



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

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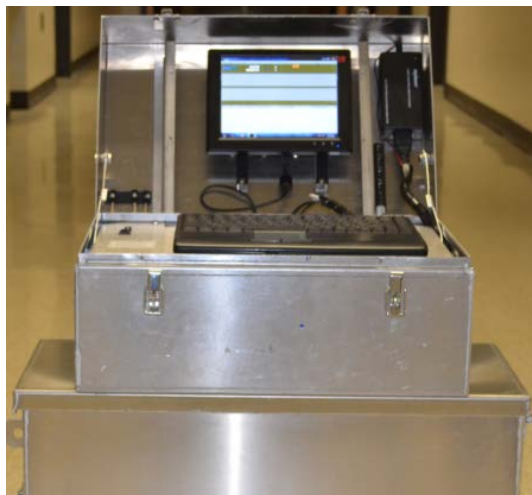


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Chapter 1: Weigh-Pad Installation

How well weigh-pads are installed on pavement can significantly affect quality of the data collected by a portable weigh-in-motion (PWIM) system. After installation, weigh-pads must be securely attached to the pavement in order to endure vehicle loads for the duration of data collection. Any movement in weigh-pad positions caused by weak attachment or vibration would decrease accuracy of WIM data, shorten the weigh-pads life, and increase risk to traffic. This chapter describes an installation method that has been used in previous research and implementation projects.

1.1 Weigh-Pad-Based Portable WIM system

A complete PWIM system consists of a pair of weigh-pads (one for upstream and the other for downstream) and a controller which translates raw load signals to WIM data. A completed system is shown in Figure 1.

The dimension of weigh-pad is 1 x 24 ft, covering two lanes. The padding materials used for weigh-pads are a type of conveyer belts used in heavy industry or mining. The sensors embedded are the Roadtrax BL (Brass Linguine) Class-1 Piezoelectric Axle Sensors (it is simply referred to as “BL sensors” in this documentation) made by the Measurement Specialties, Inc. This sensor is known for temperature sensitivity. To overcome this problem, a special charge amplifier was developed by Dr. Taek Kwon and was used in the controller. This circuit removes thermally generated charge signals by detecting a slowly changing rate of charge signals, i.e., pavement temperatures in general change slowly such as just few degrees per several minutes, while axle signals change rapidly, i.e., signal changes within just few milliseconds. The PWIM system also includes a thermocouple to record pavement temperature data. This temperature data may be used for calibration if further temperature compensation is need.



Figure 1: A pair of weigh-pads and PWIM controller

The PWIM controller has an internal battery that lasts about 45 hours when it is fully charged. Connecting an external battery pack extends operation to additional seven days. Figure 2 shows inside of the external battery pack. For the external battery pack connection, the special military-type connector with cable supplied with the battery pack must be used. External battery pack was designed as hot-swappable, i.e., the power pack can be plugged in and out without turning on/off the PWIM system power switch. It contains two deep cycle 6 Volt AGM batteries

which are connected in series to produce 12V. The model used are 6V PVX-2240T and holds maximum capacity of 224 Ah (ampere hour). Therefore, the total energy contained in the battery pack is 2,688 Watt Hours. The enclosure is well insulated using foams. The pack weighs about 145 pounds. Since it is very heavy, a caution is recommended when you lift the battery pack.

It is recommended that batteries are always stored in a near fully charged state, i.e., after using the system both the external battery pack and internal battery should be charged before storing. If batteries are stored without charging, its life can be significantly shortened. For charging, please use a charger that has an option to select “12V AGM Deep Cycle Battery”. When external battery packs were delivered, a “Schumacher SE-70MA Battery Charger” was supplied (Figure 2 right). This charger works well and is recommended for future purchases.

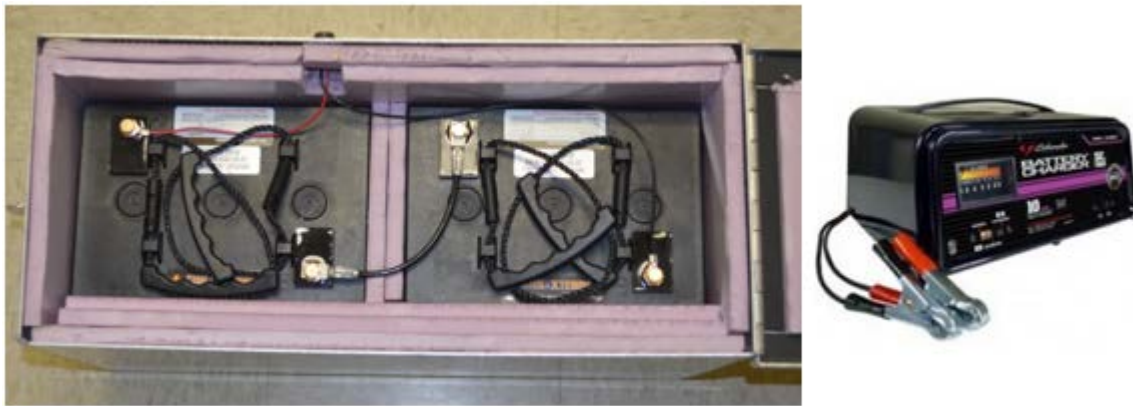


Figure 2: External battery pack with a charger

The charger for the internal battery is on the right side of the PWIM controller. This charger is a trickle down slow charger and fully charging the internal battery can take a couple of days. Letting the charger be plugged in an AC outlet for a long period (such as many days) is fine for this system and will not damage the battery. It has an automatic charge controller and does not charge if the battery was fully charged.

1.2 Installation on Bituminous Pavement

For bituminous pavement installation, the tools needed are (1) a hammer drill with a drill bit with ¼” diameter and 6” length, (2) a strong bonding utility tape, (3) ¼” x 2 ¼” threshold anchor screws (ITW Red Head TH-1420, available from Home Depot; a better deal is available from amazon.com, ITW Red Head FS-1420, \$20 for 100 pieces in a box), and (4) ¼” flat washer. These tools are further illustrated in Figure 3, and they are available from most hardware stores.





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

Figure 3: Tools needed for weigh-pad installation

The sleeve anchor installation steps on weigh-pads are as follows.

1. Drill a 1/4" diameter hole through the pad and pavement for a total depth of 2 1/4" using a hammer drill.
2. Insert a sleeve anchor and a 1/4" washer to the drilled hole. Carefully tap in using a hammer.
3. Turn the anchor screw clockwise to expand the sleeve, which fastens the pad to pavement.

Sleeve anchor screws are installed by spacing approximately **2 feet apart**, requiring 24 sleeve anchors for installation of a pair of weigh-pads. It is also a good idea to increase screw density in each end of the pads. After fastening the pads by sleeve anchors, leading and trailing edges of the pads are taped using a strong-bonding utility tape, such as a Gorilla tape shown in Figure 3. Taping prevents from the pad edges lifted by air drag or rolling resistance generated by wheels. The taping also reduces trapping of air underneath the pads. In addition, application of a carpet tape or any double sided tape underneath the sensor pads would help to further fasten the pads to the pavement. An installation example of anchor screws and tape is shown in Figure 4.

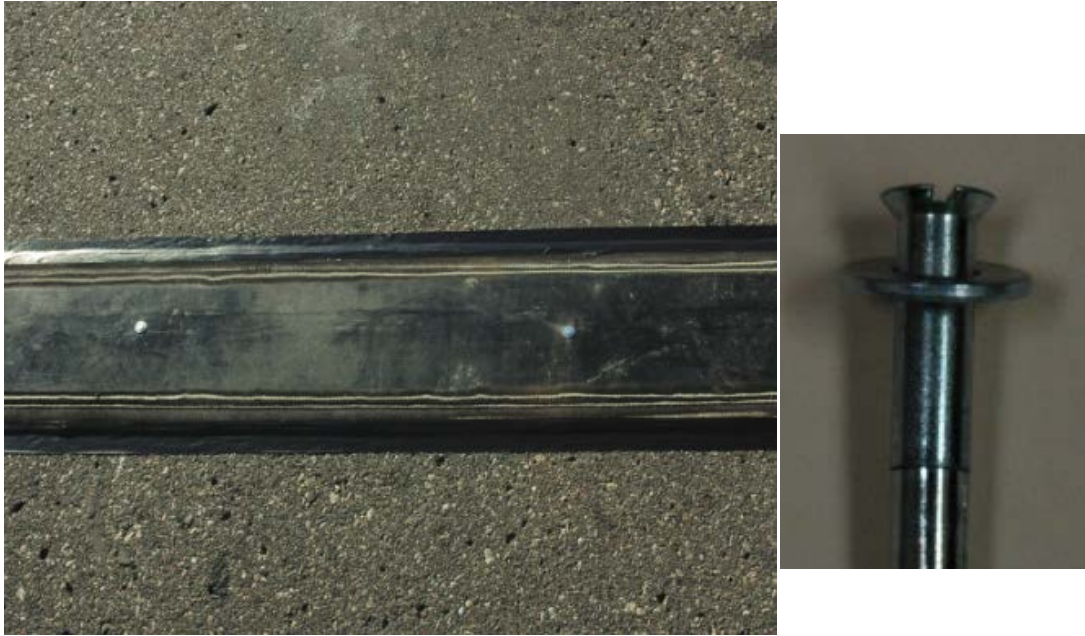


Figure 4: Sleeve anchor screws are first fastened in every 2ft space (1/4” flat washers are used with the anchor screws) and then edges are taped.

For weigh-pad installation, closing one lane at a time is required. The installation steps are as follows: (1) Begin flagging operation and close the lane closest where the console box will be placed. Sweep pavement where pads will unroll. (2) Space sensor pads 15 feet apart. (3) Unroll pads up to centerline (or end of first lane). (4) Drill holes into pavement at the location marked. Hammer in an anchor screw with washer into each drilled hole. Tighten screw with screw driver to ensure the pad is secured into the pavement. (5) Apply tape on both edges of each pad. (6) Close the remaining lane and repeat the same procedure.

Figure 5 shows unrolling the first half of the pad and then fastening it using anchor screws. The total time that takes to install two 24 feet (7.32 m) weigh-pads for a two-lane highway takes about 30 minutes, or 15 minutes per lane. Removal is simpler and takes only a half of the installation time. The average installation/removal time is summarized in Table 1.

Table 1: Weigh-Pad Installation and Removal Time

	Installation	Removal
Single Lane (two 12ft weigh-pads)	15 minutes	7 minutes
Two Lanes (two 24ft weigh-pads)	30 minutes	14 minutes



Figure 5: Weigh-pad installation at Cotton, Minnesota, TH-53

Figure 6 shows a defect of weigh-pad installation. This picture was taken after one day of operation, and it was clear that the pads were not stretched and tightened before placing the anchor screws and tapes; consequently, wrinkles were formed. The pad edges were ripped out of the tape, creating a space between the pavement and weigh-pad. These wrinkles are undesirable results because it can cause vibration and creates false axle signals. Therefore, it is important that the pads must be laid and stretched flat before fastening sleeve anchors.



Figure 6: Wrinkles can cause vibrations and false axle signals

1.3 Lane Number and Port Assignments

Two BL sensor strips are connected through two coaxial cables inside a weigh-pad, and the cables are terminated with BNC female connectors. In the controller enclosure, four male BNC connectors can be found, which are labeled as Lane1 Upstream, Lane1 Downstream, Lane 2 Upstream, and Lane 2 Downstream. The actual sensor placement and these labels must precisely match. Consider Figure 7 as an example. First, lane number must be determined, and then the direction of traffic determines upstream or downstream sensor strips. In Figure 7, the PWIM controller is placed in the left side of the diagram, and the lane close to the controller is labeled Lane 1 and the other lane is labeled Lane 2. Upstream or downstream is next determined based on the lane traffic direction.

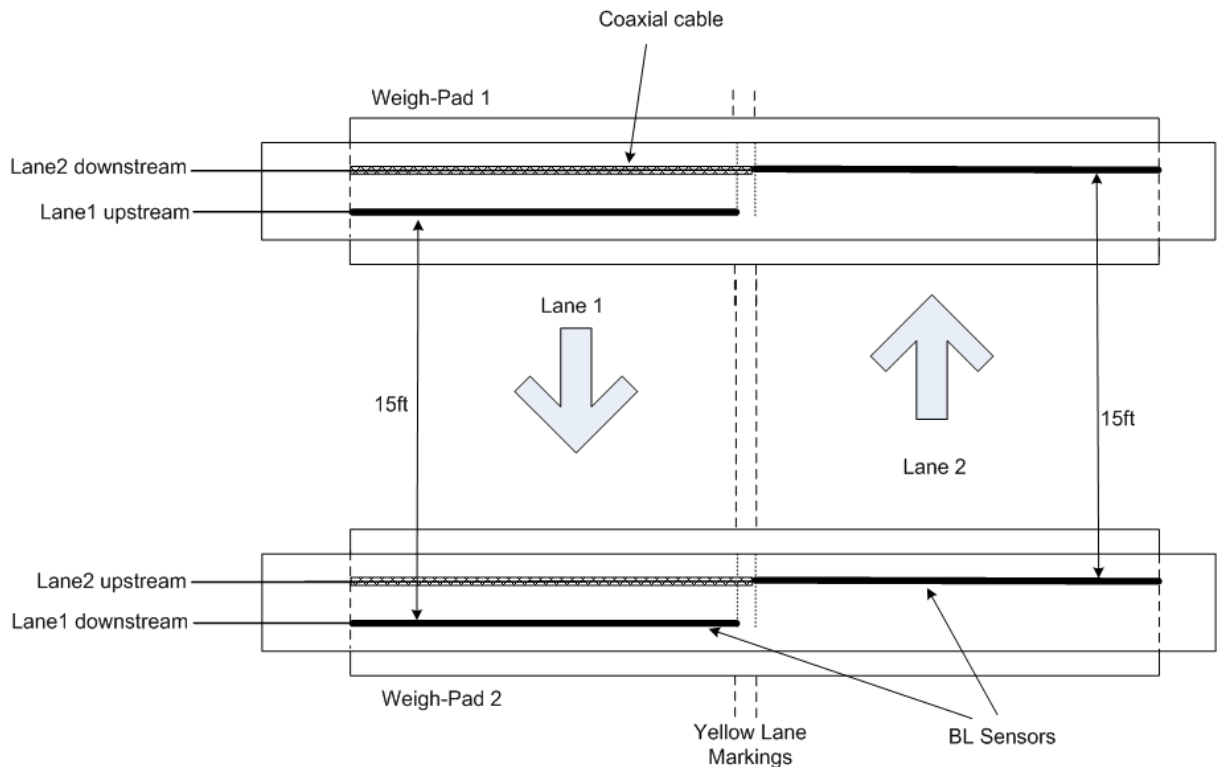


Figure 7: Sensor strip location and lane assignment

Chapter 2: Initial Quick Setup and Data Collection

This chapter describes a minimal setup required to start a PWIM system after installing the weigh-pads. In addition, a calibration is required, which is described in Chapter 3.

2.1 Site ID and Lane Setup (Step 1)

Start the PWIM controller program by double-clicking the weighpad WIM icon or the keepAlive icon on the controller desktop. Running the keepAlive program is more reliable since it monitors and starts the weighpad WIM program. It also revives the weighpad WIM if it was accidentally killed.



Once the PWIM control program was started, the first procedure must be done is setting up the **Site ID and Lanes**. Press the “**Settings/Site Setup**” menu, which would pop up a setup window shown in Figure 8.

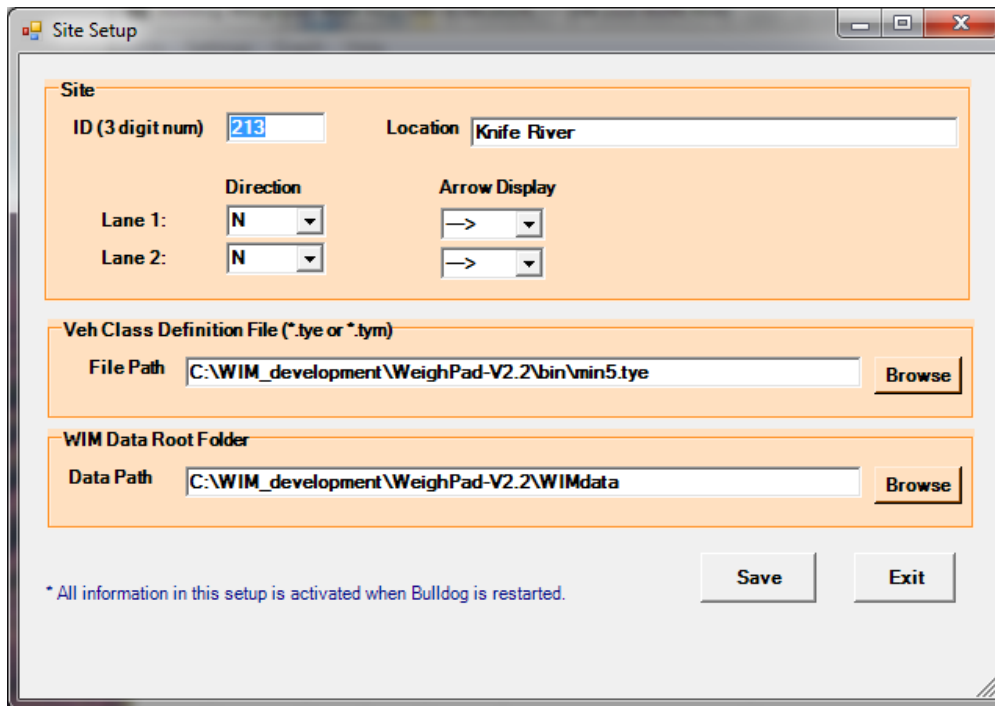


Figure 8: Site Setup Window

A three digit number should be entered in the site ID blank. This site ID is important because it determines the data directory and file names. In the above example, the data directory of this site is created in “C:\WIM_development\WeighPad-V2.2\WIMdata\Site_213\” and the data files are named “yyyymmdd.213.csv” where yyyymmdd are eight digits of year/moth/day

string. The **Location** string can be any text string, and it will appear in the heading of the PWIM controller window.

There are only two lanes in PWIM setup, i.e., Lane 1 and Lane 2. Lane number for physical lane is determined as described in Section 1.3. More specifically, if a pair of weigh-pad upstream and downstream BNC connectors are plugged into the two controller connectors labeled Lane 1, that lane becomes Lane 1. Similarly, Lane 2 is connected. A simple rule of thumb would be assigning Lane 1 to the lane close to the controller and Lane 2 to the lane further away. **Lane direction** should be selected to match the physical lane direction. **Arrow Display** should be chosen to match with the actual traffic direction displayed on the screen. In Figure 8, both lanes (driving and passing) are in north direction and the arrow displays are set to right, thus the PWIM controller is located in the east side of the road.

Next, a vehicle class definition file must be selected. PWIM controller uses the same files as the BullConverter or BullReport [1] program. Use the “**Browse**” button in the GroupBox labeled “Veh Class Definition ...” to navigate files and select a class definition file. It accepts either a metric (.tym) or English unit definition file (.tye) in the same way that BullConverter reads in.

Last, the user must set a valid root directory for the WIM data to be collected. Use the “**Browse**” button in the GroupBox labeled “WIM Data Root Folder” to navigate folders and select the directory. Data files are then stored in a subdirectory named **Site_###** where ### is the three digit site ID. It creates the date directory in “yyyymmdd” format and stores the data files. User is only responsible for setting the root folder of the WIM data. The site and date directories are automatically created by the PWIM controller program.

It is important to remember that **the user must press the “Save” button to save all entries**. If the “**Exit**” button is pressed without saving, all new entries entered will be lost. A restart is required to activate the new values in Site ID Setup.

Note: The vehicle classification definition file and root data folder locations are already set at proper locations when the PWIM system is delivered. Therefore, the user will only need to setup the Site ID, Location of the site, and the Lane Direction and Arrow Display.

2.2 Axle Sensor Spacing Setup (Step 2)

Setting an accurate spacing value between the upstream and downstream weigh-pads is extremely important because it affects speed, axle spacing, and weight computations. Pressing the “Settings/Axle Sensor Setup” menu opens up the setup window shown in Figure 9. A recommended distance between the upstream and downstream pads is 15 feet; enter this value as shown in Figure 9, which should match with the physical sensor spacing. The WIM Sensor Sensitivity should be left as default. The “Save Changes” button should be pressed to save the new values. A restart of the program or activation of parameters is required, i.e., restart by pressing the “File/Restart” menu or the “Setting/Activate Settings”.

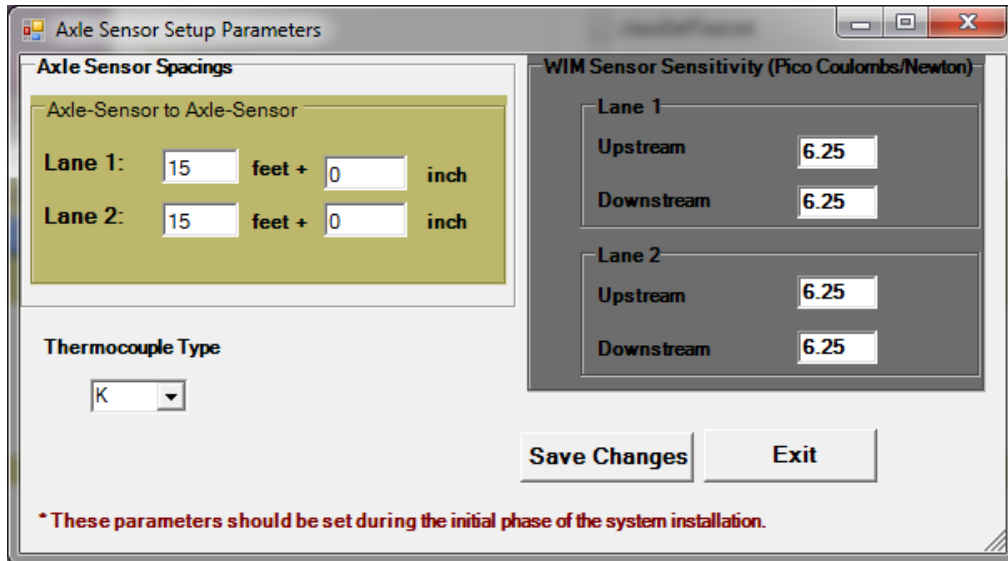


Figure 9: Axle sensor spacing setup

2.3 Limit Parameters (Step 3)

The limit parameters are set by the “**Settings/Limit Parameters**” menu. Most parameters can be left as default, but there are two values that should be changed according to the local conditions.

“Low possible speed on this road”

“High possible speed on this road”

These two values should be set according to the local traffic speed range. The value of “Low possible speed on this road” is internally 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 bigger than the low limit set, it tells those two axles are not the same vehicle.

The value of “High possible speed on this road” is internally 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 becomes a candidate for a false axle signal which may be filtered out if it meets another filtering condition.

In Figure 10, the “Low possible speed on this road” value was set at 25 mph. It is extremely important to note that this value should never be set to 0 mph because this will lead to channel-to-channel axle spacing limit to infinity. It basically tells the system that, low possible vehicle speed is zero, and it would take an infinite amount of time for a low speed vehicle to cross two axle sensors.

Other limit parameters could be left default or modified if local conditions demand. For details on limit parameters, please read Chapter 4.

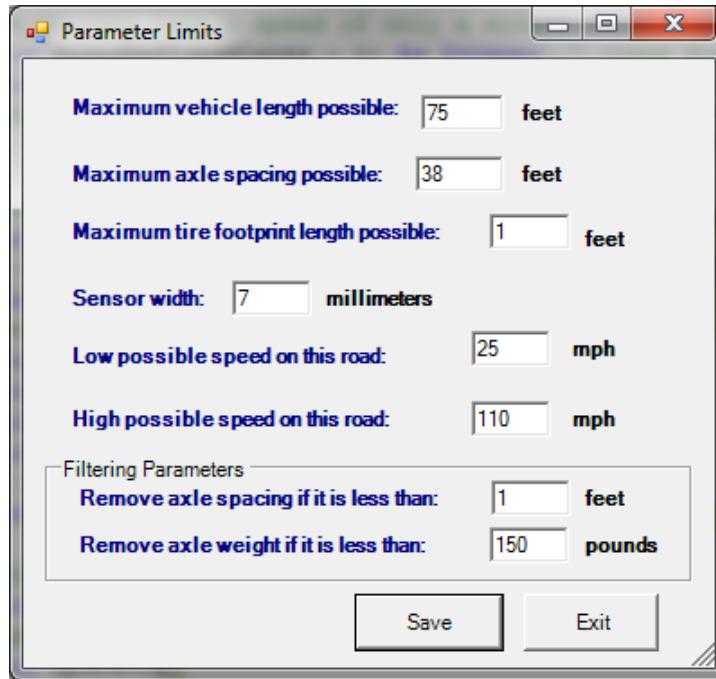


Figure 10: Limit parameters

2.4 Initial Speed and Speed Reference Setup (Step 4)

Initial speed estimate for each lane is entered using the “**Settings\Initial Lane Speeds**” menu. This information is used to compute initial vehicle spacing, i.e., distance from rear axle of the first vehicle to steer axle of the next vehicle. Once a real speed is computed, this value is no longer used. This value is not critical but should be set using **a typical or an average traffic speed** of the lane at the time of program start. Figure 11 shows the setup window.

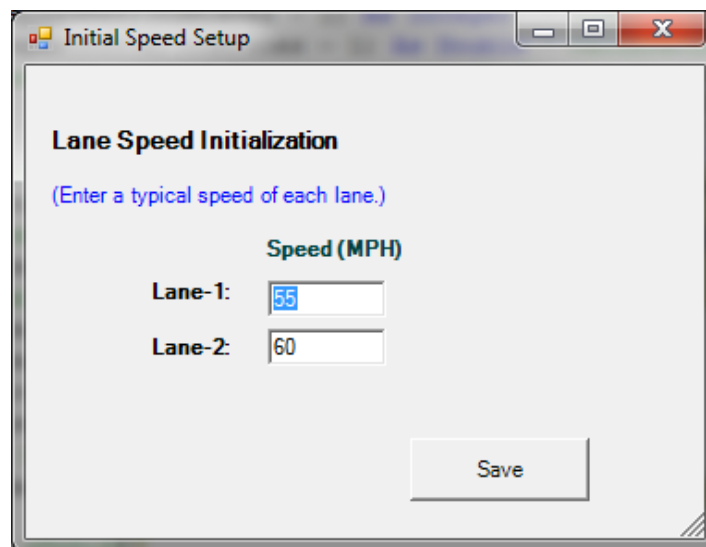


Figure 11: Initial speed estimate of each lane

Vehicle speed is computed using activation timing of two axle sensors. If one of them fails, speed cannot be computed. One way of overcoming this problem is using the adjacent lane

speed. This setup is done using the “Settings/Lane Speed Reference” menu. In Figure 12, Lane-2 is the passing lane and its traffic is 5 percent faster than Lane-1. This setup reads, if one of the Lane-1 axle sensors fails, Lane-2 speed is used but by decreasing it by 5 percent. If one of the Lane-2 axle sensors fails, Lane-1 speed is used but by increasing it by 5 percent.

If the traffic in the two lanes are in opposite directions, the calibration should be 1.00 for both lanes.

Any axle sensor failure is a serious error and reported in the vehicle record but the axle spacing and weights are still computed using the neighboring lane speed. If the axle sensors of the referring lane also fail, vehicle record is no longer computed and the “both axle failure” error is reported.

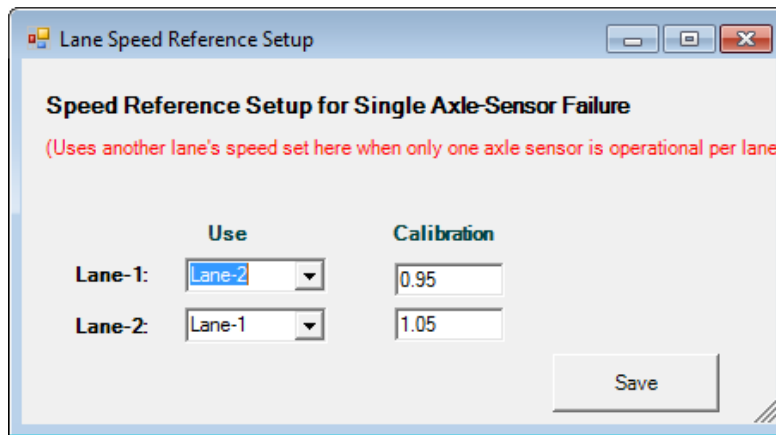


Figure 12: Speed reference setup

2.5 Calibration Setup (Step 5)

If a vehicle with a known weight is available, calibration steps described in Chapter 3 should be performed. The range of the calibration factor is in general $0.5 < c.f. < 0.7$ where c.f. denotes calibration factor. If a calibration vehicle is not available, please set the theoretical calibration factor, 0.6.

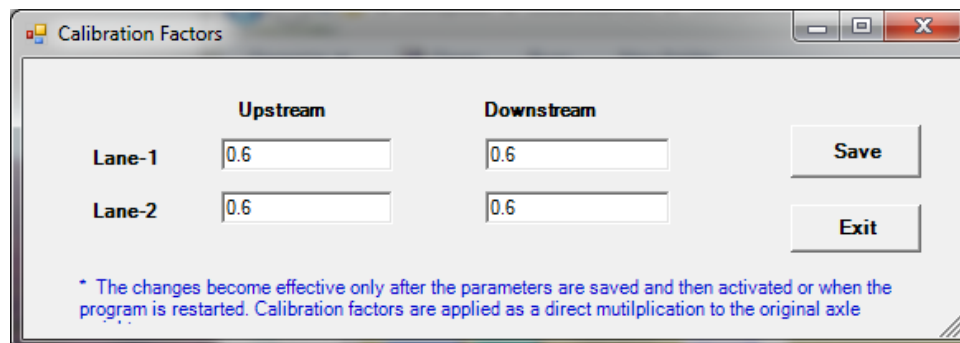


Figure 13: Calibration factor setup

2.6 Threshold Setup (Step 6)

Signal threshold level of a channel determines initial detection of an axle signal. To measure a signal threshold level, user must open up the graph window using the “**Graph\Show Graph**” menu. This window displays actual signal voltages of the selected channels. The channels are selected as a pair, i.e., (ch-0 and 1) or (ch-2 and 3), which are upstream and downstream sensor signals of selected lane. In the graph window, first set the y-range by entering “y-min=-0.5” and “y-max=1.5” and then press the **Set** button. Press the hold button when a small passenger car signal is in the window. It is important to capture a small passenger car as their threshold is much lower. Figure 14 shows two-axle signals in which blue signals are from the upstream sensor and red signals are the downstream sensor. A threshold level should be picked at slightly lower than half of the smallest axle signal height. In this example, 0.4 should be a good value for both channels 0 and 1.

To enter the measured signal thresholds use the “**Settings\Signal Thresholds**” menu, which is shown in Figure 15. The measured threshold levels should be entered and saved. It is important to note that saving the setup values does not activate the parameters. User must activate the parameters by using the “**File\Restart**” menu.

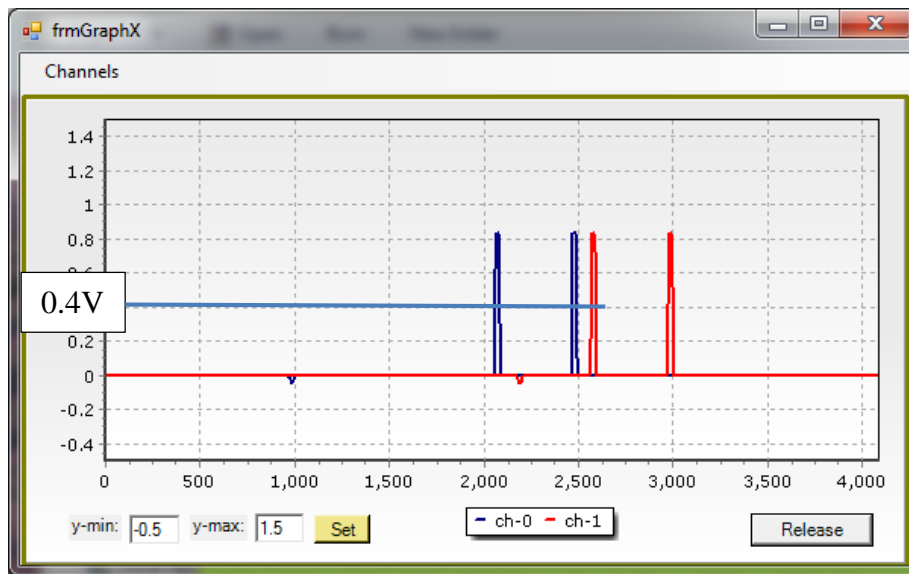


Figure 14: Signal threshold measurement

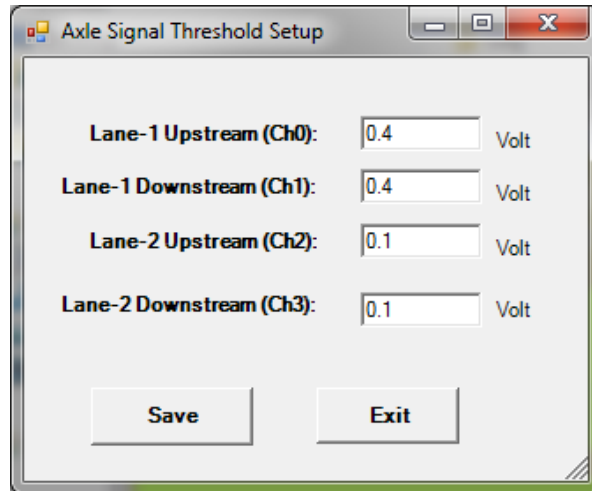


Figure 15: Threshold setup window

2.7 Data Collection (Step 7)

Data collection is automatically started as soon as the PWIM controller program is started. If the PWIM system is properly running, “**Running**” is displayed in the **Operation** status and the count value is constantly incremented. If the count value is stuck at a constant such as 0, a computer reset would be required. This happens when the A/D driver could not synchronize with the PC PCI bus. This problem does not occur frequently but it is always resolved by a system reset.

The collected data is stored in the folder set in the Site Setup window and can be downloaded using a USB flash drive.

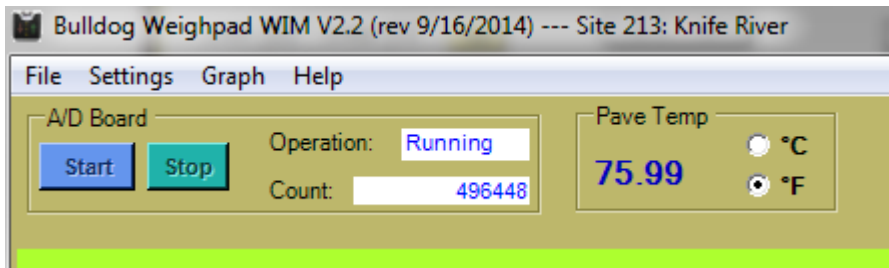


Figure 16: Running state display

Chapter 3: Calibration

As described in Section 2.5, the theoretical calibration factor of PWIM is 0.6. This theoretical value must be adjusted depending on environmental conditions, such as pavement roughness, slope, weigh-pad tightness to pavement, etc. This adjustment process is referred to as calibration. If a vehicle with a known static weight is available, calibration can be easily performed and can increase the measurement accuracy. This chapter describes a recommended calibration procedure developed in prior projects.

3.1 Preparation

First, a vehicle with a known gross vehicle weight (GVW) must be available to perform PWIM calibration. A static scale could be used to measure GVW. An ideal calibration vehicle would be weights evenly distributed to all axles, so that potential bouncing between front and back or left and right is minimized. Also, a heavier truck would be preferred over a light weight vehicle such as a passenger car or a pickup truck. This is due to the following reason. The sensor sensitivity could be limited to, such as 1 to 4 Kips for a weight range of 5 to 80 Kips. For an 80 Kips vehicle, the variance would be 4 Kips which is only 5 percent of GVW, while the variance of 1 Kips for a 5 Kips truck would be 20 percent. This means that more runs would be required for lighter GVW vehicles.

Second, prepare a data recording sheet for calibration runs. A sample recording sheet is shown in Figure 17.

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		
1			2		
1			2		
1			2		

Figure 17: Calibration run recording sheet

Third, check the signal threshold level and basic parameters described in Chapter 2 before starting calibration runs. Set all calibration factors to 1 (Figure 18) and then restart the program, i.e. “**File/Restart**”.

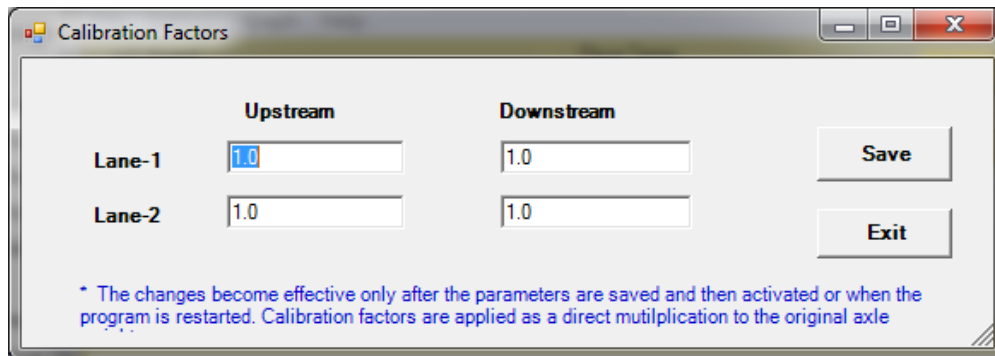


Figure 18: Set all calibration factors to 1.0 and restart

3.2 Calibration Runs

The driver of calibration vehicle should try best to drive at a constant speed when the vehicle passes over the sensors and middle of the lane.

Once calibration run data were collected, the measured weights should be averaged, excluding outliers. The calibration factor (c.f.) for each lane is computed using:

$$\text{c.f.} = (\text{Known GVW}) / (\text{Average of Calibration Run GVW's})$$

The c.f. for upstream and downstream lanes are the same in PWIM system. Once a c.f. value per lane obtained, save them and then activate the settings or restart the PWIM controller program.

Chapter 4: Details on System Operations

Previous chapters only described minimal required information on operations of the PWIM system. This chapter describes details of the operations and information on all setup parameters and where they are used.

4.1 Power On/Off Sequence

4.1.1 Power-On Sequence

The system should be turned on by following the sequence: (1) turn on the master switch, and then (2) press the PC reset switch using a wooden stick. The boot up takes longer because this system is using a USB monitor. The Windows-7 boot up time is 1 minute 40 seconds. The PWIM is loaded in 13 seconds.

Three icons are visible on the controller desktop screen, as shown in Figure 19. The main program that runs the PWIM controller is the “WeighPad WIM” program, and the other two are utility programs.



Figure 19: Three program icons

If the WeighPad program was not automatically started, simply double click on the keepAlive program. This program checks every 30 seconds whether the WeighPad WIM program is alive or not (running or not). This program will start the WeighPad WIM program if it was not running. This approach is a more reliable way of running the weighpad WIM program, since the keepAlive program will restart the PWIM program if it was accidentally closed by user or by a system error or reset.

Wpad-Plot is a plot utility used for plots of raw binary data, and it is a tool for axle signal examination and will be discussed later. The weighpad WIM executable file is located in:

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

4.1.2 Data Collection

Data collection is automatically started when the weighpad WIM program is started and continued until the program is closed. No special user action is required for data collection. The LCD monitor should be turned off to save battery hours when the system is left alone for continuous data collection.

4.1.3 Power-Off Sequence

After data collection period is over, the system must be turned off and brought back to office. A power-off sequence is given below.

1. **Kill the “keepAlive” program** using Windows Task Manager (Figure 20) where you press the **End Task** button after selecting the keepAlive program.
2. Close the WeighPad WIM program using the File/Exit menu.

3. **Turned off the computer** by pressing the reset button or using the Windows **Shutdown** menu.
4. **Turn off the Master switch.** (If this switch is not turned off, power is still consumed by the standby mode.)

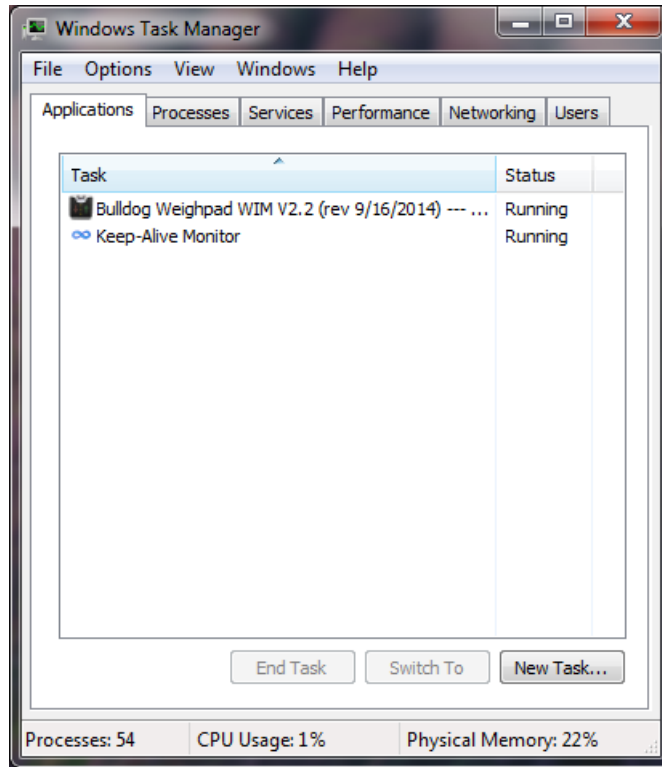


Figure 20: Windows Task Manager is used to kill the keepAlive program.

4.1.4 Data Download

Collected PWIM date is downloaded using one of the USB ports available in the controller, and they located below the LCD screen. Other ways are also available since this machine is a PC. Data files are located in the folder defined from the Site Setup menu under the group box “WIM Data Root Folder” and 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 csv file which is compatible with BullReport or BullConveter.

4.2 PWIM Overall GUI and Tool Sets

The controller computer runs on a Windows embedded PC OS (XP or 7) and is equipped with an SVGA LCD monitor (800 x 600 pixels). Using this monitor, an easy-to-use graphical user interface (GUI) was developed for PWIM operations.

The GUI design was created based on operational needs of the system and required components. Visual modeling of a vehicle record is one of the requirements, since a visual form can make verification of correct operation simple at the site, i.e., the vehicle model on the monitor can be visually compared with the actual vehicle passing by. Information displayed on the vehicle model includes:

- axle weights
- axle spacing
- speed
- classification
- GVW
- ESAL
- time
- error messages

Additional lane and vehicle index information is displayed in the right side:

- lane number
- lane direction using an arrow along with direction literals
- vehicle identification number (this number matches with vehicle record in the data file)

Figure 21 shows an example of the visual vehicle model, and it is designed as a .Net component in Windows programming. This visual component displays information listed above and is assigned to each vehicle.

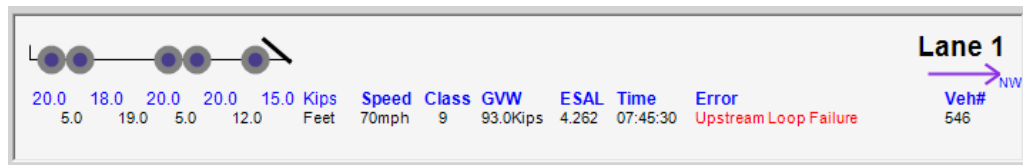


Figure 21: Custom component “vehShow.dll” developed for visual modeling of individual vehicle records

Figure 22 shows the entire PWIM GUI, including this visual vehicle model. Notice that both lanes are set to northbound along with the arrows indicating the traffic direction in reference to the controller location. The letter, N, at the tip of arrow indicates north direction. If the arrow direction is changed, the vehicle model automatically changes its heading to match up with the arrow direction.

There is also a table of vehicle records at the lower half that users can track and review. This is equivalent to the actual vehicle records stored in the WIM data file.

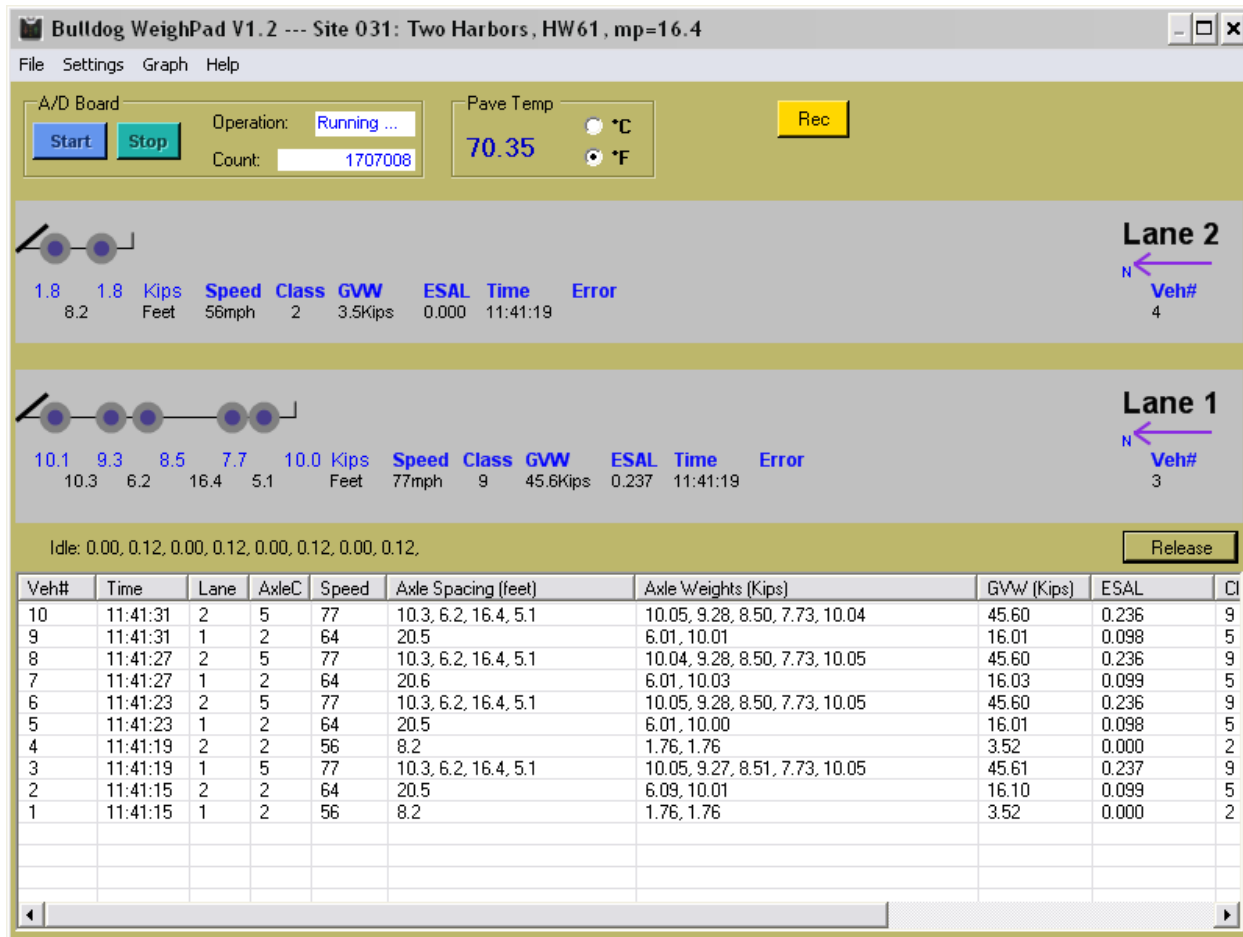


Figure 22: GUI screen shot of the weighpad-based PWIM controller

In Figure 22, please note availability of a **Release** button in the middle right. This is a toggle switch, switching between “**Hold**” and “**Release**” controls. If this switch is pressed when the button text is “**Hold**,” the vehShow controls and the vehicle record table are immediately frozen, holding the display of the last vehicle record. If the button is pressed when its text shows “**Release**,” the vehShow control and vehicle record table returns back to normal, continuously updating new vehicle records. This Hold/Release button is an importable tool for calibration. For example, when a calibration vehicle passes by, the operator may freeze the vehShow control to copy GVW and vehicle number. *It should be noted that during the holding state only the screen display is frozen; the actual vehicle records are continuously computed and saved in the background in the data file.*

There is also a yellow “**Rec**” button available next to the “Pave Temp” groupbox. When this button is pressed, raw binary channel signals (ADC or Analog-to-Digital Converter output) are recorded into a file. A red “**Stop**” button appears when the “**Rec**” button disappears, and pressing this button stops the ADC output recording. The recorded raw data can be later viewed using the Wpad-Plot program.

After recording raw ADC data using the **Rec** button, a utility tool called “WeighPad-Plot” is used to analyze the data. It is available from the desktop with the icon name, **Wpad-Plot**. This tool allows for the plot window to move forward or backward in the sample space, as well

as zoom in/out using settings of Y-range, X-range values. A sample screen of the WeighPad-Plot utility is shown in Figure 23. Please note data navigation buttons on the lower right side. This is a useful tool to diagnose signal problems, such as pad vibration problems or abnormal signal idle levels.

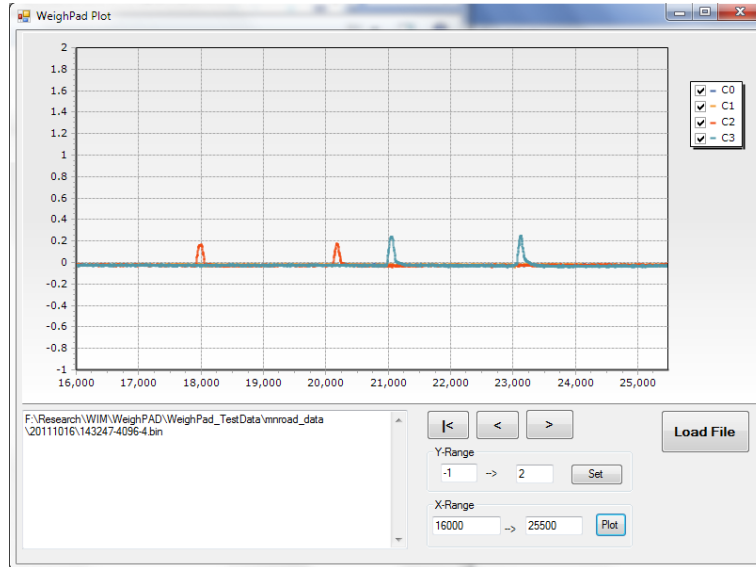


Figure 23: Weigh-pad plot utility

The main window also includes a display of pavement temperatures either in Fahrenheit or Celsius depending on user’s selection. It accepts type-J or type-K thermocouple, which is set from Axle Sensor Setup (Section 4.3.3). A thermocouple must be taped on the pavement and its lead must be plugged into the controller box to properly display the temperature: otherwise, “N/A” is displayed. (Note: In a recent modification, the thermocouple was enclosed in the bottom chamber of the enclosure, thus it now measures temperature inside the controller. This modification was made to diagnose the controller problem in overheating. The thermocouple should be diverted back to an outside probe in the future.)

For diagnostics it is extremely useful to have a real-time plot of axle load waveforms. Under the graph menu, there is a menu item called “**Show Graph**”. When this item is selected, a plot window opens up 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 24. 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** menu. This utility could be used to check charge amp or ADC signals. It is an essential tool to check threshold levels and resting voltages of each channel. This routine also provides a Hold/Release button by which signal updates can be frozen and released.

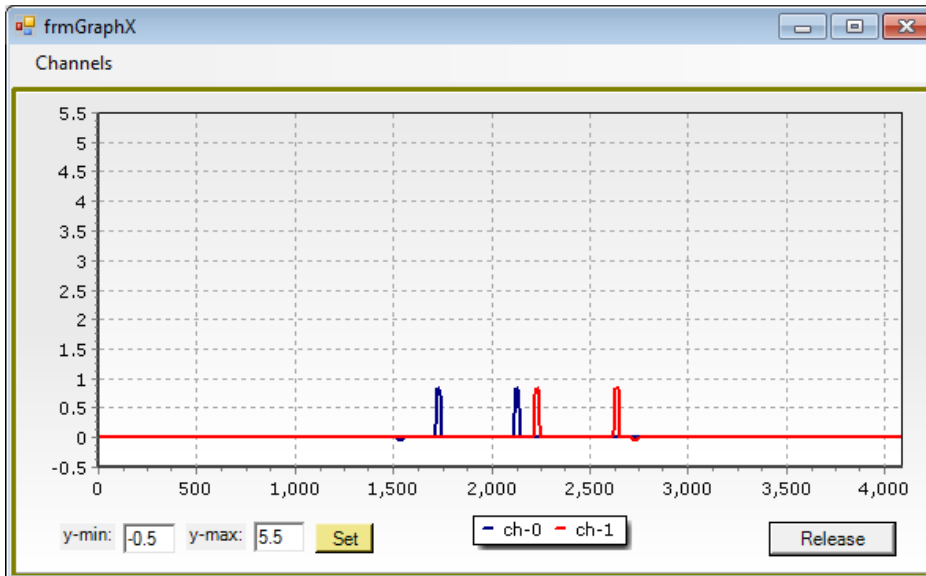


Figure 24: Real-time plot of ADC channels

If a more detailed signal analysis is necessary, the operator should always record the raw data using the **Rec** button 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 the **“Help/Read data file”** item 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.

In summary, the following functions are available in the PWIM controller.

- Visual vehicle model
- Table of WIM records
- Update Hold/Release buttons
- Real-time recording of axle-load signals
- Plot utility for recorded binary 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
- Real-recording of WIM data

4.3 PWIM Settings

4.3.1 Overall Description

PWIM controller requires various settings which must be carefully set for best results. All settings are listed under the “Settings” menu in the main window. The items in this menu are

- Site Setup
- Axle Sensor Setup
- Calibration Factors
- Speed Adjustment Factors
- ESAL Setup
- Limit Parameters
- Signal Thresholds
- Lane Speed Reference
- Initial Lane Speeds
- Activate Settings

Selecting any of the menu items above would pop up a setup window that guides the user to an easy-to-use GUI. Each setup item is described one-by-one in the following subsections. Some information is overlapped with Chapter 2 but provided for completeness.

4.3.2 Site Setup

The Site Setup window is opened by the “**Settings/Site Setup**” menu and shown in Figure 25. All settings in Site Setup are prerequisite to system startup and must be set before any data collection is initiated.

The site ID should be a three-digit numeric number. The Location textbox can be any text including numbers and symbols that describe the location. The site ID number is extremely important since PWIM data files are named using date and site ID.

The lane and arrow direction combo-box determines the lane direction and traffic flow direction 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.

PWIM controller uses the same vehicle classification algorithm and software components deployed in BullConverter [1] which requires a class definition file. The “Browse” button in the Veh Class GroupBox allows navigation of files and directories for selection of a class definition file. It accepts either a metric (.tym) or an English unit definition file (.tye) in the same way BullConverter reads in.

The last important entry is setting up where to store the data in the file system. The user must set a valid root directory and must use the Browse button in the “WIM Data Root Folder” groupbox. The data is then stored in a subdirectory named Site_### where ### is the three-digit site ID. It then creates the date directory in “yyyymmdd” format and stores the data in that directory. The user is only responsible to set the root folder for the WIM data.

As the last step, the user must press the “Save” button to save all entries. If the “Exit” button is pressed without saving, all of the new entries will be lost. To activate the new settings, restart of the program is required, i.e., press “**File/Restart**”.

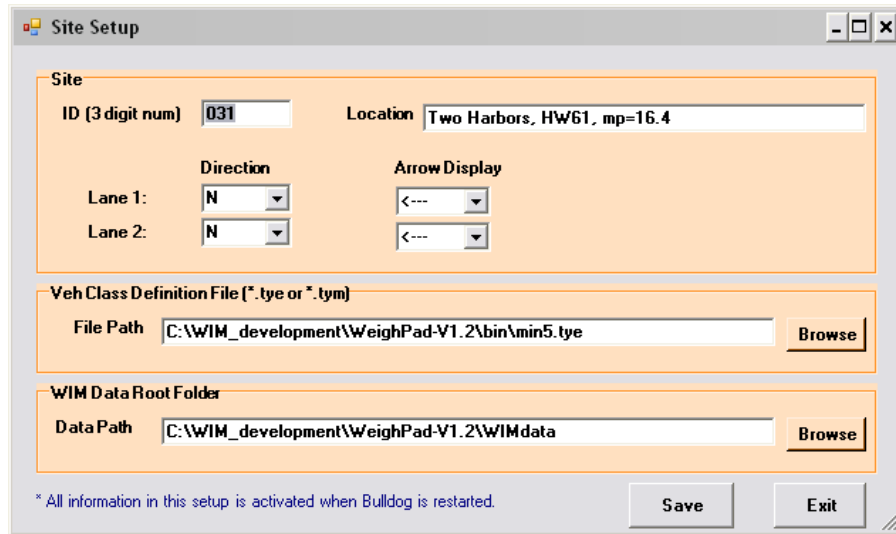


Figure 25: Site setup window

4.3.3 Axle Sensor Setup

To compute vehicle speeds, the distance between two axle sensors per lane must be known. This spacing is set from the Axle Sensor Setup menu as shown in Figure 26. 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 portion is left 0, i.e., the inch entry is only provided for convenience of inch-to-feet conversion in the field.

Suppose that you entered 14.2 in the feet textbox and 6 in the inch textbox. This will then be translated into 14.7 feet internally, and it will be next time displayed in the feet textbox 14.7 and 0 in the inch textbox. Alternatively, you could also enter 176.4 in the inch textbox and 0 in the feet textbox, which would be translated into 14.7 feet.

Sensitivity for each sensor segment must be also set, which is supplied by the sensor manufacturer. The default sensitivity value of BL sensors used PWIM is 6.25.

This setup window also includes selection of thermocouple type. Presently, it supports J and K types and should be selected according to the type of thermocouple connected.

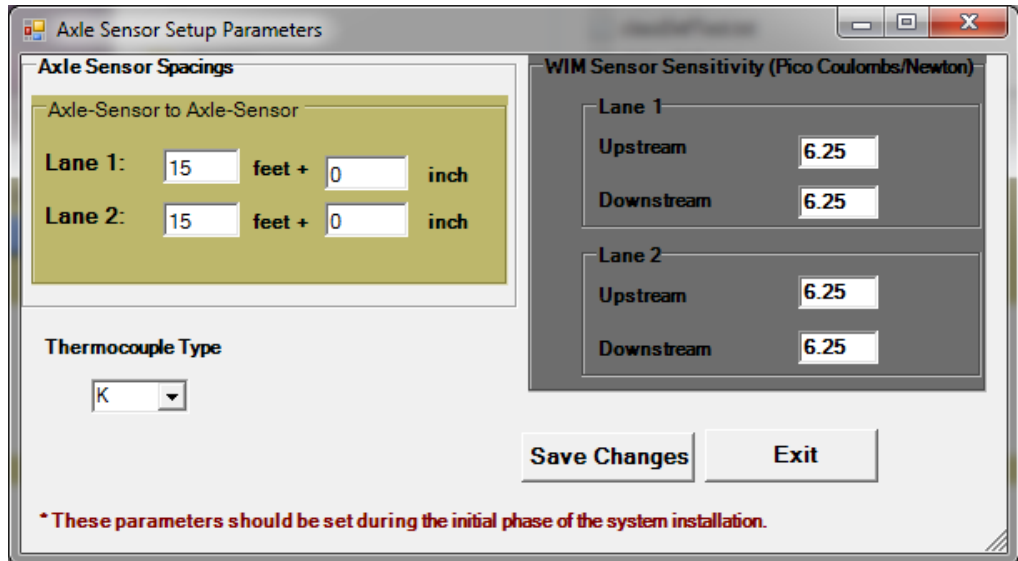


Figure 26: Axle sensor setup window

4.3.4 Calibration Factor Setup

Calibration factors are entered using the “**Settings/Calibration Factors**” menu and a sample window is shown in Figure 27. These values should be obtained using the calibration procedure described in Chapter 3. It should be noted that 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. The theoretical default value of the calibration factor is 0.6. Each lane should have the same calibration factors for both upstream and downstream if each sensor strip was not separately calibrated.

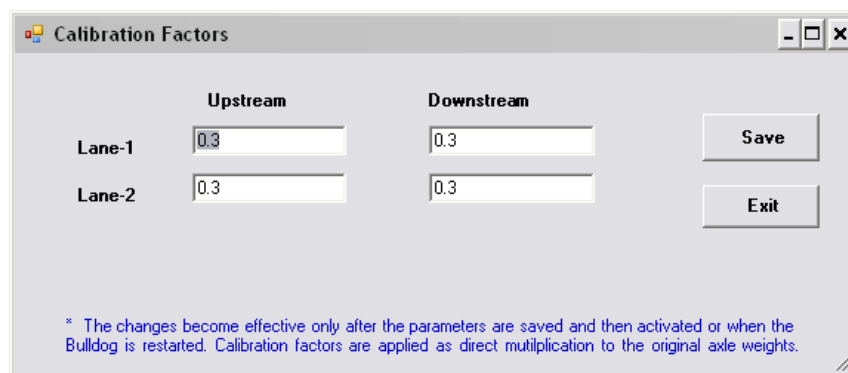


Figure 27: Calibration factor setup window

4.3.5 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 using the “**Settings/Speed Adjustment Factors**” menu. Figure 28 shows the sample setting window. Each entry in Figure 28 is the mid-point of the speed range, from which the rest of points are linearly interpolated. For example, 5 mph calibration factor is 1.3080 and 15 mph calibration factor is 1.1366 for Lane 1. In this case, if speed is 10 mph, its calibration factor is internally computed as:

$$\text{Speed adjustment factor at 10 mph} = \{(1.1366 - 1.308)/(15-5)\}*(10-5) + 1.308$$

The reason for existence of this adjustment factors in PWIM settings is based on the following observations made during 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 theoretical zero horizontal force. The horizontal component of wheel force is $f \cdot \cos(\theta)$ and its theoretical value is zero since θ is 90 degrees. Unfortunately, this θ becomes less than 90 degrees when weigh-pad installation is poor, producing higher applied force to the sensor as speed increases and thus translated into a higher weight.

If installation of weigh-pads on the pavement is secure, axle weights would be no longer a function of speed, and thus **all of the weigh adjustment factors per speed should be set to 1.0**.

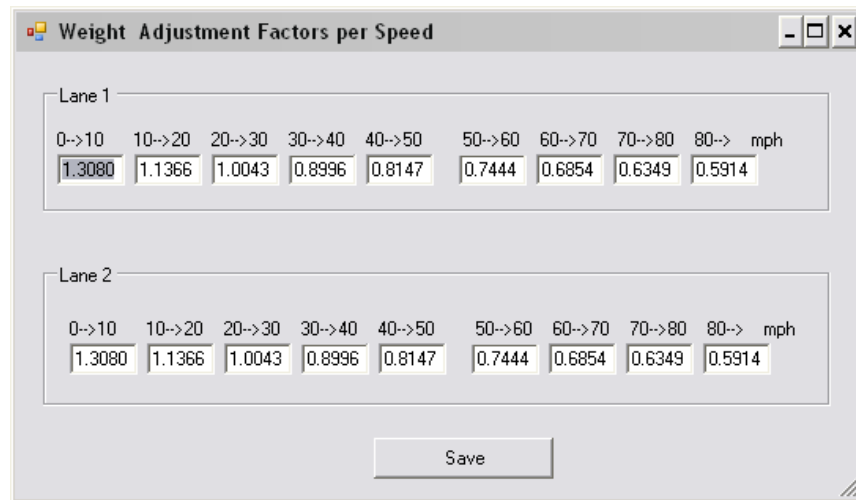


Figure 28: Weight adjustment factors per speed

4.3.6 ESAL Parameter Setup

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

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

in which m is the number of axle load groups, F_i is the EALF for the i th-axle load group, and n_i is the number of passes of the i th-axle load group during the design period [3].

The ESAL setup window, Figure 29, is opened by the “**Settings/ESALSetup**” 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. MnDOT 2007 Pavement Design Manual 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’s recommends 8 inches for D and 2.5 for P_t .

MnDOT generally just uses the flexible ESAL numbers when evaluating pavements. The 1986 American Association of State Highway and Transportation (AASHTO) “Guide for Design of Pavement Structures,” Appendix D contains ESAL factors for additional axle configurations, structural numbers, slab thicknesses, and terminal serviceability values.

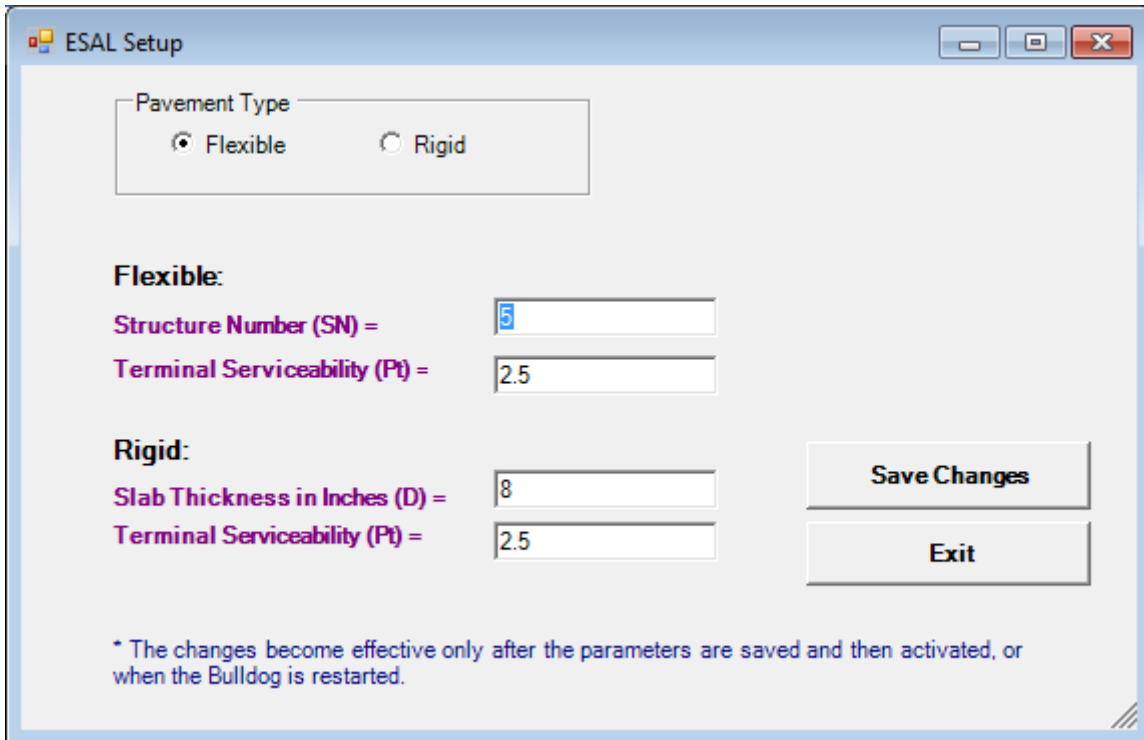


Figure 29: ESAL parameter setup window

4.3.7 Limit Parameter Setup

PWIM utilizes a number of user supplied limit parameters for vehicle end detection and error filtering algorithms. The limit parameter setting window is shown in Figure 30, which would open by the “**Settings/Limit Parameters**” menu.

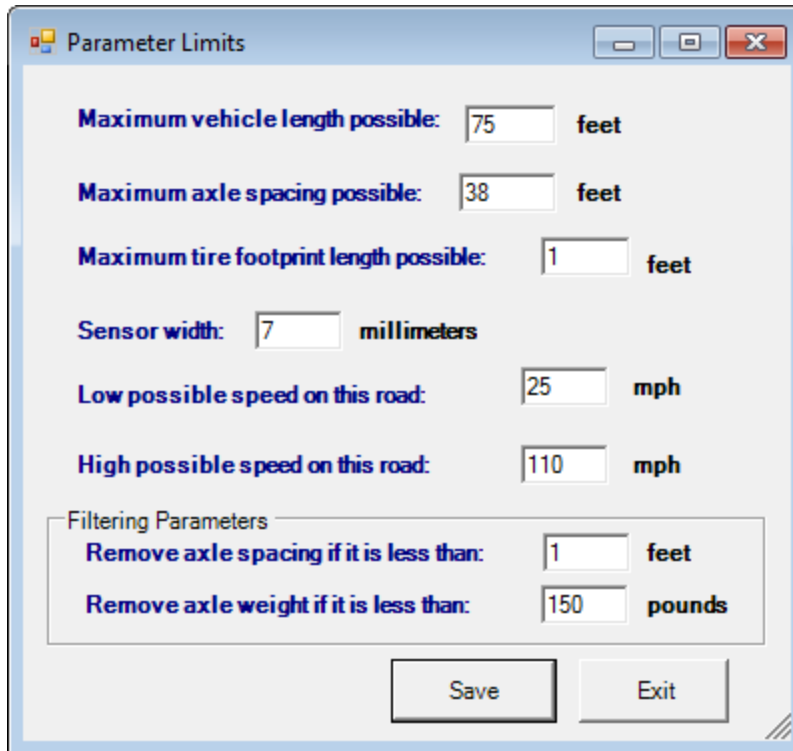


Figure 30: Limit parameter setup window

Each limit parameter is described one-by-one next based on Figure 30 values.

Maximum vehicle length possible --- This value is the maximal possible distance in feet between the steer and rear axle among the vehicles on this road. This value is used for vehicle end detection. For example, if axle signals are continuously showing up in a channel, the vehicle detection algorithm is forced to cut at 75 feet limit and declares end of a vehicle.

Maximum axle spacing possible --- If any axle spacing is longer than this value, end of a vehicle is declared. In Figure 30 example, if any axle spacing between two consecutive axle signals is greater than 38 feet, a vehicle end is declared. So the first axle is the rear axle of a vehicle, and the second axle is the steer axle of the subsequent vehicle, i.e., the axle signals do not belong to the same vehicle.

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

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

Low possible speed on this road --- This value 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 spacing computed by this limit, the two axles are not likely belong to the same vehicle, and thus end of a vehicle is marked by the algorithm.

High possible speed on this road --- This value is used to compute a potential minimum time spacing between the 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 becomes a candidate for a false axle signal which may be filtered out based on further reviews such as existence of matching signals, meeting minimum required weight, or minimum axle spacing.

Remove axle spacing if it is less than --- 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, there is no vehicle in this world that has less than 1 feet axle spacing.

Remove axle weight if it is less than --- If an axle weight is less than this limit, it is likely a noise signal, so this axle signal is filtered out.

4.3.8 Axle Signal Threshold Setup

An axle signal is a Gaussian shape pulse consisting of a rising edge, a top portion, and a falling edge. An axle signal shape along with the axle signal segmentation procedure used in PWIM is illustrated in Figure 31. 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 a valley and marks it as the end of axle signal (4). Because of this adaptive procedure, 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.

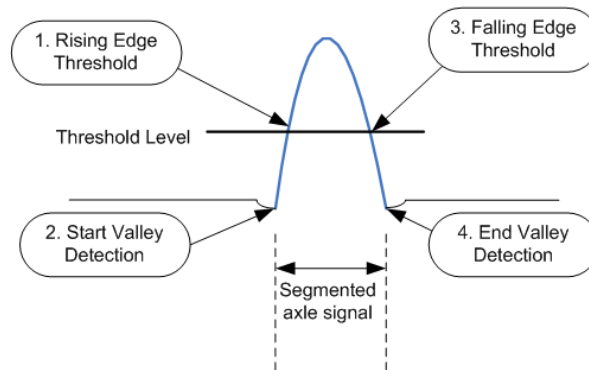


Figure 31: Axle signal segmentation process

Axle signal thresholds are set using the “**Settings/Signal Threshold**” menu and its window is shown in Figure 32. 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 as described in Section 2.6. In general, if the channel is not noisy, a reasonable threshold level would be in the range of 0.9-0.12 volts.

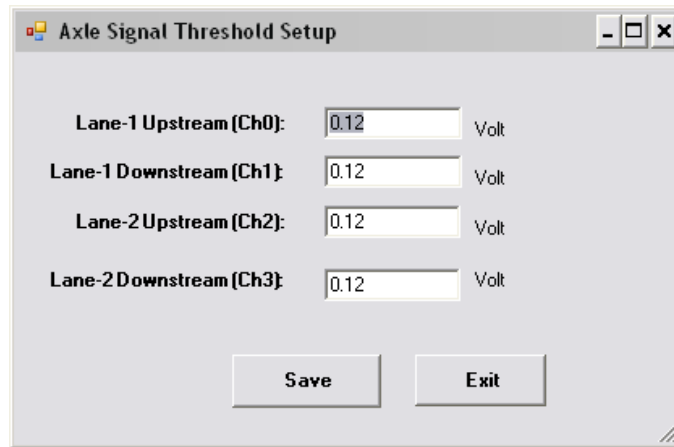


Figure 32: Axle signal threshold setup

4.3.9 Lane Speed Reference Setup

Vehicle speed in PWIM is computed using activations of two weigh-pads (axle sensors) per lane. Since the distance between two weigh-pads are known, time difference of activations gives the speed information. If one of the weigh-pads fails and does not produce any axle signals, speed cannot be computed, and, subsequently, no weights and axle spacing. Unfortunately, losing one axle signal can happen even if two sensors work perfectly. For example, if a vehicle changes lane after passing the first sensor, the second sensor is not activated. Another case it happens is that, if the threshold level of one sensor was set too high, only the other sensor produces axle signals.

One way of overcoming this problem is using one of the adjacent lane speeds. Consider the setup in Figure 33. In this setup, Lane-2 is the passing lane and its traffic is 5 percent faster than Lane-1. This setup says, if one of the Lane-1 axle sensors fails, speed is borrowed from Lane-2 but by decreasing it by 3 percent. If one of the Lane-2 axle sensors fails, Lane-1 speed is borrowed but by increasing it by 5 percent.

Any axle sensor failure is a serious error and reported in the vehicle record data but the vehicle record is still computed using the neighboring lane speed. If both axle sensors of the lane fail (i.e., if the referenced lane fails), vehicle record is no longer computed and a “both axle failure” error is reported.

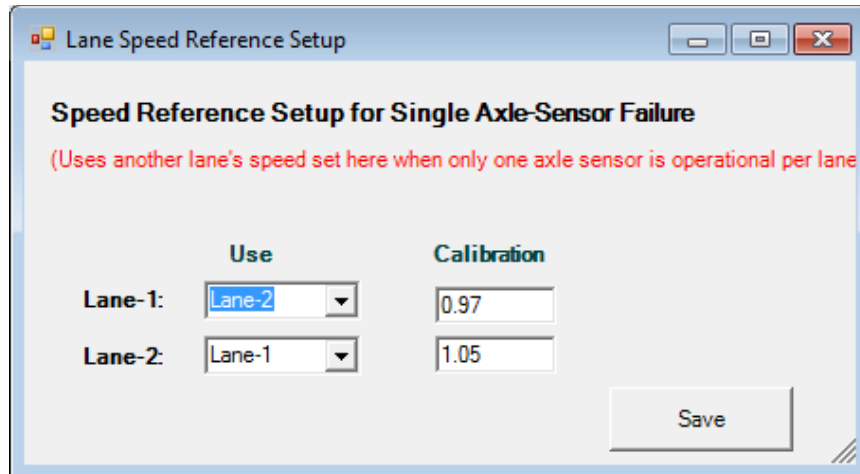


Figure 33: Lane speed reference setup window

4.3.10 Initial Lane Speed Setup

The PWIM system deployed does not know what a typical traffic speed of each lane is at the beginning. This initial speed estimate must be entered by user using the “**Settings\Initial Lane Speeds**” menu. This setup window is shown in Figure 34. This speed information is used to compute initial vehicle spacing, i.e., rear axle of the first vehicle to front axle of the second vehicle. Once the real speed is computed for the first vehicle, a moving average of traffic speed is maintained by system, and initial speed is no longer used.

This value should be set using **a typical or an average traffic speed** of the lane at the time of the PWIM program start.

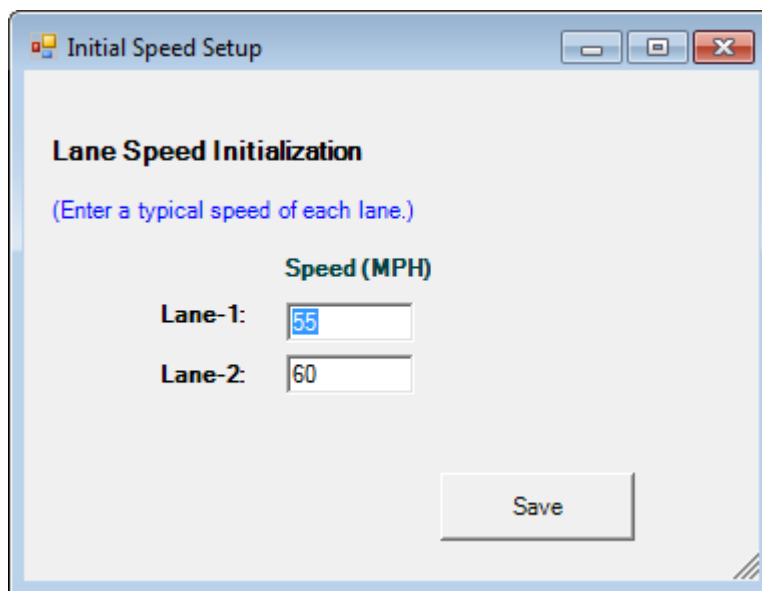


Figure 34: Initial speed setup window

4.3.11 Activate Settings

All setup parameters must be saved before closing the setup window. These saved parameters must be activated so that the PWIM system use them. All parameters related to real-time computation, such as calibration factors, ESAL setup, limit parameters, speed reference, etc., are activated by the “**Settings\Activate Settings**” menu. However, this command cannot activate the parameters in the Site Setup.

In order to completely activate all parameters, restart of the PWIM program is required. Restart, i.e., “File/Restart”, activates all setup parameters including the parameters in Site Setup.

4.3 Data Format

The weigh-pad system produces text-based CSV files for WIM data. The filename follows a format that consists of the date and site ID text strings as follows:

yyyymmdd.###.csv

where yyyymmdd is (year, month, day) and ### is the three digit site ID. The column format is summarized in Table 2. The columns up to #32 are identical to the BullConverter column format. The 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 site folder, “Site_###”, which again is a part of the data root path defined in the Site Setup menu.

Table 2: Weigh-Pad CSV Column Format

Column Number	Column name	Description
1	Index	Vehicle record is numerically indexed and this column shows the index
2	Lane#	Lane number of 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. It contains total 11 fields separated by comma.
17-28	Axle weights(AW): AW1,...,AW12	Axle weights in Kips. It contains total 12 fields separated by comma.
29	GVW	Gross Vehicle Weight (GVW) in Kips. It is simply a summation of each axle weight.
30	Class	Vehicle class determined by the classification algorithm
31	Err#	It is a numeric code that represent an error (See Table 3 for detail)
32	100thSec	100 th seconds of the time in Column 3.
33	pavTemp	Pavement temperature in Fahrenheit

References

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

[2] T. M. Kwon, (2012) Development of a Weigh-Pad-Based Portable Weigh-In-Motion System, Final Report Mn/DOT 2012-38, Minnesota Department of Transportation, St. Paul, MN.

[3] Y. H Huang, (2004) *Pavement Analysis and Design, 2nd Edition*, Pearson Prentice Hall, Upper Saddle River, NJ.