signals or channel-to-channel axle signals. If any channel-to-channel axle spacing is less than this limit value, the axle signal is potentially a false axle signal, which may be filtered out if it meets another filtering condition.
4. Click **Save** to save the new entries.
5. Click **Exit** to return to the PWIM main screen.
6. Activate the new settings by selecting **Restart** in the **File** drop-down menu or **Activate Settings** in the **Settings** drop-down menu.

4.6 Step 6: Initial Speed Setup

Initial speed estimates are used to compute initial vehicle spacing, that is, the distance from the rear axle of the first vehicle to the front axle (steer axle) of the second vehicle. Once the real speed is computed for the first vehicle, the PWIM system maintains a moving average of traffic speed, and initial speed is no longer used. While the initial speed value is not critical, it should be set using a typical or average traffic speed of the lane at the time of program start.

To enter the initial speed values:

1. From the **Settings** drop-down menu, select **Initial Lane Speeds** to access the **Initial Speed Setup** screen (Figure 13).

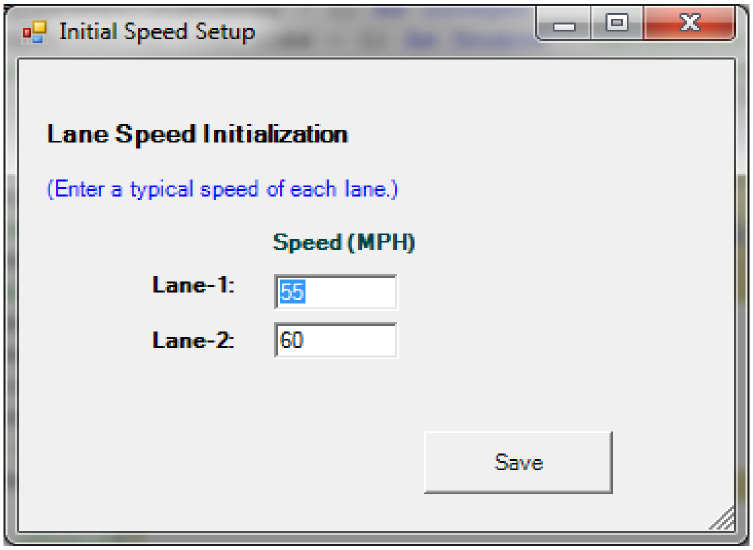

Figure 13: Initial Speed Setup Screen

2. Enter the typical speed for Lane 1 and Lane 2.
3. Click **Save** to save all entries.

4.7 Step 7: Lane Speed Reference Setup

Vehicle speed is computed using the activation timing of two weigh-pads per lane. Since the distance between the two weigh-pads is known, the time difference of activations gives the speed information.

If one of the weigh-pads fails and does not produce any axle signals, the speed cannot be computed and the weights and axle spacing cannot be determined. Losing one axle signal can occur even if the two sensors are working perfectly. For example:

- If a vehicle changes lanes after passing the first sensor, the second sensor is not activated.
- If the threshold level of one sensor is set too high, only the other sensor will produce axle signals.

To resolve these conditions, adjacent lane speed is calibrated. In Figure 14, Lane 2 is the passing lane and its traffic is 5 percent faster than Lane 1. If one of the Lane 1 weigh-pads fails, the Lane 2 speed is used but is decreased by 5 percent. If one of the Lane 2 weigh-pads fails, the Lane 1 speed is used but is increased by 5 percent.

Any weigh-pad failure is a serious error and reported in the vehicle record data, but the axle spacing and weights are still computed using the neighboring (reference) lane speed. If the weigh-pad of the neighboring lane also fails, vehicle record data is no longer computed and the "both axle failure" error is reported.

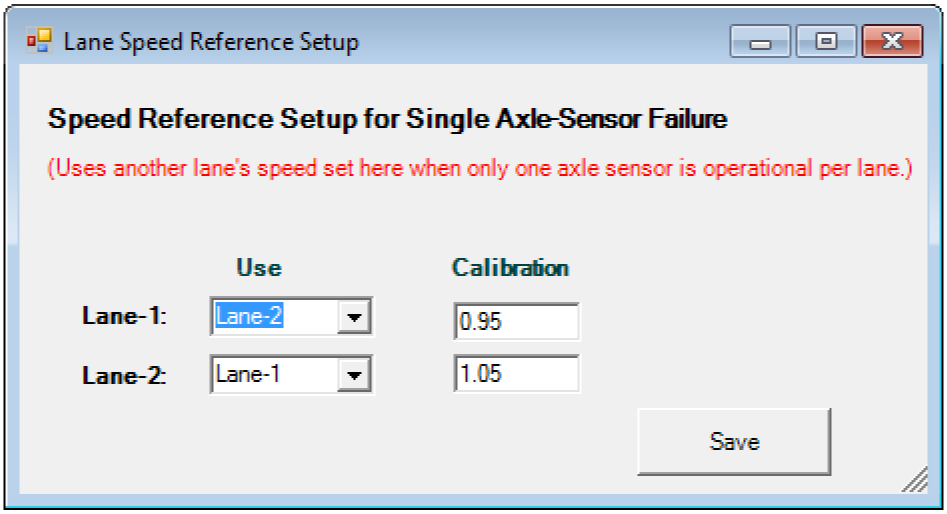

Figure 14: Lane Speed Reference Setup Screen

To enter the lane speed calibration values:

1. From the **Settings** drop-down menu, select **Lane Speed Reference** to access the **Lane Speed Reference Setup** screen (Figure 14).
2. Select the reference lane to use for Lane 1 and Lane 2 under **Use**.
3. Enter the calibration values for Lane 1 and Lane 2.
    - If the traffic in the two lanes is in opposite directions, the calibration should be 1.00 for both lanes.
4. Click **Save** to save all entries.
5. Activate the new settings by selecting **Restart** from the **File** drop-down menu or **Activate Settings** from the **Settings** drop-down menu.

4.8 Step 8: Calibration Setup

The theoretical calibration factor of the PWIM system is 0.6. However, environmental conditions such as pavement roughness, slope and weigh-pad tightness to the pavement may require that the calibration factor be adjusted. If a vehicle with a known static weight is available, calibration can be easily performed and can increase the measurement accuracy.

- **If a calibration vehicle (a vehicle with a known weight) is available**, use the calibration procedure described in Section 5 to obtain the calibration factors.
- **If a calibration vehicle is not available**, use the theoretical calibration factor (0.6).

To enter the calibration factors:

1. From the **Settings** drop-down menu, select **Calibration Factors** to access the **Calibration Factors** screen (Figure 15).

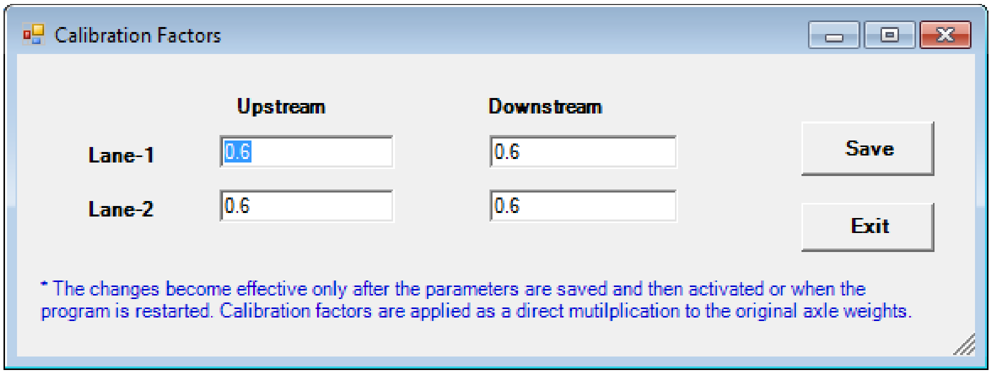

Figure 15: Calibration Factors Screen

2. Enter the calibration factors for Lane 1 and Lane 2.
    - Each lane should have the same calibration factors for both upstream and downstream if each sensor strip was not separately calibrated.
3. Click **Save** to save all entries.
4. Click **Exit** to return to the PWIM main screen.
5. Activate the new settings by selecting **Restart** from the **File** drop-down menu or **Activate Settings** from the **Settings** drop-down menu.

4.9 Step 9: Signal Threshold Setup

The signal threshold level of a channel determines the initial detection of an axle signal. (For more information about axle signals, see Section 6.2.5.)

To measure a signal threshold level:

1. From the **Graph** drop-down menu, select **Show Graph** to access the **frmGraphX** screen (Figure 16).

- This screen displays the actual signal voltages of the selected channels.
- The channels are selected as a pair — ch-0 and ch-1 or ch-2 and ch-3, which are the upstream and downstream sensor signals, respectively, of the selected lane.

2. Set the y-range by entering:
   a. -0.5 for y-min.
   b. 1.5 for y-max.
3. Click **Set** to save.
4. When a small passenger car signal is in the window, set the **Hold/Release** toggle switch to **Hold**.
   - It is important to capture a small passenger car as this vehicle's threshold is much lower.
5. Select a threshold level that is slightly lower than half of the smallest axle signal height.
   - Figure 16 shows two axle signals in which blue signals are from the upstream sensor and red signals are from the downstream sensor. In this example, 0.4 volt is a good value for both channels 0 and 1.

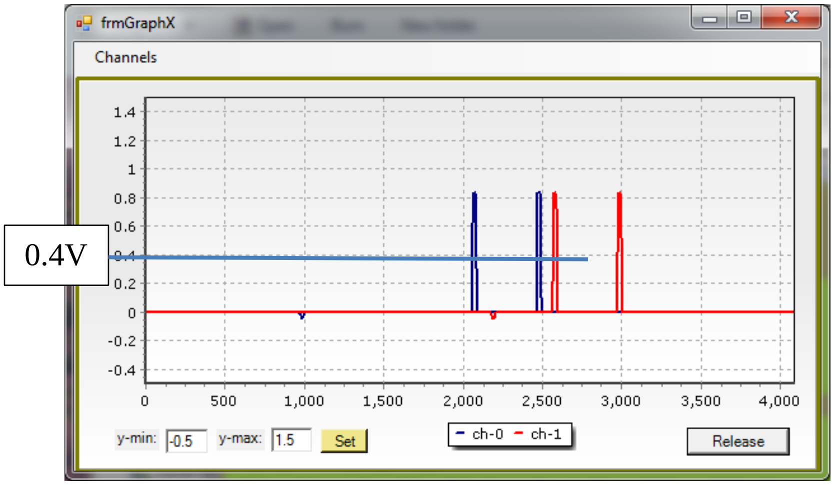

Figure 16: Signal Threshold Measurement Screen

To enter the measured signal thresholds:

1. From the **Settings** drop-down menu, select **Signal Thresholds** to access the **Axle Signal Threshold Setup** screen (Figure 17).

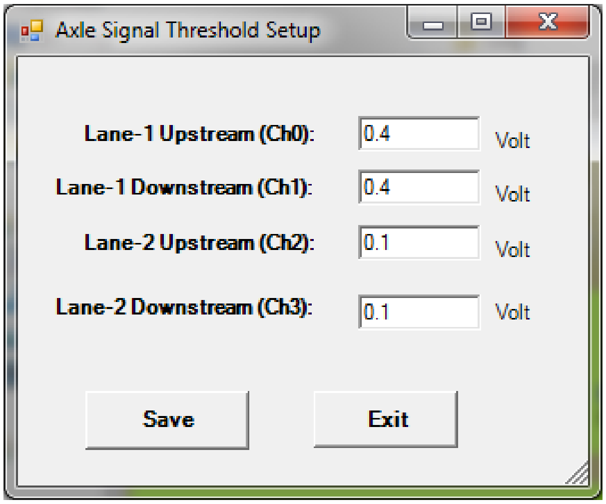

Figure 17: Axle Signal Threshold Setup Screen

2. Enter the measured threshold levels for Lane 1 and Lane 2 upstream and downstream.
    - Since signal conditions of each channel can be different, a different threshold value per channel may be required. What is important is reviewing each channel and observing axle signals.
    - In general, if the channel is not noisy, a reasonable threshold level would be in the range of 0.9 to 0.12 volt.
3. Click **Save** to save all entries.
4. Click **Exit** to return to the PWIM main screen.
5. Activate these settings by selecting **Restart** in the **File** drop-down menu.

4.10 Step 10: Data Collection

Data collection automatically begins when the **weighpad WIM** program is started and continues until the program is closed. No special user action is required for data collection.

- If the PWIM system is running properly, **Running** is displayed in the **Operation** status box and the **Count** value is constantly increasing (Figure 18).

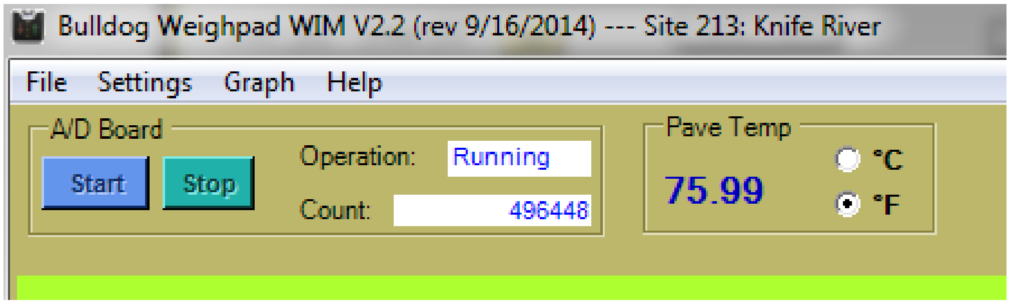

Figure 18: Running State Display

- If the **Count** value remains constant (such as 0), the controller must be reset.
    - If the A/D driver could not synchronize with the PC PCI bus, the **Count** value may stop functioning. This problem does not occur frequently but it is always resolved by a system reset.
- Collected data is stored in the folder created during site setup and can be downloaded using a USB flash drive (see Section 4.12).
- To save battery hours when the system is left unattended for continuous data collection, the LCD monitor should be turned off.

4.11 Step 11: Power-Off Sequence

At the end of the data collection period, turn off the system and return the unit to the field office.

To power off:

1. Exit the **keepAlive** program using **Windows Task Manager**.
    a. To access **Windows Task Manager**, press the Ctrl + Alt + Delete keys simultaneously. In the list of options that display, select **Start Task Manager**.
    b. In the **Windows Task Manager** screen (Figure 19), select **Keep-Alive Monitor** and then click on **End Task**.

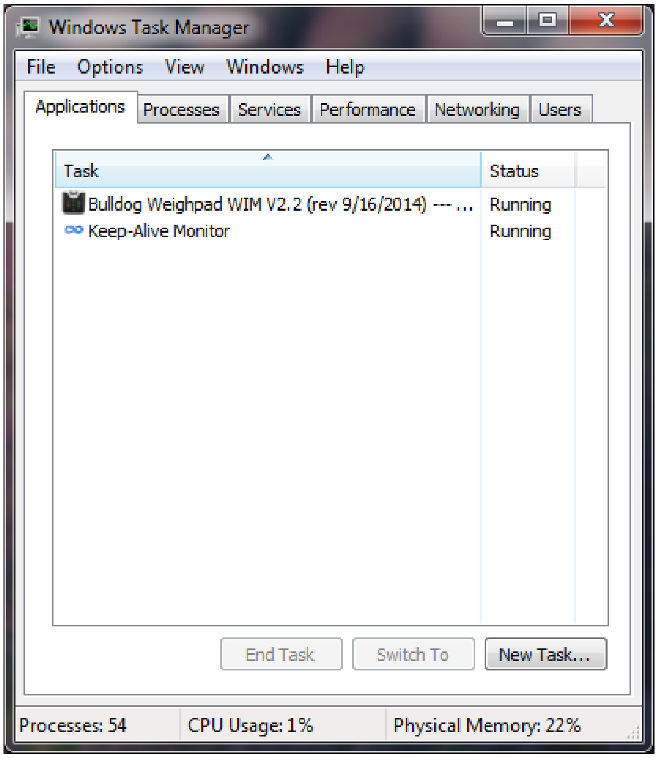

Figure 19: Windows Task Manager Screen

2. Close the **weighpad WIM** program by selecting **Exit** from the **File** drop-down menu.
3. To turn off the computer, press the reset button or use the Windows **Shut down** menu.
4. Turn off the master switch. (If this switch is not turned off, power will still be consumed by the standby mode.)

4.12 Step 12: Data Download

There are several ways to download the PWIM data collected during the monitoring process. However the recommended procedure is to download the data using one of the USB ports located below the LCD monitor in the controller.

Data files are located in the folder defined in the **Site Setup** screen under **WIM Data Root Folder** by the site ID. For example, data files for "siteID = ###" are located at:

C:\WIM_development\WeighPad-V2.0\WIMdata\Site_###\.

Inside each date directory, the actual data file is saved as a comma separated values (CSV) file, which is compatible with BullReporter or BullConverter.

5 Calibration

As described in Section 4.8, the theoretical calibration factor of PWIM is 0.6. However this theoretical value may need to be adjusted depending on environmental conditions, such as pavement roughness, slope or weigh-pad tightness to the pavement.

If a vehicle with a known static weight is available, calibration can be easily performed and can increase the measurement accuracy. This section describes a recommended calibration procedure.

5.1 Preparation

1. Use a vehicle with a known gross vehicle weight (GVW) to perform the PWIM calibration.
   - Use a static scale to measure GVW.
   - If possible, use a calibration vehicle whose weight is evenly distributed over all axles to minimize potential bouncing between the front and back axles or from left to right.
   - Use a heavier truck instead of a lightweight vehicle (such as a passenger car or a pickup truck) to limit sensor sensitivity.
     - The sensor sensitivity could be limited to 1 to 4 kips for a vehicle weight range of 5 to 80 kips. In an 80-kip vehicle, the variance would be 4 kips, which is only 5 percent of GVW. In a 5-kip truck, the variance would be 1 kip, which is 20 percent of GVW and would require more calibration runs.
2. Prepare a data sheet to record data from the calibration runs (see the sample data sheet in Figure 20).
3. Check the signal threshold level and basic parameters described in Section 4 before starting the calibration runs.
4. From the **Settings** drop-down menu, select **Calibration Factors** to access the **Calibration Factors** screen (Figure 21).
5. Set all calibration factors to 1.0.
6. Click **Save** to save all entries.
7. Click **Exit** to return to the PWIM main screen.
8. Activate the new settings by selecting **Restart** in the **File** drop-down menu.

Date and Time : ____________________________________

Site ID: _____________ **Location:**____

Direction: Lane 1_____ **Lane 2:** ______

Calibration Runs

Lane #	Vehicle Index	Gross Vehicle Weight	Lane #	Vehicle Index	Gross Vehicle Weight
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		
1			2		

Figure 20: Sample Calibration Run Recording Sheet

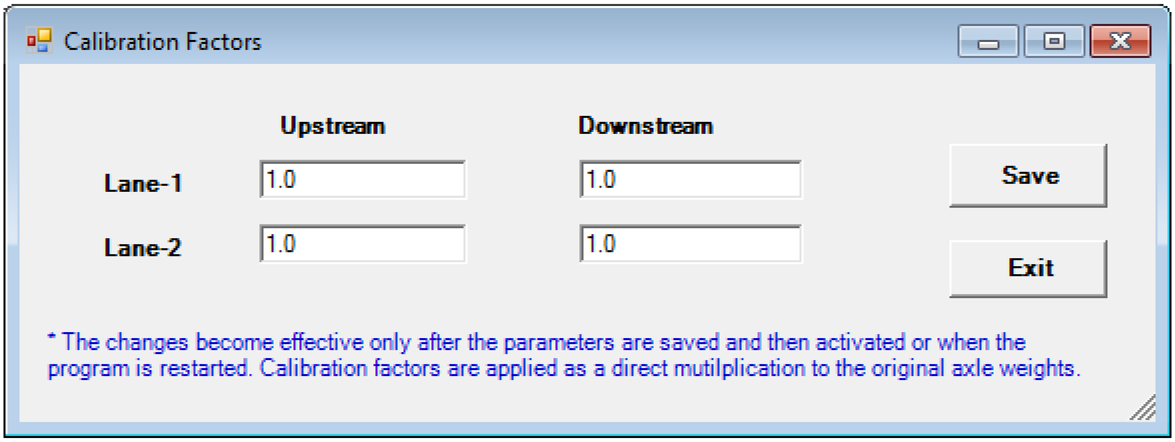

Figure 21: Calibration Factors Screen with Factors Set to 1.0

5.2 Calibration Runs

During the calibration runs:

1. Ensure the driver of the calibration vehicle maintains a constant speed in the middle of the lane when driving the vehicle over the sensors.
2. Conduct calibration runs for each lane, completing the recording sheet with vehicle index and GVW data for each run.
3. Once calibration run data are collected, average the measured weights, excluding the outliers.
4. Compute the calibration factor for each lane using the following formula:

   Calibration factor = (known GVW)/(average of calibration run GVWs)

   - The calibration factor for the upstream and downstream lanes is the same in the PWIM system.
5. Return to the **Calibration Factors** screen by selecting **Calibration Factors** in the **Settings** drop-down menu.
6. Enter the **Upstream** and **Downstream** calibration factors for Lane 1 and Lane 2.
   - Remember: The calibration factor for the upstream and downstream lanes should be the same.
7. Click **Save** to save all entries.
8. Click **Exit** to return to the PWIM main screen.
9. Activate the new settings by selecting **Restart** in the **File** drop-down menu or restart the PWIM controller program.

6 Details on System Operations

This section provides more information about the functionality of the PWIM controller, details about some of the system settings and a brief discussion about the data files produced by the PWIM system.

6.1 PWIM GUI and Tool Sets

The PWIM controller provides the following functions:

- Visual vehicle model.
- A table of WIM vehicle records.
- Real-time recording of axle-load signals.
- Plot utility for recorded binary analog-to-digital converter (ADC) channel signals.
- Real-time plot of raw axle-load signals.
- Real-time display of pavement temperature.
- A text reading tool for the WIM vehicle record data.

Visual modeling of a vehicle record was one of the key requirements of the PWIM GUI since a visual form can easily verify operations at the site (i.e., the vehicle model on the monitor can be visually compared with the actual vehicle on the roadway). The visual vehicle model in the PWIM GUI was designed as a .NET component (vehShow) in Windows programming. Properties of the model include axle weights and spacing, speed, classification, GVW, ESAL, time, error messages, lane number and direction, and vehicle identification number (which matches the vehicle record in the data file). An example of a visual vehicle model including this information is shown in Figure 22.

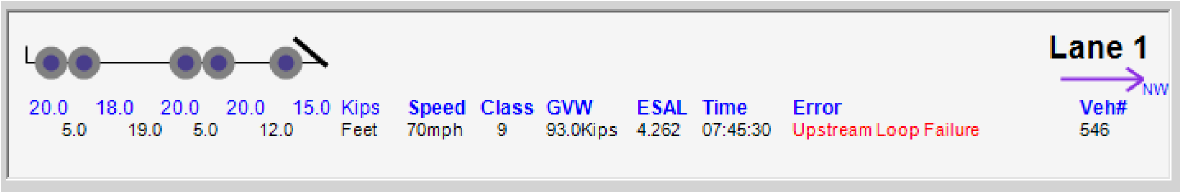

Figure 22: The vehShow Component Developed for the Visual Model of Vehicle Records

Figure 23 shows the entire PWIM GUI, including the visual vehicle model from Figure 22. In Figure 23, both lanes are set to northbound, with arrows indicating the traffic direction in reference to the controller location and the letter N at the tip of the arrow. If the arrow direction is changed, the vehicle model automatically changes its heading to match the arrow direction. Below the visual model is a table of vehicle records that is similar to the actual vehicle records stored in the WIM data file.

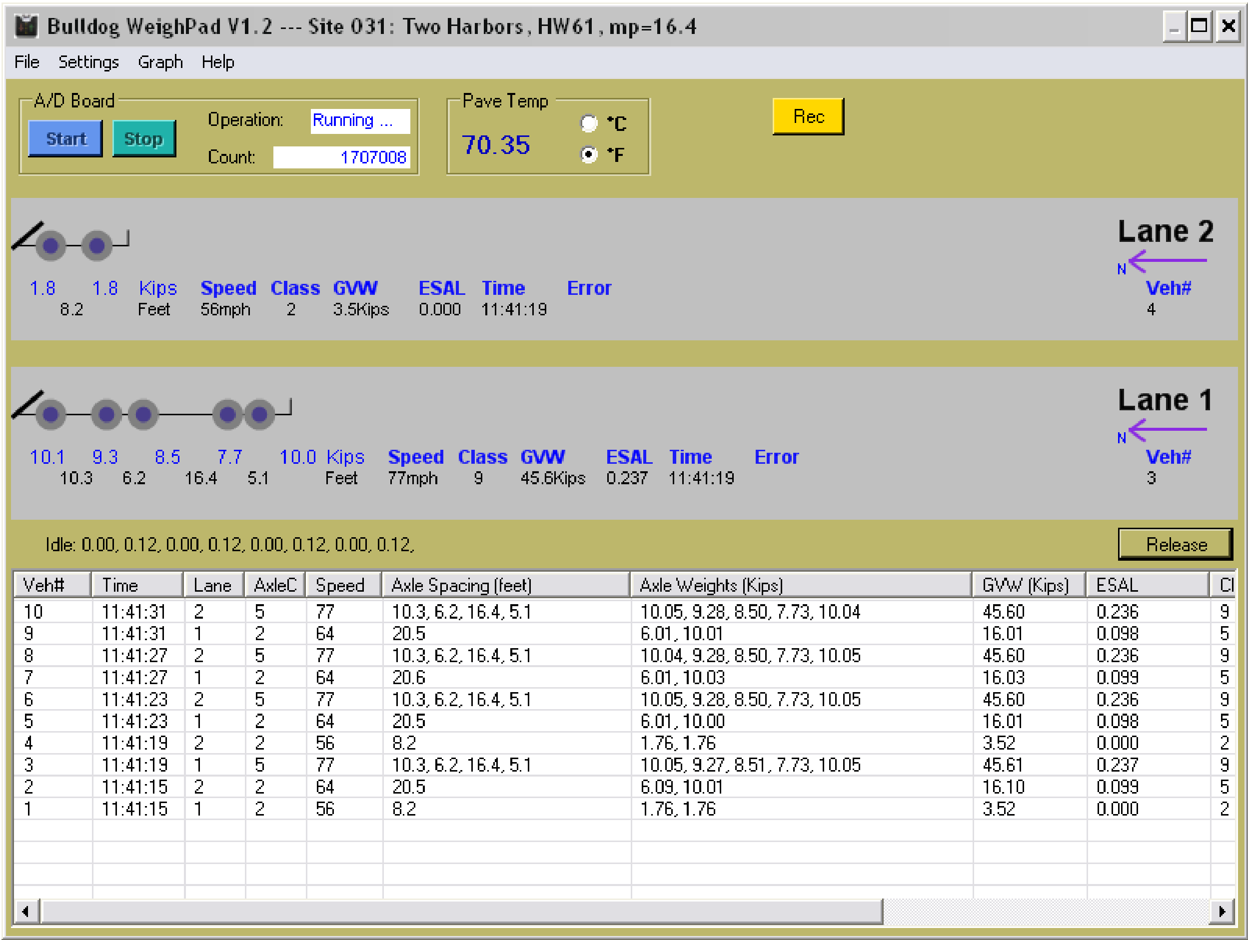

Figure 23: PWIM GUI Screen

Above the table of vehicle records in Figure 23 is a **Release/Hold** toggle switch, an importable tool for calibration because it allows a user to freeze the vehShow control, which gives the user enough time to copy the GVW value and the vehicle number of the sensor-crossing calibration vehicle. When the switch is set to **Hold**, the vehShow controls and the vehicle record table are immediately frozen, holding the display of the last vehicle record. (Note: Only the screen display is frozen; the actual vehicle records are continuously computed and saved in the data file.) When the switch is set to **Release**, the vehShow controls and vehicle record table return to routine operation, continuously updating new vehicle records.

At the top of the screen is a **Rec/Stop** toggle switch. When the switch is set to **Rec** (yellow), raw binary channel signals (ADC output) are recorded into a file. When the switch is set to **Stop** (red), the ADC output recording stops. The recorded raw data can be analyzed with WeighPad Plot (available from the icon **Wpad-Plot** on the controller desktop). This utility tool is useful for diagnosing signal problems such as pad vibration or abnormal signal idle levels. It allows the plot window to move forward or backward in the sample space as well as zoom in or out using various settings of Y-range and X-range values. A sample screen from the WeighPad Plot utility is shown in Figure 24. Data navigation settings are located in the lower right side of the screen.

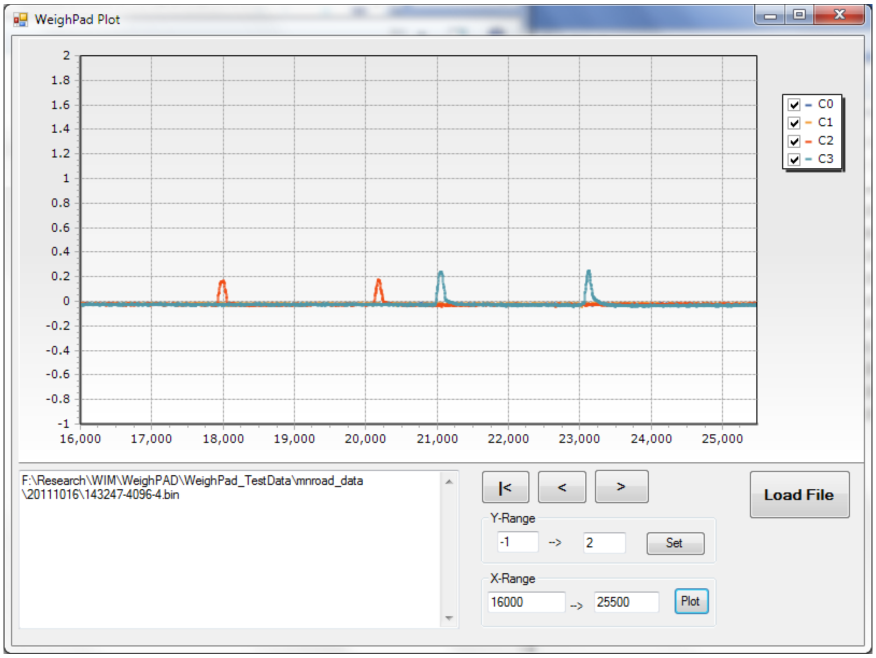

Figure 24: WeighPad Plot Utility Screen

The WeighPad main screen also displays pavement temperatures (either in Fahrenheit or Celsius). It accepts a Type J or Type K thermocouple, which is set from the **Axle Sensor Setup Parameters** screen (see Section 4.4). A thermocouple must be taped to the pavement and its lead must be plugged into the controller box to display the temperature. If the thermocouple is not connected properly to the system, “N/A” is displayed.

A real-time plot of axle load waveforms is very useful for diagnostics. This plot is accessible from the **Graph** drop-down menu. When **Show Graph** is selected, a plot window opens and real-time axle signals of a sensor pair (upstream and downstream channels) of the selected lane are plotted. A sample screen is shown in Figure 25.

Because the graph must plot signals in real time while computing all WIM values, only 256 samples per second out of 4,096 samples are plotted. Consequently, the plot appears blocky. It displays one lane at a time, and the lane can be selected using the **Channels** drop-down menu. This utility could be used to check the charge amp or ADC signals, and is essential for checking threshold levels and resting voltages of each channel. This screen also provides a **Release/Hold** function to freeze and release signal updates.

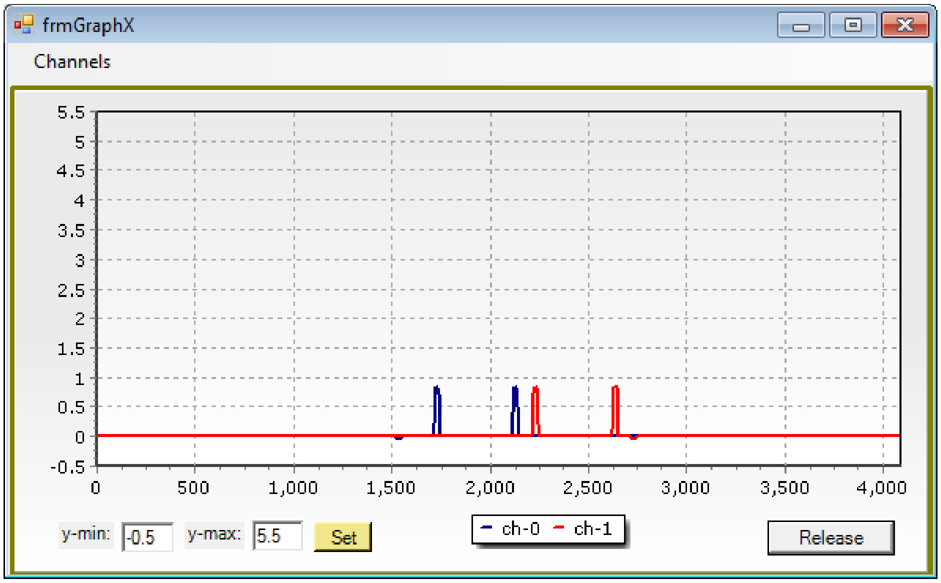

Figure 25: Real-Time Plot of ADC Channels

If a more detailed signal analysis is necessary, the user should record the raw data using the **Rec** function in the PWIM GUI and review the signals using the **Wpad-Plot** tool where the signals are displayed in the original resolution (i.e., 4,096 samples per second).

When **Help/Read data file** is selected, it is directed to the root data folder from which the user can select a WIM CSV file. It simply loads the WIM data file on Windows Notepad.

6.2 PWIM Settings

All settings required for initial PWIM system operation were introduced in Section 4. This section provides detailed information about the following settings:

- Calibration factors.
- Speed adjustment factors.
- ESAL parameter.
- Parameter limits.
- Axle signal threshold.

6.2.1 Calibration Factor Setup

Calibration factors are entered from the **Calibration Factors** screen (Figure 26). These values should be obtained using the calibration procedure described in Section 5.

Calibration factors are simply the final multiplied value to the raw weight obtained. For example, if a calibration factor was set to 0.3 and the raw weight obtained was 10 kips, the PWIM system would output 3 kips as the final weight.

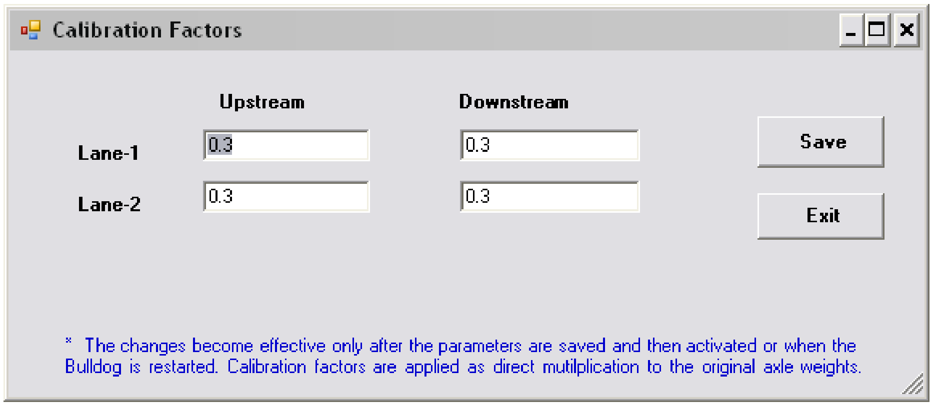

Figure 26: Calibration Factors Screen with Factors Set to 0.3

6.2.2 Speed Adjustment Factors Setup

Weights may be adjusted based on speed ranges. For example, if the system tends to overestimate weights at a high speed, it can be easily calibrated from the **Speed Adjustment Factors** screen in the **Settings** drop-down menu. Figure 27 shows a sample setting screen. Each entry in Figure 27 is the midpoint of the speed range from which the rest of the points are linearly interpolated. For example, in Lane 1 the 5 mph calibration factor is 1.3080 and the 15 mph calibration factor is 1.1366. If the speed is 10 mph, its calibration factor is internally computed as:

$$\text{Speed adjustment factor at 10 mph} = \{(1.1366 - 1.3080)/(15 - 5)\}*(10 - 5) + 1.3080$$

These adjustment factors were developed based on observations made after the initial PWIM development. When weigh-pads were not securely attached to the pavement, a higher horizontal force of a wheel was transmitted to the sensors at a higher speed instead of the theoretical zero horizontal force. The horizontal component of the wheel force is $f * cos(\theta)$ and its theoretical value is zero since θ is 90 degrees. But θ becomes less than 90 degrees when weigh-pad installation is poor, applying greater force to the sensor as speed increases, which is translated into a higher weight.

When weigh-pads are securely attached to the flat pavement (zero slope), axle weights are no longer a function of speed, and all of the weigh adjustment factors per speed should be set to 1.0.

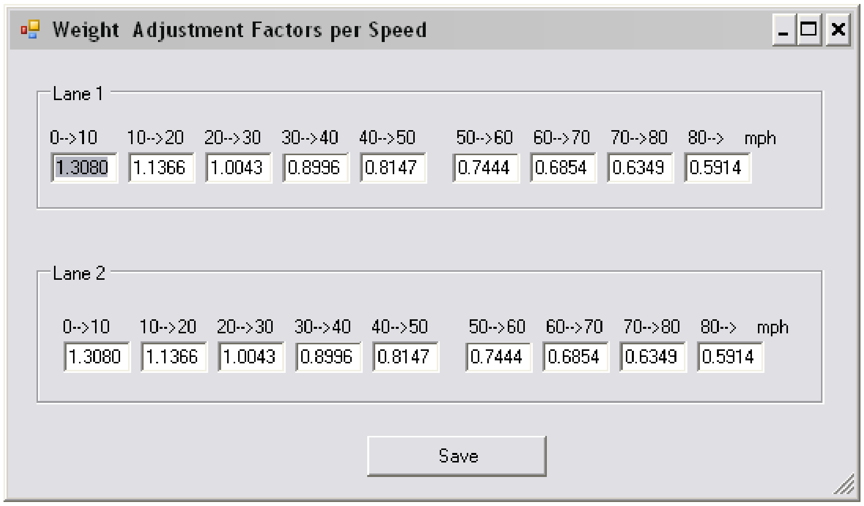

Figure 27: Weight Adjustment Factors per Speed Screen

6.2.3 ESAL Parameter Setup

An equivalent axle load factor (EALF) defines the damage per pass to the pavement by the axle relative to the damage per pass of a standard axle load (usually 18-kip single axle load). ESAL is computed by:

$$ESAL = \sum_{i=1}^{m} F_i n_i$$

where m is the number of axle load groups, F_i is the EALF for the ith-axle load group and n_i is the number of passes of the ith-axle load group during the design period [2].

The **ESAL Setup** screen (Figure 28) is accessed from the **Settings** drop-down menu. First, a pavement type, flexible or rigid, must be selected. For flexible pavements, structural number (*SN*), which is a function of thickness and modulus of each layer and the drainage conditions of base and subbase, and terminal serviceability (P_t), which indicates the pavement conditions to be considered as failures, must be supplied. The 2007 MnDOT Pavement Design Manual [3] recommends 5 for *SN* and 2.5 for P_t. For rigid pavements, slab thickness in inches (*D*) must be supplied along with P_t. MnDOT recommends 8 inches for *D* and 2.5 inches for P_t.

MnDOT generally uses the flexible ESAL numbers when evaluating pavements. ESAL factors for additional axle configurations as well as structural numbers, slab thicknesses and terminal serviceability values are available in Appendix D of the 1986 American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures [4].

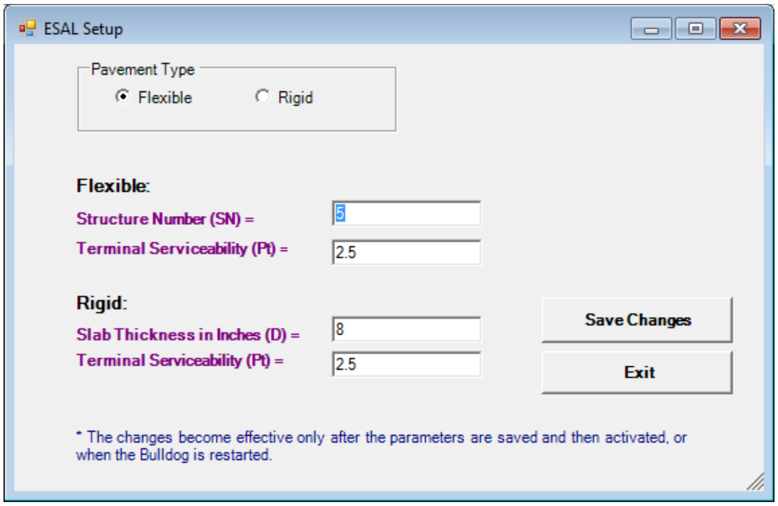

Figure 28: ESAL Setup Screen

6.2.4 Parameter Limits Setup

PWIM utilizes a number of user-supplied limit parameters for vehicle end detection and error filtering algorithms. These parameters are entered in the **Parameter Limits** screen (Figure 29), which can be accessed from the **Settings** drop-down menu.

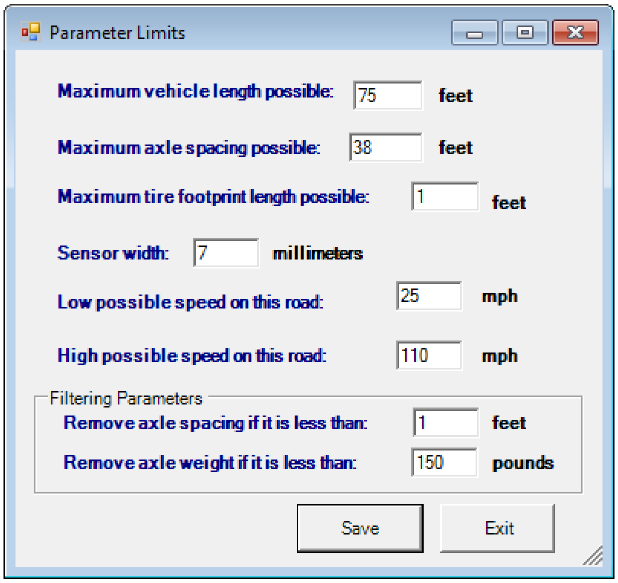

Figure 29: Parameter Limits Setup Screen

Maximum vehicle length possible is the maximum distance (in feet) between the steer and rear axle among the vehicles on the road. This value is used for vehicle end detection. In Figure 29, this value was set to 75. If axle signals are continuously showing up in a channel, the vehicle detection algorithm is forced to cut at the 75-foot limit and declares end of a vehicle using this value.

Maximum axle spacing possible is used when any axle spacing is longer than this value; then end of a vehicle is declared. In Figure 29, this value was set at 38 feet. If any axle spacing between two consecutive axle signals is greater than 38 feet, a vehicle end is declared.

Maximum tire footprint length possible determines the limit of the acceptable width of an axle signal. The width of an axle signal is determined by the tire footprint length and speed of the vehicle. If an axle signal exceeds this width limit, it is considered an error condition (i.e., erroneous axle signal).

Sensor width is used in computing axle weight. The values for BL sensors are 7 millimeters. If a new type of sensor with a different width is used, this value should be changed to the new width.

Low possible speed on this road is used to compute a potential maximum time spacing between the upstream and downstream axle signals of the same axle. If an upstream-to-downstream spacing is greater than the spacing computed by this limit, the two axles probably don't belong to the same vehicle, and an end of a vehicle is marked by the algorithm.

High possible speed on this road is used to compute a potential minimum time spacing between a pair of upstream and downstream axle (channel-to-channel) signals of the same axle. If any channel-to-channel signal spacing is less than this limit, the axle signal is potentially false and may be filtered out based on further reviews such as the existence of matching signals, meeting the minimum required weight and meeting the minimum axle spacing.

Remove axle spacing if it is less than is used to remove noise signals. If an axle-to-axle spacing is less than this limit, the trailing axle signal is likely a noise signal or a false axle, so it is filtered out. For example, no vehicle could have less than 1-foot axle spacing.

Remove axle weight if it is less than is used to remove noise signals. If an axle weight is less than this limit, it is likely a noise signal, so the axle signal is filtered out.

6.2.5 Axle Signal Threshold Setup

An axle signal is a Gaussian-shaped pulse consisting of a rising edge, an upper limit and a falling edge. An axle signal shape along with the axle signal segmentation procedure used in PWIM is illustrated in Figure 30.

The PWIM axle-detection algorithm first detects the rising edge when it crosses the preset threshold (1). From this point, the algorithm searches backward until it finds a valley of the curve and marks it as the start of the axle signal (2). It then moves forward and searches the falling edge threshold (3). From this threshold, it again searches forward for a valley and marks it as the end of the axle signal (4).

Because of this adaptive procedure, the threshold level does not have to be accurate to detect the beginning and end of the signal. However, it should be set somewhere above noise level and below the peak of the pulse.

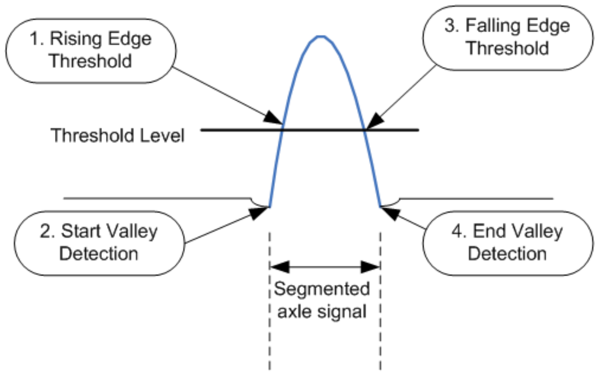

Figure 30: Axle Signal Segmentation Process

Axle signal thresholds are entered in the **Axle Signal Threshold Setup** screen (Figure 17), which is accessible from the **Settings** drop-down menu. (For information about threshold data entry, see Section 4.9.)

6.3 Data Format

The PWIM system produces text-based CSV files for WIM data. The filename consists of the date and site ID in the following format:

yyyymmdd.###.csv

where yyyymmdd is the year, month and day, and ### is the three-digit site ID.

The column format is summarized in Table 2. Columns 1 through 32 are identical to the BullConverter column format. Column 33, which is the pavement temperature, is available for the weigh-pad system and new Bulldog WIM systems. The CSV file is stored in the yyyymmdd date folder, which is a part of the site folder (Site_###) in the data root path defined in the **Site Setup** screen (Figure 10).

Table 2: PWIM CSV Column Format

Column Number	Column Name	Description
1	Index	Number of the vehicle record
2	Lane#	Lane number that the vehicle passed through
3	Time	Time (in hh:mm:ss, where hh is military hour)
4	AxleC	Number of axles on the vehicle
5	Speed	Speed of the vehicle (in mph)
6-16	Axle spacing (AS): AS1,…,AS11	Axle spacing (in feet); 11 fields separated by commas
17-28	Axle weights (AW): AW1,…,AW12	Axle weights (in kips); 12 fields separated by commas
29	GVW	Gross vehicle weight (in kips); the sum of each axle weight
30	Class	Vehicle class determined by the classification algorithm
31	Err#	Numeric code that represents an error (see Table 3)
32	100thSec	100^{th} second of the time in Column 3
33	pavTemp	Pavement temperature (in Fahrenheit)

Table 3: PWIM Error Codes

PWIM Error Number	Description
0	Normal, no error
1	Upstream loop failure (downstream loop only)
2	Downstream loop failure (upstream loop only)
3	Both upstream and downstream loop failure
4	Loop in wrong order
5	High/low idle level
6	Maximum number of axles exceeded (>12)
7	Zero axles detected (failure of both axle sensors)
8	Unequal axle counts (difference of upstream and downstream axle counts)
9	Zero axles on upstream (axle sensor error)
10	Axle sensors in wrong order
11	Axle spacing too short
12	Zero axles on downstream (axle sensor error)
13	Vehicle too slow (indicated by loop activation)
14	Processing error (buffer error, missed axle processing)
15	Invalid vehicle (contradictory sensor inputs received)
16	Axle on sensor too long (vehicle too slow or stop and go, causing measurement period time out)
17	Vehicle too fast (to obtain a measurement)
18	Loop bounce
19	Single axle vehicle detected
20	Unknown error (error code not translatable, unknown or undefined)

7 References

[1] Kwon, T. M. 2012. *BullConverter: User Manual*. University of Minnesota Duluth: Transportation Data Research Laboratory.

[2] Huang, Y. H. 2004. *Pavement Analysis and Design*, 2nd Edition, Upper Saddle River, N.J.: Pearson Prentice Hall.

[3] Minnesota Department of Transportation. 2007. *MnDOT Pavement Design Manual*. St. Paul, Minn.: Minnesota Department of Transportation.

[4] American Association of State Highway and Transportation Officials. 1986. *AASHTO Guide for Design of Pavement Structures*. Washington, D.C.: American Association of State Highway and Transportation Officials.

Additional Resources

Kwon, T. M. 2012. *Development of a Weigh-Pad-Based Portable Weigh-in-Motion System*. Final report. Mn/DOT 2012-38. St. Paul, Minn.: Minnesota Department of Transportation.