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Texas A&M Transportation Institute

# Implementation of Portable Weigh-In-Motion (WIM) Technology on Texas Highways: Technical Report

Technical Report 5-6940-01-R1

Cooperative Research Program

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16. Abstract

There are a limited number of available permanent WIM stations on the Texas highway network. As such, it is not feasible to generate accurate load spectra data required for pavement design, maintenance, and rehabilitations on every highway project. The net result is unoptimized designs or poor performing pavement structures with increased maintenance costs or high construction costs due to over-designing, with high overall life cycle costs. Deployment of portable WIM technology can offer a practical alternative or supplement as a cost-effective tool to rapidly measure and quantify traffic loading for any given highway site. In research project 0-6940, Develop Systems to Render Mechanistic-Empirical Traffic Data for Pavement Design, portable WIM technology has been successfully explored and demonstrated to accurately measure and collect site-specific traffic data from the intended highway location to supplement the permanent WIM station data for pavement designs and maintenance or rehabilitation. Therefore, statewide portable WIM system implementation was imperative in order to collect traffic data where permanent WIM stations are not available.

In this implementation project, standardized procedures and guideline was developed to aid users understand more thoroughly the portable WIM system deployment and its operation for traffic data collection. The guideline includes portable WIM system components, site selection, installation, calibration, troubleshooting, and data analysis. Additionally, long-term portable WIM experimentation and demo-monitoring stations were established for demonstration, training, and certification at the TTI RELLIS campus and several in-service highways. The demo-monitoring stations are operational and have been very instrumental in providing technical support for the ongoing statewide portable WIM traffic measurements and data collection efforts.

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# IMPLEMENTATION OF PORTABLE WEIGH-IN-MOTION (WIM) TECHNOLOGY ON TEXAS HIGHWAYS: TECHNICAL REPORT

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# DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of this project was Lubinda F. Walubita.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AADT | Average annual daily traffic |
| AADTT | Average annual daily truck traffic |
| ADT | Average daily traffic |
| ADTT | Average daily truck traffic |
| ALD | Axle load distribution |
| ALDF | Axle load distribution factor |
| ALS | Axle load spectra |
| ASTM | American Society for Testing Materials |
| ATHWLD | Average ten daily heaviest wheel load |
| EB | Eastbound |
| ESAL | Equivalent single axle load |
| FHWA | Federal Highway Administration |
| FM | Farm-to-market |
| FPS | Flexible Pavement System |
| GVW | Gross vehicle weight |
| HDF | Hourly distribution factor |
| IH | Interstate Highway |
| IRD | International Road Dynamics |
| KNN | K-Nearest Neighbors |
| LEF | Load equivalent factor |
| LiDAR | Light Detection and Ranging |
| LS | Load spectra |
| M/R | Maintenance or rehabilitation |
| MAF | Monthly adjustment factor |
| ME | Mechanistic-empirical |
| MESAL | Million equivalent single axle load |
| ML | Middle Lane |
| MNT | Maintenance Division |
| MS | Microsoft |
| MTD | Materials and Testing Division |
| NB | Northbound |
| NCHRP | National Cooperative Highway Research Program |
| OW | Overweight |
| SB | Southbound |
| SH | State Highway |
| T-DSS | Traffic data storage system |
| TF | Truck factor |
| TRS | Traffic Recording System |
| TTI | Texas A&M Transportation Institute |
| TxDOT | Texas Department of Transportation |
| TxME | Texas Mechanistic-Empirical Flexible Pavement Design System |
| USB | Universal Serial Bus |
| USDOT | United States Department of Transportation |
| VBA | Visual Basic for Applications |

| | |
|---|---|
| VCD | Vehicle classification distribution |
| WB | Westbound |
| WIM | Weigh-in-motion |

# CHAPTER 1. INTRODUCTION

Axle load spectra or axle load distribution factors constitute a crucial part of the primary traffic data input for the mechanistic-empirical (ME) pavement design. Typically, site-specific traffic load spectra data—generated from weigh-in-motion (WIM) systems—is used during the pavement design process to ensure optimal pavement structural design. However, due to high costs, there are a limited number of available permanent WIM stations on the Texas highway network (mostly located on interstate highways). As such, it is not feasible to generate accurate load spectra data required for every highway project other than relying on antiquated estimates, even for the 18-kip equivalent single axle loads (ESALs) used in Flexible Pavement System (FPS) designs. The net result is unoptimized designs or poor performing pavement structures with increased maintenance costs or high construction costs due to over-designing, with high overall life cycle costs. Successful statewide implementation and calibration of the mechanistic-empirical (ME) pavement design methods are also highly dependent on the availability of accurate axle load spectra data, and so is the need for rapid quantification of accurate site-specific traffic data.

At a fraction of the cost of permanent WIMs, the portable WIM technology offers a practical alternative or supplement as a cost-effective tool to rapidly measure and quantify traffic loading (i.e., volume counts, vehicle class distribution, speed, vehicle weights, ESALs, FPS/ME inputs) for any given highway site. In research project 0-6940, Develop Systems to Render Mechanistic-Empirical Traffic Data for Pavement Design, portable WIM technology has been successfully explored and demonstrated to accurately measure and collect site-specific traffic data from the intended highway location to supplement the permanent WIM station data for pavement designs and maintenance or rehabilitation (M/R) purposes. In this implementation project, standardized procedures and guideline was developed to aid users understand more thoroughly the portable WIM system deployment and its operation for traffic data collection. The guideline can be used as a main guide for the portable WIM system implementation on Texas highways. Additionally, long-term portable WIM experimentation and demo-monitoring stations were established for demonstration, training, and certification at the TTI RELLIS campus and several in-service highways.

## PROJECT OBJECTIVES

As a supplement to the limited permanent WIM stations, one of the primary goals of this project was to implement the portable WIM system technology for generating ME design-ready traffic data for pavement design. In line with this goal, the specific objectives of the project were as follows:

- Implement the portable WIM system technology on the Texas highway network.
- Provision of site-specific traffic data support to the Texas Department of Transportation (TxDOT) Districts for pavement design and rehabilitation.
- Develop standardized procedures and guidelines for the portable WIM system deployment which include portable WIM system components, site selection, preparation, installation, calibration, site maintenance, and data processing and analysis.

## RESEARCH TASK AND WORK PLAN

To achieve the objectives of the project, researchers:

- Provided standardized procedures and guidelines for portable WIM system installation and data analysis to assist the Maintenance Division (MNT), Materials and Testing Division (MTD), Receiving Agency districts, and other stakeholders to implement and readily use the new system.
- Established demonstration and experimentation stations at TTI RELLIS campus and in-service highways for training, demonstration, portable WIM calibration, documentation, improvement, and general technical support.
- Conducted portable WIM system site-specific traffic measurements on selected highways, on-site training, and workshops.

## REPORT CONTENTS AND ORGANIZATION

This report consists of seven chapters including this one (Chapter 1), which provides the background, research objectives, methodology, and scope of work. The rest of the chapters are organized as follows:

- Chapter 2—Literature review.
- Chapter 3—Portable WIM system guideline.
- Chapter 4—Portable WIM traffic data collection and analysis
- Chapter 5—Experimentation, training, and demonstration station.
- Chapter 6—Microsoft (MS) ® Access ME traffic database.

Chapter 7 summarizes the report and includes a list of major findings and recommendations. Some appendices containing important data are also included at the end of the report.

## SUMMARY

This first chapter of the report presented an overview on the background and the work performed throughout the project. The chapter also provided a brief description of the research tasks, the research methodology, and the structuration of the report contents. Specifically, this report provides a documentation of the work accomplished throughout the whole project period.

# CHAPTER 2. LITERATURE REVIEW

This chapter of the report provides a summary review of extensive information and literature search of WIM sensors and accuracy, American Society for Testing and Materials (ASTM) WIM specifications, and portable WIM system description. Different WIM sensors and sensors used for portable WIM system are discussed. Additionally, the ASTM standards for WIM accuracy are also described.

## WIM SENSORS AND ACCURACY

Depending on the system functionality, WIM system utilizes different types of sensors, such as bending plate sensors, load cell sensors, polymer piezo sensors, quartz piezo sensors, etc. Table 1 provides a list the measurement mechanisms and different WIM sensor types that are available on the commercial market.

**Table 1. Summary of Various WIM Sensors (USDOT, 2018)**

| Measurement/Sensor Type | Strength | Weakness | Installation Method | Recommended Use |
|---|---|---|---|---|
| Load cell | High accuracy | High cost, high maintenance | Used in concrete only, destructive | Highway monitoring, highway design and planning, pre-screening |
| Bending plate | High accuracy | High to moderate cost | Used in concrete only, destructive | |
| Quartz piezo | High accuracy, low maintenance | Moderate cost | Destructive | |
| Polymer piezo | Low cost, low maintenance, portable | Low accuracy, temperature sensitive | Non-destructive (pocket tape method) | Highway monitoring, design, planning, and pavement damage assessment |

Typically, portable WIM systems used for traffic data collection and monitoring utilize polymer piezo sensors due to their low capital and installation costs, among other factors (PBS&J & E-Squared Consulting Corporation, 2008), whereas load cell, bending plate, and quartz piezo sensors are mostly used for freight monitoring and overweight trucks screening due to high accuracy. The FHWA has indicated that both bending plates and load cell sensors can provide more accurate data than other types of sensors. Therefore, they are best suited for weight enforcement and pre-screening applications. However, the installation of these sensors is more intrusive to the pavement structure and time consuming with lengthy traffic flow disruptions as opposed to polymer piezo sensors which are non-destructive and portable (Cambridge Systematics Inc, 2009).

## THE ASTM WIM STANDARDS AND SPECIFICATIONS

Currently in the United States, the ASTM E1318-09 'Standard Specification for Highway Weigh-In-Motion Systems with User Requirements and Test Methods' (ASTM, 2017) from the American Society for Testing Materials (ASTM) is being used as the standard guideline for local approvals or just to classify WIM systems. The ASTM E1318-09 specifies four different types of WIM systems, depending on the application and functional performance requirements. Type I and II systems are mostly used for traffic data collection purposes, while Type III systems are used for overweight screening. Type IV systems are not yet approved to be used in the United States but are intended for use for low-speed weighing at the weigh stations (USDOT, 2018). Table 2 shows a summary of performance specifications of three different WIM types as per ASTM E1318-09. As of 2018, Type IV WIM systems had not yet been approved for use in the United States, therefore, the specifications for these systems are not listed in Table 2.

**Table 2. ASTM E1318-09 Functional Performance Requirements for WIM Systems (ASTM, 2017)**

| Function | Tolerance for 95% Compliance | | |
|---|---|---|---|
| | Type I | Type II | Type III |
| Wheel load (single or dual tires) | ± 25% | | ± 20% |
| Axle load | ± 20% | ± 30% | ± 15% |
| Axle-group load | ± 15% | ± 20% | ± 10% |
| Gross vehicle weight (GVW) | ± 10% | ± 15% | ± 06% |
| Speed | ± 1 mph | | |
| Axle-spacing and wheelbase | ± 0.5 ft | | |

Portable WIM systems installed using polymer piezo sensors can provide a gross vehicle weight (GVW) measurement accuracy within 15 percent of the actual vehicle weight for 95 percent of the trucks measured during data collection, which meets the requirement for ASTM E1318-09 Type II WIM systems. However, with proper installation and frequent calibration, polymer piezo sensors can provide weight data that meet the ASTM E1318-09 Type I WIM systems where the GVW measurement accuracy is within 10 percent (USDOT, 2018). Researchers have successfully used the portable WIM system on several Texas highways to collect site-specific ME-compatible traffic data, with an accuracy of 87~90 percent in the data (Faruk, et al., 2016). With some modifications and enhancement of the installation method for the portable WIM system, an accuracy of ± 6.5 percent can be achieved. Key contributing factors to this accuracy improvement have been a rigorous on-site calibration regime, proper site selection, and improved sensor installation techniques through use of metal plates.

## USE OF PORTABLE WIM SYSTEMS

While permanent WIM stations have been commonly used by the Federal Highway Administration (FHWA) and other state transportation agencies, the portable WIM systems can be an optimal and cost-effective solution for traffic monitoring and planning purposes (Walubita et al., 2019). However, there are limited studies that have objectively evaluated the portable WIM system applicability, ease of handling, and reliability of the obtained data. Kwon (Kwon, 2012) developed a weigh-pad-based portable WIM system to perform evaluative comparison with permanent WIM stations on Minnesota highways. The corresponding results indicated good correlations between the portable and permanent systems in terms of the gross vehicle weight (GVW), speed, and axle specification data. Refai et al. (2014) also implemented a portable WIM system for traffic data collection on Oklahoma highways and found that at merely 10 percent of the cost to be a feasible option to permanent WIM systems.

Portable WIMs are very practical and ideal for collecting and generating site- or project-specific traffic data in areas where permanent WIM stations are unavailable, such as farm-to-market (FM) roads in Texas. On highway locations high-volume roads where the permanent WIM stations are available, use of portable WIMs is not necessary unless as a supplement or where site-specific traffic data are needed. Nonetheless, permanent WIM stations are considered the most accurate and desired method of generating traffic data. However, the associated costs (e.g., installation, operation, maintenance) are some of the key challenges limiting the statewide installation of permanent WIM stations on most of the state's road network. Portable WIM systems, on the other hand, are cheaper, cost-effective, and easy to deploy at any desired highway location to collect and generate site- or project-specific traffic data with reasonable accuracy (± 90 percent), especially on the rural low-volume road network—where in most cases, the costlier permanent WIM stations are unavailable. Thus, portable WIMs serve as a cost-effective and practical supplement for site-specific traffic data collection (volume counts, speed, VCD, and vehicle weight measurements).

## SUMMARY

This chapter reviewed and presented different WIM sensors comparison, the ASTM WIM standards, the portable WIM system accuracy, and the use of portable WIM system. Typically, portable WIM systems utilize polymer piezo sensors to their low costs and non-destructive method installation (pocket-tape method). Portable WIM systems installed using polymer piezo sensors can provide a GVW measurement accuracy within 15 percent of the actual vehicle weight for 95 percent of the trucks measured during data collection. However, with proper installation, polymer piezo sensors will provide weight data that meet the ASTM E1318-09 Type I WIM systems where the GVW measurement accuracy is within 10 percent. Ultimately, with proper site selection and improved installation methods, an accuracy of portable WIM system traffic data within 6.5 percent can be achieved.

While permanent WIM stations are the preferred methods, installation and operational costs limit the statewide installation of permanent WIMs on the state's road network. Portable WIMs are a cost-effective and practical supplement for site-specific traffic data collection (volume counts, speed, VCD, and vehicle weight measurements).

# CHAPTER 3. PORTABLE WIM SYSTEM GUIDELINE

This chapter of the report presents a comprehensive summary of portable WIM system procedures and guidelines that include:

- Portable WIM system components
- Portable WIM site selection methods
- Portable WIM installation and calibration
- Portable WIM troubleshooting and maintenance
- Traffic data processing and analysis
- Generation of FPS and TxME traffic input.

A detailed and comprehensive guideline for deploying portable WIM system can be found in the TTI's standardized guidelines and procedures for portable WIM installation, calibration, and data analysis.

## PORTABLE WIM SYSTEM COMPONENTS

Portable WIM system consists of several main components and support accessories. The main components for the deployment of the TTI's hybrid portable WIM system for one lane requires a traffic recording system (TRS) unit, two piezoelectric sensors, two custom-made metal plates with the end caps, piezo channel box, and an energy recharging system that includes 12-volt battery, solar panel, and solar charger controller. Optionally, a modem system can also be added to the system to enable real-time remote access to the WIM data and monitor the functionality of the deployed system. The main components needed for the installation of portable WIM system on one lane of a road section include the following:

- **TRS Unit** – A traffic recording machine to collect traffic data in portable WIM system, which includes volume data, speed data, classification data, weight data, etc. (Figure 1).

**Figure 1. TRS Unit (IRD, 2021).**

- **Set of two Polymer Piezoelectric Sensors** – 6-ft or 8-ft long sensors that can be used depending on the lane width and plates in use (Figure 2).

**Figure 2. Piezoelectric Sensor (IRD, Piezoelectric Sensors, 2021).**

- **Set of two Metal Plates –**The use of the metal plates is essential as it homogenizes the vibration from vehicles and reduces potential noise on data quality due to pavement distresses (Figure 3).

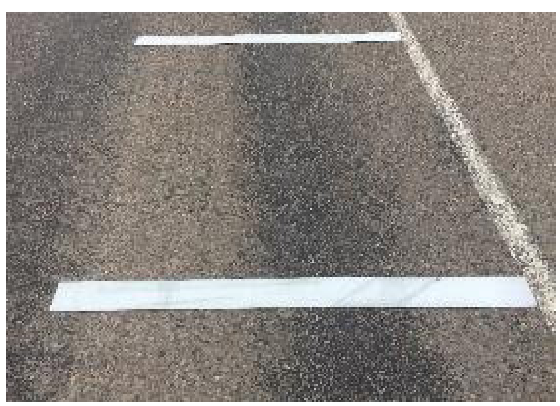


**Figure 3. Metal Plates Placement on the Road**

- **Set of two custom-made metal ramps (end caps)** – The metal ramp is used as end caps for the metal plates to cover the sensor cable connection (Figure 4). When placed above the sensor cable connection, the metal ramp protects the cable sensor from incoming vehicles.

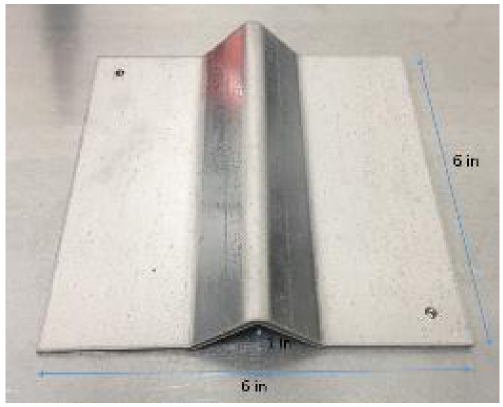



**Figure 4. Metal Ramp.**

- **Piezo Channel Box (Piezo Inputs)** – An adapter to connect multiple piezoelectric sensors (BNC connectors) to the TRS unit (18-pin connectors) (Figure 5).

**Figure 5. Piezo Channel Box.**

- **Battery (12 volt)** – Needed to keep the TRS unit charged continuously (Figure 6).


**Figure 6. 12-Volt Battery.**

- **Solar Panel –** Used for harnessing ambient solar energy to recharge the 12-volt battery, allowing the system to function properly with no energy outage in the long term (Figure 7).

**Figure 7. Solar Panel.**

- **Solar Charger Controller** – A device used to regulate the voltage and current received from the solar panel to charge the 12-volt battery safely and keep the battery from overcharging (Figure 8).

**Figure 8. Solar Charger Controller.**

- **Mastic Tapes** – The mastic type uses a rubberized asphalt base as its adhesive (Figure 9). The tapes required for the sensor installation include the following:

    - Pocket tapes: Piezoelectric sensors are imbedded and protected in the pocket tapes to last longer, keep functioning properly, and provide accurate data.
    - Road tapes: Road tapes are also necessary to provide more protection to the sensors.

These mastic tapes are recommended to be used for temperatures of 55°F and higher, otherwise the tapes will not adhere properly.

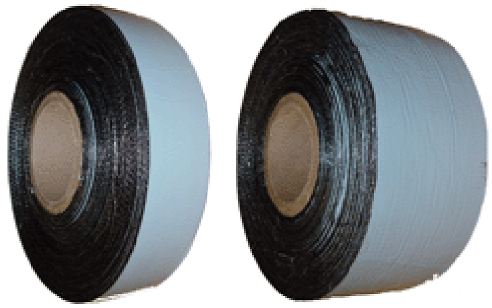


**Figure 9. Mastic Tapes.**

- **Metal Box** – It is highly recommended to keep all portable WIM main components inside of the metal box to protect from extreme weather. The metal box (Figure 10) should be locked and placed close by the pole with chains for added security against theft.

**Figure 10. Metal Box.**

- **Modem System** – It enables users to access real-time portable WIM traffic data remotely and monitor the functionality of the deployed portable WIM system using the IRD® Road Reporter II software (Figure 11).


**Figure 11. Modem System.**

## PORTABLE WIM SYSTEM SITE SELECTION

Selecting portable WIM installation location is required before heading to the field and starting the installation. Google® Map and Google Street View are useful tools that can be used to check and study the location. Additionally, conducting a site survey manually would also be helpful as the maps of several locations on Google Map are occasionally not updated. These are considerations in selecting an ideal highway site for a portable WIM system deployment:

- The portable WIM should be installed at minimum or more than 200 ft away from a bridge, intersection, curve, etc., to ensure all vehicle axles (steering and rear axles) pass through the sensors.
- Install portable WIM sensors where there is a continuous flow of traffic and avoid installing in an area where vehicles will stop, accelerate, or slow down on the sensors (e.g., installing portable WIM sensors near intersection, parking areas, bus stops, areas with heavy congestion, loading zones, etc.).
- Install the portable WIM sensors perpendicular to the flow of traffic.

- A site with a permanent pole is preferable (not temporary pole) due to the needs of mounting a solar panel and attaching a modem antenna.
- Metal plates should be installed on dry and clean flat pavement without any distresses such as cracking and rutting.

There are different schematic plans for installing portable WIM system, depending on the location conditions and total lanes for each direction as followings:

1. Single lane in each direction

Two 6-ft or 8-ft portable WIM sensors and one TRS unit installed for each lane (See Figure 12–Figure 13).

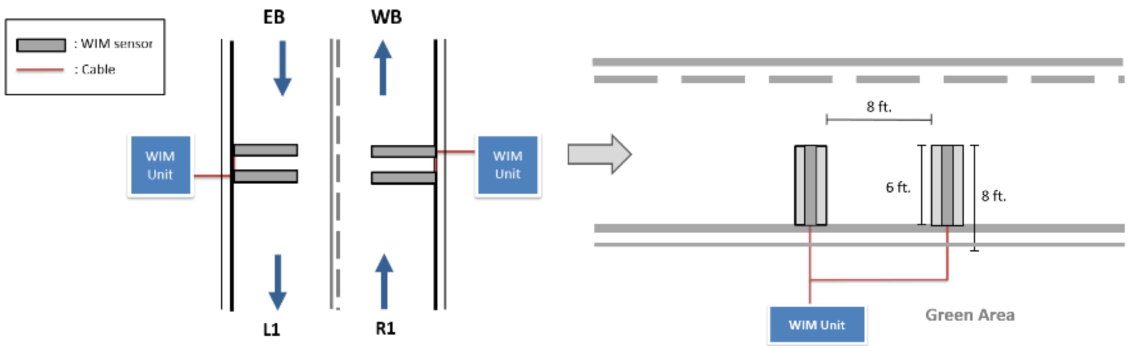



**Figure 12. Portable WIM Installation Schematic Plan for Single Lane Using 6-ft Sensors.**

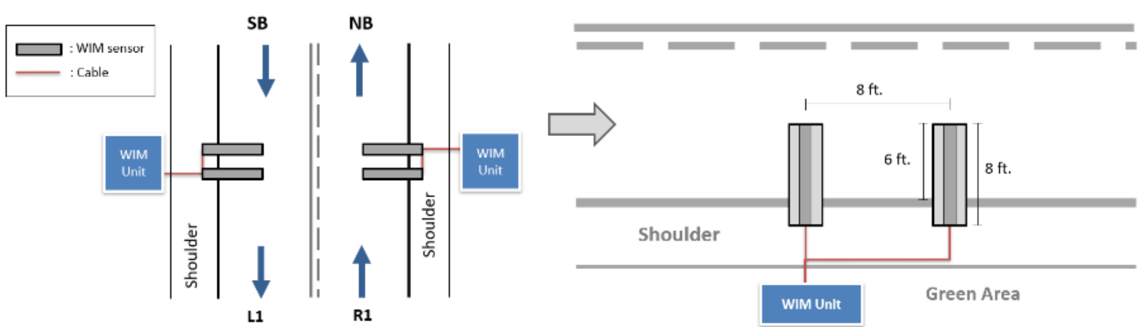



**Figure 13. Portable WIM Installation Schematic Plan for Single Lane Using 8-ft Sensors.**

2. Two lanes in each direction (outside lane only)

Two 6-ft or 8-ft portable WIM sensors and one TRS unit installed on outside lane for each direction (See Figure 14).

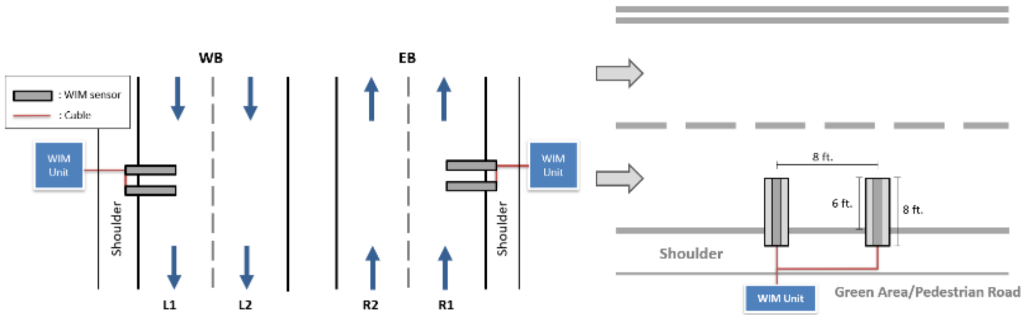



**Figure 14. Portable WIM Installation Schematic Plan for Outside Lane.**

3. Two lanes in each direction (outside and inside lane)

Two 6-ft or 8-ft portable WIM sensors installed on outside and inside lanes with one TRS unit for each direction (See Figure 15).

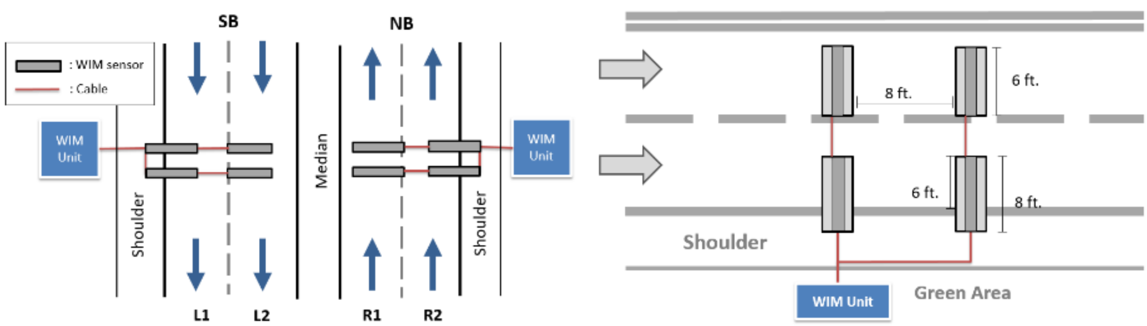



**Figure 15. Portable WIM Installation Schematic Plan for Outside and Inside Lanes.**

4. Multiple lanes in each direction (outside, inside, and/or middle lane)

Two 6-ft or 8-ft portable WIM sensors installed on outside, inside, and/or middle lanes with one TRS unit for each direction (See Figure 16).

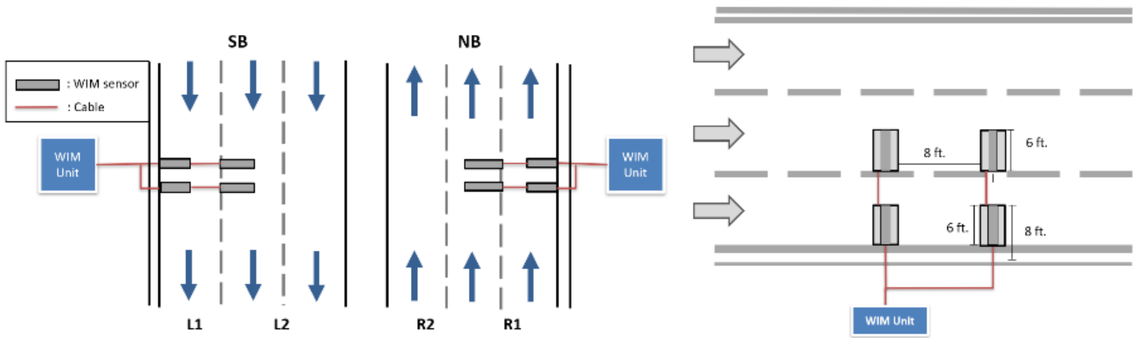



**Figure 16. Portable WIM Installation Schematic Plan for Outside and Middle Lanes.**

5. Multiple lanes in both directions

   Two 6-ft or 8-ft portable WIM sensors installed for each direction and one TRS unit installed for both directions (See Figure 17).

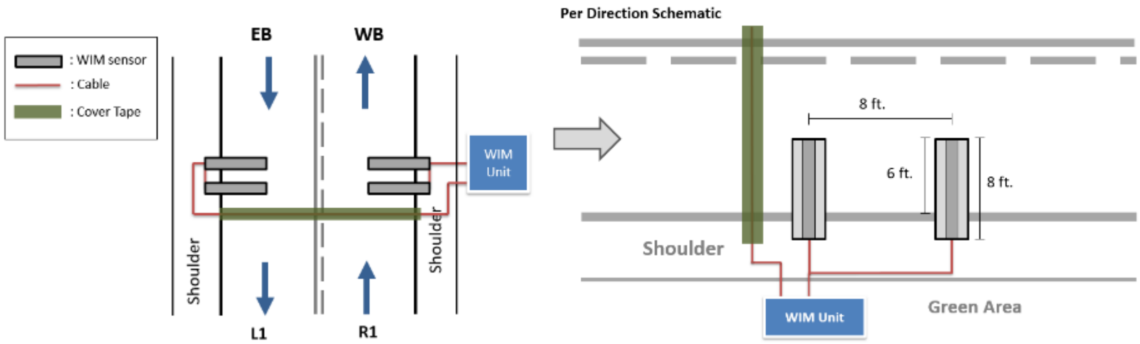



**Figure 17. Portable WIM Installation Schematic Plan for Both Directions.**

## PORTABLE WIM SYSTEM INSTALLATION

Depending on the site environment or condition, installation methods may need to be changed or improvised; therefore, engineering judgement is always needed whenever evaluating the portable WIM site condition and installation process. Once the appropriate installation site has been identified, portable WIM system installation can be initiated by placing two metal plates on top of the pavement with the distance of 8 ft between each plate and placed across the roadway by half of the width of lane. The installation point must be a flat section with no or minimal pavement distress (e.g., cracks, rutting, potholes). Each piezoelectric sensor is imbedded into a devised pocket tape then pasted on top of the metal plate. Once the sensors have been tested to ensure they are working properly, the remaining part of metal plates, pocket tapes, and sensor cables can be covered with additional road tapes and TRS unit, piezo channel box, solar charger controller, and 12-volt battery are kept inside the in-house metal-protective box. In addition, solar panel is also installed on the pole and connected to solar charger controller. Once the TRS unit is ready to be operated, portable WIM traffic data collection can be started.

It is recommended to have at least 7 days of data to ensure complete weekly data. It is not recommended to include the data from the first day (the day of portable WIM system is initially installed) for portable WIM traffic data processing and analysis as the system is still calibrating. On a few cases, the weight calibration of the portable WIM system may take more than one day depending on the volume of the FHWA class 9 trucks (FHWA class 9 vehicles are used as a reference for auto calibration in most cases).

The basic concept of portable WIM sensors is as vehicles pass over the plates, the sensors record the pressure, acceleration, strain, or force from the axle and wheel of vehicles, which are thereafter, converted to an electrical charge and transmitted to the traffic counter TRS unit. The sensors are connected to the TRS unit via piezo channel box. The TRS records the pulses, processes them to generate per-vehicle data including the vehicle class, speed, axles spacing, axles weight, and gross vehicle weight (GVW). Each day per-vehicle traffic data is stored by the TRS unit. These raw files are downloadable remotely (if a modem system is in use) or directly from the TRS using a universal serial bus (USB) flash drive. The raw files can then be converted into excel compatible (.csv) format using the IRD Road Reporter II software. A detailed and comprehensive guideline for installing portable WIM system can be found in the TTI's standardized guidelines for portable WIM installation, calibration, and data analysis (Prakoso et al., 2021).

## PORTABLE WIM SYSTEM CALIBRATION

It is highly recommended for the WIM sensors to be calibrated so that the unit can report axle weight accurately. The TRS unit calculates axle weights by multiplying the input signal from the piezoelectric sensors installed on the pavement by a scaling number to produce the axle weight. Theoretically, all sensors would produce an identical signal under all site conditions. However, in the field, each sensor output varies slightly and can change depending on installation method, temperature, pavement condition, and other variables. Therefore, calibration factor is needed as a parameter that can produce a weight that is closer to actual axle weight. The

TRS unit has two methods for on-site calibration, namely manual calibration and auto calibration. Additionally, there is also off-site post calibration whenever on-site calibration needs to be verified or on-site calibration is not conducted.

On-Site Manual Calibration: Performing an initial manual calibration can greatly reduce time it takes for auto-calibration of the sensors. The calibration factor is manually set for each axle sensor using a test vehicle with known axle weights and axle spacing. Performing manual calibration is described as follows:

1. Pass over the piezoelectric sensors using a test vehicle at a constant speed, preferably a Class 9 truck. In lieu of Class 6 truck, a Class 6 dump truck that is readily available in most TxDOT districts can be used.
2. After the vehicle information is displayed, record all axle weights and the gross weight.
3. Calibration factors should be adjusted, until the TRS unit is weighing the test vehicle within tolerance of about ±5% for the steering axle weight. Note that for calibration purposes, a stringent ±5% error difference from the static weight measurements should be used for the steering axle weight. The steering axle weight is generally used as the reference datum as its weight is theoretically considered not to vary much as compared to the other axles, particularly as the gross vehicle weight changes.
4. Once the unit is weighing within tolerance, several passes of the test vehicle should be recorded and add up the total GVW to obtain the average GVW.
5. Divide the static weight by the average WIM GVW.
6. Multiply the old calibration factor by the ratio in order to get the new calibration factor. The basic formula for the final calibration factor is:

$$\text{New Factor} = \text{Old Factor} * \frac{Static\ Weight}{Average\ WIM\ Weight}$$

**Example:**

Static weight = 84000 lb

Average WIM weight = 80000 lb

Old calibration factor = 2000

New calibration factor = 2000 * $\frac{84000}{80000}$ = 2100

<u>On-Site Auto Calibration</u>: Selecting the auto calibration option makes the TRS unit automatically calibrate axle weights using a statistical method to keep a running average of the front axle weights of a specified vehicle class. The way TRS unit does auto calibration is by averaging the front axle weight of a specified vehicle class for a specified number of that vehicle type. It compares the average sampled weight with the entered statistical mean weight of the front axle for that vehicle class, and if there is a difference between the two weights, the calibration factor for each sensor will be automatically adjusted by the system so that the calculated values match the configured target weight.

<u>Off-Site Post Calibration</u>: Post calibration primarily serves as a supplement and verification of the on-site calibration, but it is also very helpful in situations where on-site calibration was not conducted. Post calibration is generally conducted off-site during data processing and involves filtering all the Class 9 trucks, averaging their steering axle weights, and then, computing a representative *CF* as expressed below:

$$CF_{Post} = \frac{Wt_{Std(C9)}}{Wt_{avg}}$$

$CF_{Post}$ is the calibration factor; $Wt_{std(C9)}$ is the standard Class 9 truck steering axle weight, and $Wt_{std}$ is the average of all the measured Class 9 truck steering axle weights. Post calibration is an automated process using an Excel Macro and is essentially conducted to recheck the accuracy of the axle weight measurements, and if needed, apply some post-calibration (namely *CF*) to the traffic data prior to analysis. If the on-site calibration was correctly executed, $CF_{Post}$ should basically be equal to 1.0, i.e., $CF_{Post} \cong 1.0$.

## PORTABLE WIM SYSTEM TROUBLESHOOTING AND MAINTENANCE

There are several problems that might occur during portable WIM installation, the followings are several tips on possible causes of the problem:

- TRS unit is not turning on:
  - Check the battery to make sure it is above 5.5 volts.
  - Verify battery harness is connected properly.
- TRS unit is not counting:
  - Check to see if the sensors are operating under the System/Diagnostics menu.
  - Ensure the TRS unit is programmed correctly, and the sensors are operating correctly.
  - Check the sensor connections to be sure they are attached properly in order.
  - Try different piezo channels or another piezo channel box.
  - Check the sensitivity settings on the TRS unit.
  - Ensure the piezo channel box is connected to the correct port.
- TRS unit is not getting charged by the 12-volt battery:
  - Check charger to ensure it is working properly by connecting it to other TRS units.
  - Check battery to ensure it will take and retain a charge.
  - Ensure the solar panel is installed on the proper position to receive good exposure to direct sunlight.
  - Ensure the solar panel is outputting enough voltage to charge the battery.
  - Check the solar charger controller to ensure it regulates the voltage and current coming from the solar panel to the battery properly.
  - Ensure the positive and negative cables of the solar panel and solar charger controller are connected correctly.
- Modem unit is not functioning properly:
  - Ensure that the modem is connected to a sufficient power supply.

- Ensure that the modem is getting cellular signal.
- Check the light indicators of the modem and ensure that they are bright green.

In order to ensure all the portable WIM system can function properly after the deployment of the system, maintenance of portable WIM system components need to be performed regularly. TRS unit is the main core of the portable WIM system; therefore, TRS system needs to be checked regularly before and after deployment. Ensuring the TRS units to be fully charged is important because once TRS battery reaches zero capacity; the unit can no longer be charged; therefore, the old battery inside of the TRS unit needs to be replaced with a new battery.

Once the portable WIM system is installed on the site, it is recommended to perform routine maintenance by going to the site and checking the TRS unit, the sensors, and the mastic tapes regularly. When performing routine maintenance, it is important to perform quality control on the mastic tapes applied on the pavement, whether they remain intact. If some parts of the tapes get worn out, applying more road tape is necessary. The TRS unit should also be still fully charged, recording data, and capturing the appropriate traffic.

## PORTABLE WIM DATA ANALYSIS MACROS

To ensure consistency and accuracy, portable WIM macro was developed using Visual Basic for Applications (VBA) to automate the processing, analysis, and generation of the required general traffic parameters and ME inputs. The portable WIM macro is a MS Excel (.xlsm) file that is used to analyze the raw data that has been retrieved and exported from the TRS Unit. The portable WIM macro is managed in MS Excel VBA platform as MS Excel is able to support various computing methodologies required for the data analysis and is compatible with most computer machines. Essentially, the macro requires the raw data from the TRS unit to generate Mechanistic-Empirical (ME) compatible traffic data. The purpose of the Portable WIM Macro is to generate ME compatible traffic data for pavement design from the raw data obtained through WIM. Figure 18 shows the portable WIM macro main screen.

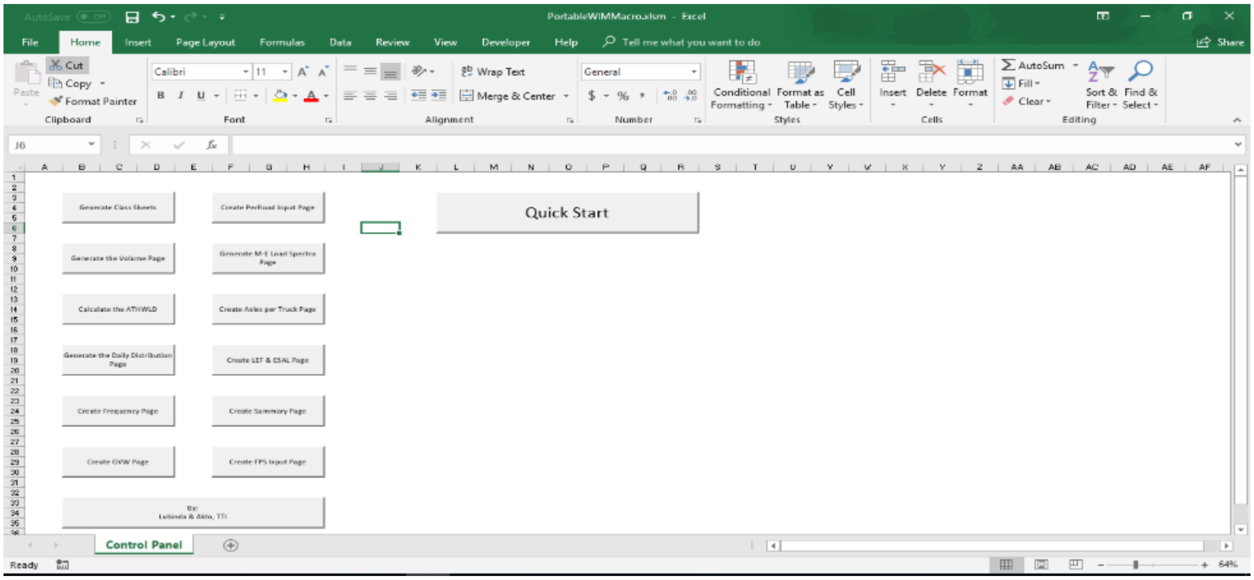



**Figure 18. Portable WIM Macro Main Screen.**

There are several buttons on the main screen of the program. To execute the portable WIM macro, the user can simply click on the Quick Start button on the right side of the screen, pick the destination folder where the result of the macro will be saved, and then pick the raw data files to be analyzed. It is recommended for users to select the Quick Start option since all data (e.g., volume, speed, weight, classification) can be generated in one single process. The left side of the screen shows several options with different functions. These options allow more specific and customized data analysis if the user desires to do so. In addition, minimum of seven days data is required to ensure complete weekly data analysis.

The data analysis file is in .xlsm format, and this file contains all the ME compatible traffic data of the analyzed highway. The data analysis file consists of several worksheets containing the data results and calculations. Some of the featured worksheets are described as follow:

- **Vol-Class-Speed** – Summary sheet of the report, which contains the volume traffic data (ADT, ADTT, %Trucks, etc.), vehicle class distribution graph, and speed data.
- **FPS Input** – Contains input values necessary for the FPS Software.
- **TxCRCP-ME Input** – Contains input values necessary for TxCRCP-ME.
- **Truck Factor (TF)** – Shows the Truck Factor value of the highway based on both Flexible and Concrete ESAL calculation.

- **Volume –** Shows a deeper look at the traffic data of the highway such as daily traffic and daily class distribution.
- **Hourly Distribution –** Shows the average distribution of vehicles and trucks for each hour.
- **Daily Distribution –** Shows the average distribution of vehicles and trucks for each day.
- **Truck Overweight Statistics –** Contains statistics on the overweight trucks such as %Overweight Trucks, Max Overweight recorded, Average Hourly Overweight trucks, etc.

## GENERATION OF FPS AND ME TRAFFIC INPUT PARAMETERS

### FPS Traffic Input Data

FPS is the primary software that is routinely used by TxDOT for the design of flexible pavements. Figure 19 and Figure 20 show the main FPS21 and traffic-data input screens, respectively. As shown from Figure 21, all the FPS21 traffic data inputs can be obtained from the output of portable WIM macro.


**Figure 19. Main FPS Screen.**

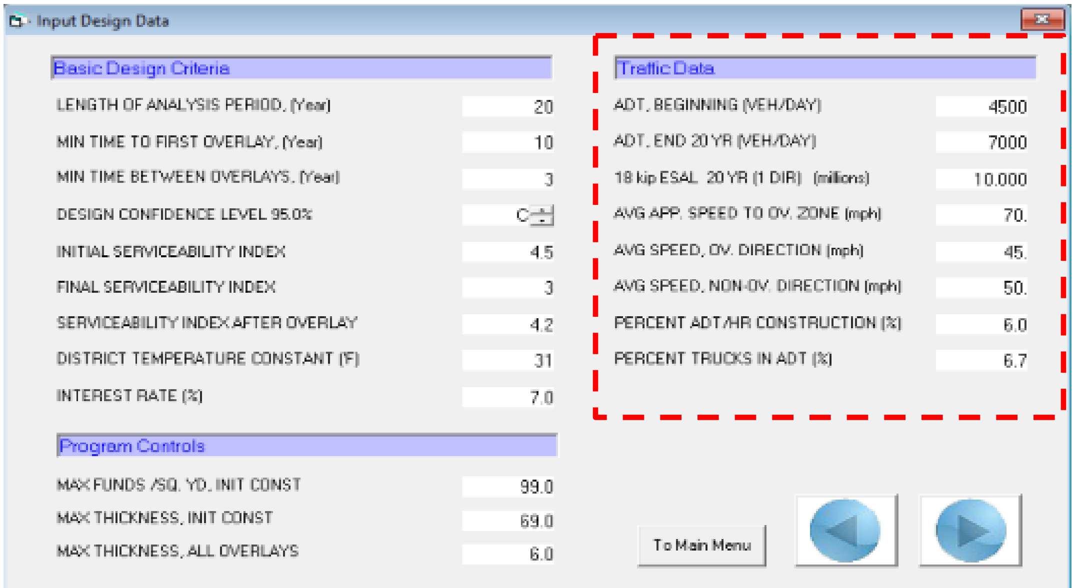



**Figure 20. FPS Traffic-Data Input Screen.**

| | | Value | Comment |
|---|---|---|---|
| Design Life (Years) | | 20 | Can be changed as desired (Typical = 20 yrs)! |
| Annual Growth Rate (%) | | 3.00 | Can be changed as desired (Typical = 2.5-5.0%) |

**FPS Input Parameters**

| Parameter | | Value | Comment |
|---|---|---|---|
| ADT-Beginning | | 11163 | ADT (Both directions) at the beginning of the design period |
| ADT-END | 20 Yrs | 20161 | ADT (Both directions ) at the end of the design period |
| 18 kip ESALs (million) | 20 Yrs | **26.83** | Design lane MESALs (EB) |
| Avg. vehicle speed (mph) | | 57.33 | Approach speed assumed to be equal to operational speed |
| % trucks in ADT | | 31.7% | |
| | | | |
| ATHWLD | | 13.52 | Kips |
| % Tandem Axles | | 41.11% | |

**Figure 21. Example FPS Traffic Inputs from the Portable WIM Macro – SH 302 (Odessa District)**

## TxCRCP-ME and Concrete Traffic Input Data

TxCRCP-ME, an algorithm in MS Excel macro format, is one of the commonly used routine methods by TxDOT for designing concrete pavements. As shown in Figure 22, the key required traffic input parameters are the number of lanes and the 30-year 18-kip ESALs in one direction. As listed in, these two parameters can be obtained from the output of portable WIM macro (Figure 23).

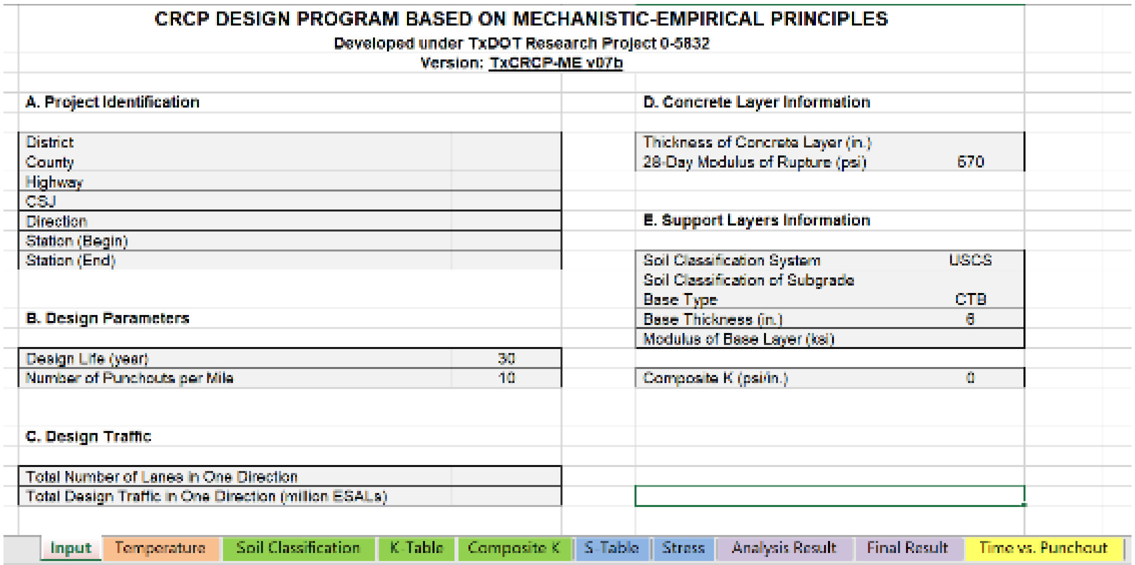



**Figure 22. Main MS Excel Worksheet for the TxCRCP-ME.**

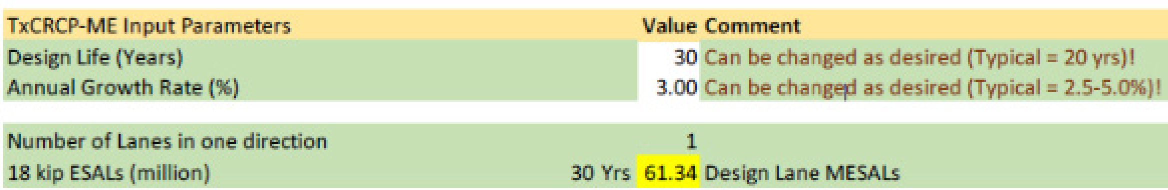



**Figure 23. Example TxCRCP-ME Traffic Inputs from the Portable WIM Macro – SH 302 (Odessa District)**

### TxME Traffic Input Data

TxME is an ME based software used for the design, structural analysis, and performance predictions of flexible pavements. When using the TxME software, the user needs to input the axle load distribution (ALD) and monthly adjustment factors (MAF) files on the Level 1: Load Spectra section (See Figure 24).

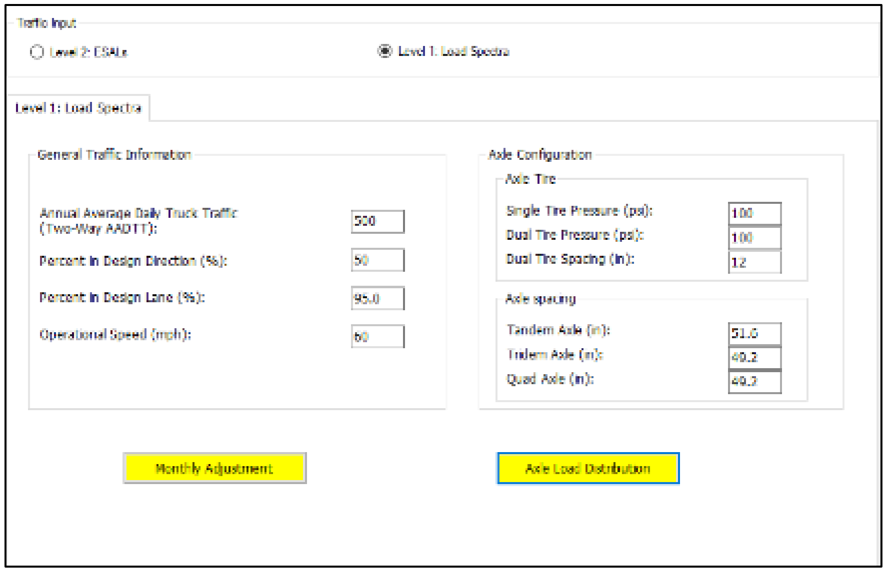



**Figure 24. Level 1: Load Spectra Input on TxME Software.**

Inputting these values to the software is an extensive process. However, the portable WIM macro can generate the input files automatically. The user can then directly export both the ALD and MAF files to the TxME software by selecting the Monthly Adjustment and ALD option in the Level 1: Load Spectra screen menu. To generate the MAF and ALD files, the user can simply run the data analysis process using the portable WIM macro and select Yes when prompted to generate MAF and ALD files. The portable WIM macro generates two file versions, .csv and .maf for the MAF input and .csv and .ald for the ALD input. Generating the .csv file provides an easy access for the user to see the values using a MS Excel. Whereas both .maf and .ald files are used as an input for the TxME software. Despite having different versions, both files contain the same values.

## SUMMARY

This chapter presented and discussed the portable WIM system deployment procedures and guidelines including traffic data processing and analysis. There are several main components needed in order to deploy portable WIM system which include TRS unit, piezo sensors, metal plates, metal ramps, piezo channel box, 12-volt battery, solar charger controller, solar panel, mastic tapes, and protective metal box. A modem system can also be connected to the portable

WIM system to enable real-time remote access to the WIM data. Additional information of portable WIM unit installation and setup can be found in Appendix I.

Selecting portable WIM installation location is required before heading to the field and starting the installation. There are a few considerations in selecting an ideal highway site for a portable WIM system deployment. For example, the portable WIM should be installed at minimum or more than 200 ft away from a bridge and intersection and where there is a continuous flow of traffic. Also, metal plates should be installed on dry and clean flat pavement without any distresses. Depending on the site condition, installation methods may need to be changed or improvised; therefore, engineering judgement is always needed whenever evaluating the portable WIM site condition and installation process. Once the appropriate installation site has been identified, portable WIM system installation can be started. Once the portable WIM system is installed on the site, it is recommended to perform routine maintenance by going to the site and checking the TRS unit, the sensors, and the mastic tapes every day or two days.

It is recommended to have at least 7 days of data to ensure complete weekly data. It is not recommended to include the data from the first day (the day of portable WIM system is initially installed) for portable WIM traffic data processing and analysis as the system is still calibrating. It is highly recommended for the WIM sensors to be calibrated so that the unit can report axle weight accurately. The TRS unit has two methods for on-site calibration, namely manual calibration and auto calibration. Additionally, there is also off-site post calibration whenever on-site calibration needs to be verified or on-site calibration is not conducted. After obtaining minimum of 7-day traffic data from portable WIM system, portable WIM macro is used to automate the processing, analysis, and generation of the required general traffic parameters and ME inputs for pavement design.

# CHAPTER 4. PORTABLE WIM TRAFFIC DATA COLLECTION AND ANALYSIS

This chapter of the report presents a comprehensive summary of various traffic data measured by the portable WIM system, general traffic parameters and ME traffic inputs generated by the portable WIM macro, and portable WIM systems in Texas. In addition, case studies of how portable WIM systems were deployed is also described.

## PORTABLE WIM TRAFFIC DATA

There are various types of traffic data that can be collected by the portable WIM system. The type of traffic data measured, collected, and generated include traffic volume counts, vehicle classification, vehicle speed, axle spacings and weight data. Specifically, the portable WIM systems provide the following minimum type of traffic data:

- Traffic volume counts.
- Vehicle classification.
- Vehicle speed.
- GVW and individual axle loads.
- Number of axles and axle spacing.

The collected raw traffic data were processed and analyzed to generate the general traffic parameters and ME traffic inputs. The computed traffic parameters are listed below and summarized in Table 3.

- The average daily traffic (ADT), which is computed as the total number of vehicles (all classes) recorded divided by the duration of record (i.e., number of days).
- The average daily truck traffic (ADTT), which is calculated as the total number of trucks (Classes C4–C13) recorded divided by the duration of record (i.e., number of days).
- The percentage of truck = ADTT/ADT (percent).
- The VCD, the percentage of each vehicle class in the ADT.

- The average vehicle speed and the percentage of over-speeding vehicles estimated relative to the speed limit at the highway section in question.
- The axle per truck inputs, computed as the average number of single/tandem/tridem/quad axles per truck.
- The total 20-year and 30-year 18-kip ESALs, estimated using the load spectra of trucks and the annual traffic growth rate.
- The average ten daily heaviest wheel loads (ATHWLD).
- The daily GVW distribution, the daily single/tandem/tridem/quad load distribution.
- The daily overweight (OW) vehicles estimated based on the recorded GVW values and the consideration of 80 kip as the limit allowed for GVW.
- The daily OW axles, estimated based on the different axle threshold loads (e.g., 20 kip for single axles, 34 kip for tandem axles, 42 kip for tridem axles, and 50 kip for quad axles).
- Truck overweight statistics, which contains statistics on the overweight trucks such as %Overweight Trucks, Max Overweight recorded, Average Hourly Overweight trucks, etc.
- TF and ESAL calculation for rigid (concrete) pavements based on 8-inch as the default slab thickness.
- TF computation and distribution per truck class/type including generating the TF tables and graphical plots.
- Million ESAL (MESAL) computation based on the TF, %Trucks, and ADT.
- Tabulation and graphical plot traffic distribution as a function of time per day.
- Axle load distribution (ALD), estimated through the load spectra (LS) analysis.
- FPS and ME traffic inputs for TxCRCP-ME, TxME, TxACOL, TxCrackPro, and AASHTOWare.

**Table 3. Traffic Parameters Computed.**

<table>
<tr><th colspan="3">General Traffic Parameters</th><th colspan="2">ME Traffic Inputs and Software</th></tr>
<tr><td rowspan="5">Traffic volume</td><td>1)</td><td>AADT</td><td>1)</td><td>FPS</td></tr>
<tr><td>2)</td><td>AADTT</td><td>2)</td><td>TxCRCP-ME (concrete)</td></tr>
<tr><td>3)</td><td>Truck percentage</td><td>3)</td><td>TxME</td></tr>
<tr><td>4)</td><td>Axles per truck</td><td>4)</td><td>TxACOL</td></tr>
<tr><td>5)</td><td>Volume distributions, such as hourly and daily</td><td>5)</td><td>TxCrackPro</td></tr>
<tr><td>Classification</td><td>6)</td><td>VCD</td><td>6)</td><td>AASHTOWare</td></tr>
<tr><td rowspan="2">Adjustment factors</td><td>7)</td><td>MAF</td><td></td><td></td></tr>
<tr><td>8)</td><td>Hourly distribution factors (HDF)</td><td></td><td></td></tr>
<tr><td>Growth trends</td><td>9)</td><td>Traffic $G_r$—mostly from permanent WIM data</td><td></td><td></td></tr>
<tr><td rowspan="9">Weight</td><td>10)</td><td>GVW</td><td></td><td></td></tr>
<tr><td>11)</td><td>ALD</td><td></td><td></td></tr>
<tr><td>12)</td><td>Weight distributions, i.e., hourly and daily</td><td></td><td></td></tr>
<tr><td>13)</td><td>Axle load distribution factor (ALDF)</td><td></td><td></td></tr>
<tr><td>14)</td><td>18-kip ESALs</td><td></td><td></td></tr>
<tr><td>15)</td><td>Accumulated ESALs (18 kip), e.g., 20-year 18-kip ESALs for flexible pavements and 30-year 18-kip ESALs for concrete pavements</td><td></td><td></td></tr>
<tr><td>16)</td><td>Average of the ATHWLDs</td><td></td><td></td></tr>
<tr><td>17)</td><td>Truck OW data (GVW and axles), i.e., overweight and overloading statistics</td><td></td><td></td></tr>
<tr><td>18)</td><td>Load equivalent factors (LEFs)</td><td></td><td></td></tr>
</table>

As shown in Table 3, the generated ME traffic inputs for various pavement design and analysis software include flexible and concrete pavements. Although there is a diversity of pavement design software, the traffic input data required are often similar and related to traffic volume, vehicle classification, and load (weight) spectra data. For example, both the TxME and AASHTOWare (NCHRP, 2006) require annual load distributions (spectra) for each of the single, tandem, tridem, and quad axles as some of the primary design inputs (Oman, 2010; Walubita et al., 2013). These ME traffic input data were computed and generated for the most commonly used pavement software in Texas (e.g., FPS, TxME, TxCRCP-ME) and at the U.S. national level (e.g., AASHTOWare). In addition, general traffic parameters were also computed, as listed in Table 3, to provide a full spectrum of the traffic loading on a given highway. These valuable general traffic parameters can be used for various applications, including but not limited to the following: VCD characterization, planning purposes, truck overloading and pavement damage assessment, overweight quantification, and speed quantification. As discussed in the subsequent text, easy to use MS Excel macros were developed using VBA to automate the traffic data processing and analysis. Example general traffic output results from portable WIM macro analyses are included in Appendix II.

## PORTABLE WIM UNITS

Portable WIM units were deployed by these researchers for measurement, collection, and analysis of site-specific traffic data to quantify truck-loading throughout Texas for:

- Pavement design, maintenance, and rehabilitations
- Potential pavement damage assessment
- Development of a Statewide map of truck factors per district per highway functional class
- Planning and traffic growth projections
- Population of the TxDOT traffic database
- Population of the T-DSS
- Population of the TF table for various district for various road types

Ideally, portable WIM systems are deployed for collecting site-specific traffic data in areas where permanent WIM stations are unavailable, such as farm-to-market (FM) roads in Texas. However, portable WIM systems have been installed on various highways across the State, Districts, and major critical traffic routes including, but not limited to the following:

- Energy sector developmental areas
- Heavy haul routes/roads, e.g., aggregates, timber, etc.
- Port corridors and border routes

Like permanent WIM stations, the portable WIM measures traffic volume counts, vehicle classification, vehicle speed, vehicle weight data, and so forth. The portable WIM data were collected by these researchers through short-term deployment (minimum seven days) as well as long-term deployment (with routine periodic service maintenance) on selected highway sites around the state of Texas. Proper site selection (i.e., flat and straight section), proper installation, and proper calibration are the key factors to obtaining accurate and quality traffic data with portable WIM units. In particular, on-site calibration with a Class 9 truck, with varying weights and traveling at multiple speeds, is strongly recommended prior to actual traffic data measurements. With good installation, calibration, and maintenance practices, traffic data accuracy of up to 93.5 percent is attainable.

## PORTABLE WIM HIGHWAY SITES

In total, portable WIM traffic data were collected, measured, and assembled for over 66 highway sites around the state, including Amarillo District, Abilene District, Atlanta District, Austin District, Bryan District, Odessa District, Laredo District, etc. At the time of writing this report, there are seven portable WIM sites deployed in Abilene, Bryan, and Odessa District are still collecting traffic data. Figure 25 shows the location of these portable WIM highway sites. Appendix III indicates a list of deployed portable WIM systems throughout the state of Texas and highway site locations.

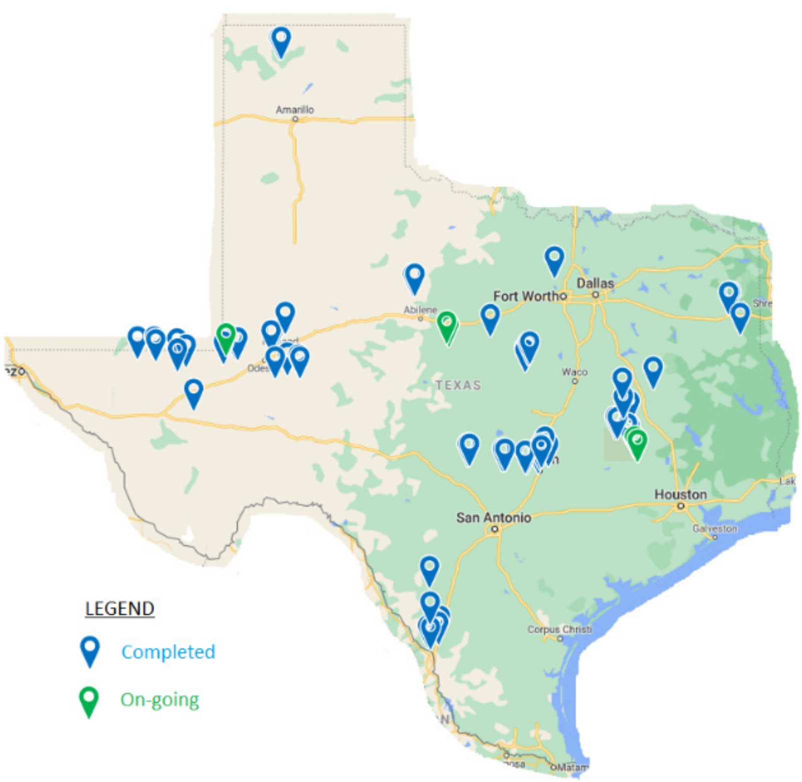



**Figure 25. Map Location of Portable WIM Sites across Texas.**

## CASE STUDIES OF PORTABLE WIM SYSTEM

### Portable WIM Installation on IH 35, Austin District

As shown in Figure 26, portable WIM system was deployed for each direction on a 3-lane highway. A set of 6-ft polymer piezo sensors were installed on outside lane and middle lane for each direction. Figure 27 shows the portable WIM installation layout used on IH 35, Austin District. Due to very high traffic volume on IH 35, portable WIM system installation was conducted during midnight (09:00 PM until 02:00 AM) on weekdays. Pavement surface was flat without any distress and far from any intersections; therefore, the site location was ideal for portable WIM installation. In addition, the installation was performed during fall season and the temperature was above 55°F; therefore, torch kit was not used to heat up the tapes and the pavement surface and there were no additional road tape strips applied on the center of the sensors.

In order for the system to collect complete weekly data, the portable WIM system was deployed for 7 days. After 7-day data was obtained, the raw data was retrieved from the TRS unit and converted to excel files using IRD Road Reporter II software. Then, the excel raw data was processed using portable WIM macro in order to generate ME compatible traffic data output for pavement design. Figure 28 and Figure 29 show a general traffic results and FPS inputs from portable WIM macro output, respectively.


(a)

(b)

**Figure 26. Portable WIM Installation on IH 35, Austin District: (a) Northbound Lane and (b) Southbound Lane.**

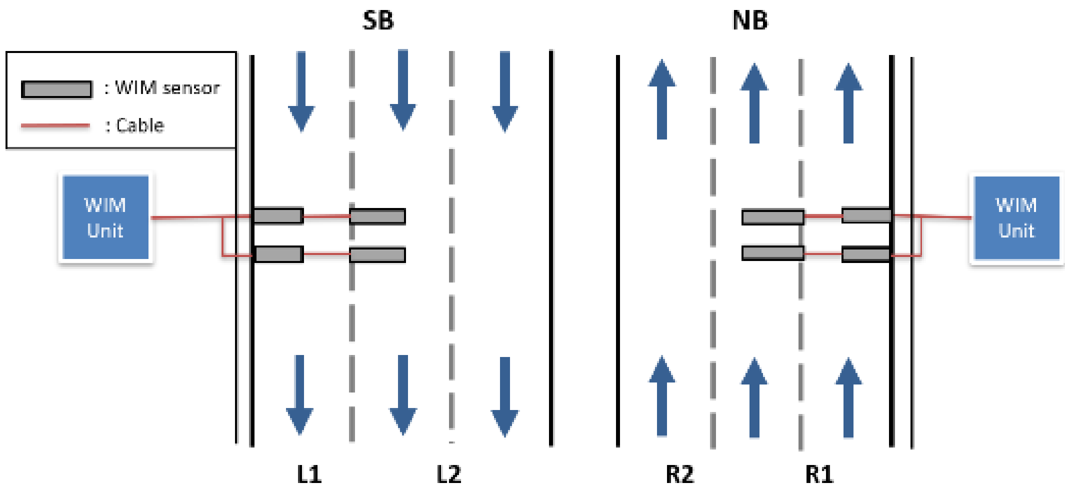
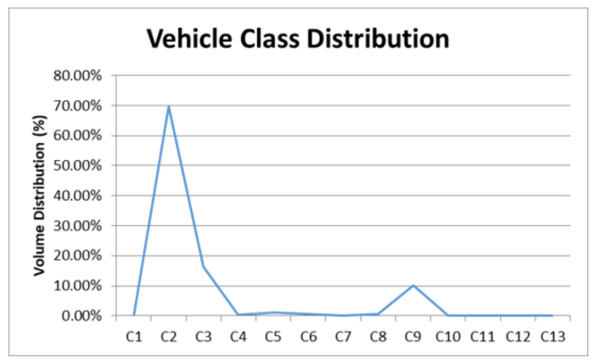



**Figure 27. Portable WIM Installation Layout Used on IH 35, Austin District.**

| Volume | IH 35 NB Middle Lane (ML) |
|---|---|
| ADT | 24530 |
| ADTT | 3361 |
| %Trucks | 13.7% |
| ATHWLDs | 14.98 |
| 20-Yr 18-kip ESALs (Million) | 50.89 |
| C5/C9 Ratio | 0.10 |

| Speed | IH 35 NB Middle Lane (ML) |
|---|---|
| Avg(All) | 60 |
| Avg(Trucks) | 58 |
| Max(All) | 99 |
| Max(Trucks) | 92 |
| Speed Limit(mph) | 70 |
| %age of Vehicles Over Speed Limit(All) | 0.55776% |
| %age of Trucks Over Speed Limit(Trucks) | 0.01186% |

Vehicle Class: C2
Truck Type/Class: C5

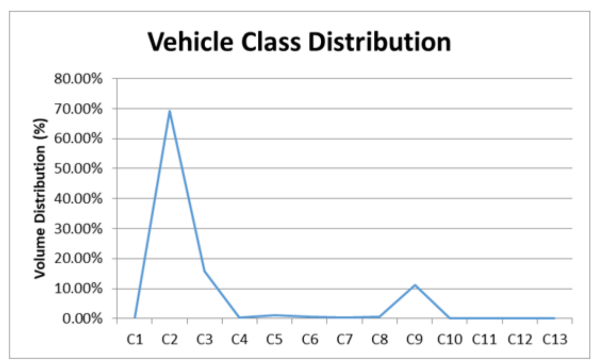



(a)

| Volume | IH 35 SB Middle Lane (ML) |
|---|---|
| ADT | 22594 |
| ADTT | 3335 |
| %Trucks | 14.8% |
| ATHWLDs | 14.8 |
| 20-Yr 18-kip ESALs (Million) | 47.91 |
| C5/C9 Ratio | 0.09 |

| Speed | IH 35 SB Middle Lane (ML) |
|---|---|
| Avg(All) | 59 |
| Avg(Trucks) | 58 |
| Max(All) | 89 |
| Max(Trucks) | 77 |
| Speed Limit(mph) | 70 |
| %age of Vehicles Over Speed Limit(All) | 0.68271% |
| %age of Trucks Over Speed Limit(Trucks) | 0.01383% |

Vehicle Class: C2
Truck Type/Class: C5




(b)

**Figure 28. Example of Traffic Volume and Vehicle Speed Data from IH 35, Bryan District: (a) Northbound Lane and (b) Southbound Lane.**

| | Value | Comment |
|---|---|---|
| Design Life (Years) | 20 | Can be changed as desired! |
| Annual Growth Rate (%) | 2.50 | Can be changed as desired! |

| FPS Input Parameters | | Value | Comment |
|---|---|---|---|
| ADT-Beginning | | 147181 | ADT (All lanes, both directions) at the beginning of the design period |
| ADT-END | 20Yrs | 241172 | ADT (All lanes, both directions) at the end of the design period |
| 18-kip ESALs (million) | 20Yrs | 50.89 | Design lane MESALs (NB ML) |
| Avg. vehicle speed (mph) | | 59.66 | Approach speed assumed to be equal to operational speed |
| % trucks in ADT | | 13.7% | |
| | | | |
| ATHWLD | | 14.98 | Kips |
| % Tandem Axles | | 47.54% | |

(a)

| | | Comment |
|---|---|---|
| Design Life (Years) | 20 | Can be changed as desired (typical for TX flexible PVMNTs = 20 yrs)! |
| Annual Growth Rate (%) | 2.50 | Can be changed as desired (typical range = 2.5 ~ 5.0%)! |

**FPS Input Parameters**

| Parameter | | Value | Comment |
|---|---|---|---|
| ADT-Beginning | | 141807 | ADT (All lanes, both directions) at the beginning of the design period |
| ADT-END | 20Yrs | 232367 | ADT (All lanes, both direction) at the end of the design period |
| 18-kip ESALs (million) | 20Yrs | 47.91 | Design lane ESALs (SB ML) |
| Avg. vehicle speed (mph) | | 59.29 | Approach speed assumed to be equal to operational speed |
| % trucks in ADT | | 14.8% | |
| | | | |
| ATHWLD | | 14.76 | Kips |
| % Tandem Axles | | 46.24% | |

(b)

**Figure 29. Example of FPS Inputs from IH 35, Bryan District: (a) Northbound Lane and (b) Southbound Lane.**

## Portable WIM Installation on US 190, Bryan District

As shown in Figure 30, a set of polymer piezo sensors were installed on a single lane road for each direction and only a single portable WIM system was deployed to capture traffic data for both directions (TRS unit was located on eastbound direction). Figure 31 shows the portable WIM installation layout used on US 190, Bryan District. Since there were rumble strips located on the shoulder near outside lane, 6-ft polymer piezo sensors were used in this case. Using 8-ft sensors may cause a problem because placing 8-ft sensors will overlap the shoulders, reaching the rumble strip areas, and due to a gap between rumble strip and metal plate, water may enter the road tape and underneath the plates, causing moisture damage to the adhesive. Even though the installation was performed during summer season and the temperature was above 55°F, there was rutting with a very low severity level on the pavement surface where the sensors were going to be installed. Therefore, additional road tape strips were added on the center of the sensors for extra protection of the sensors being detached from the road. In addition, the site location was far from any intersections; therefore, the site location was ideal for portable WIM installation.

In order for the system to collect complete weekly data, the portable WIM system was deployed for 7 days. After 7-day data was obtained, the raw data was retrieved from the TRS unit and converted to excel files using IRD Road Reporter II software. Then, the excel raw data was processed using portable WIM macro in order to generate ME compatible traffic data output for pavement design. Figure 32 and Figure 33 show a general traffic results and FPS inputs from portable WIM macro output, respectively.

**Figure 30. Portable WIM Installation on US 190, Bryan District.**

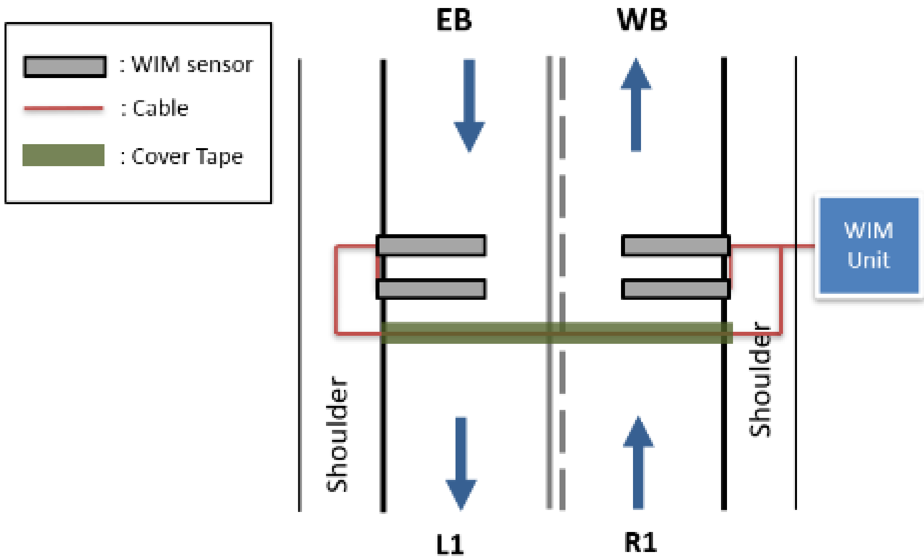
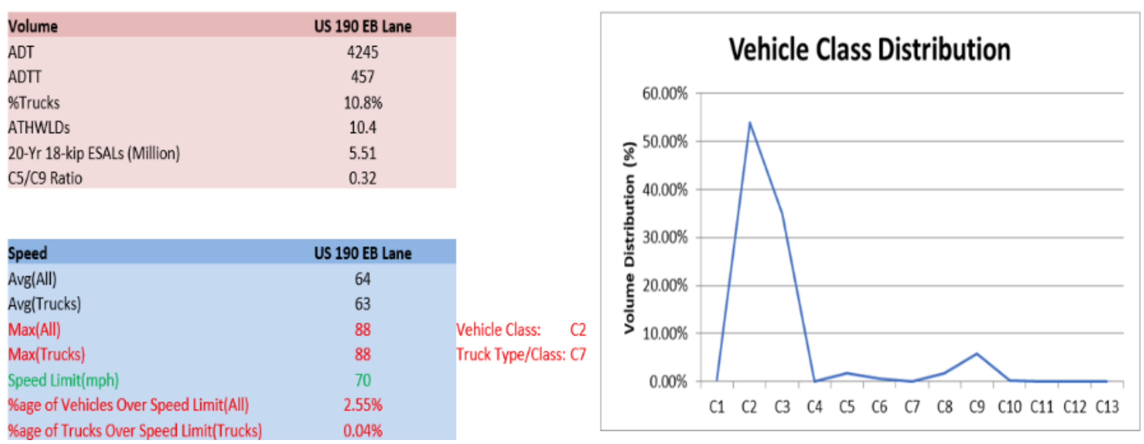



**Figure 31. Portable WIM Installation Layout Used on US 190, Bryan District.**

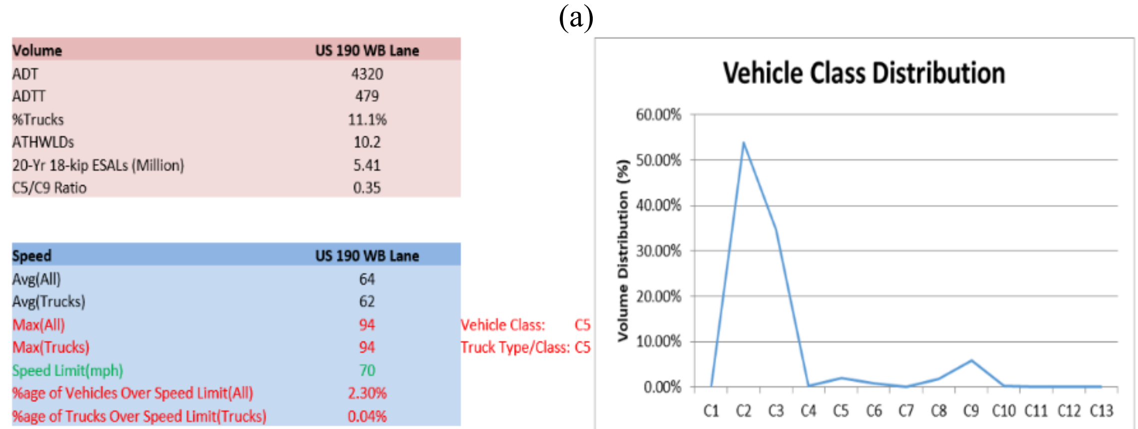


| Volume | US 190 EB Lane |
|---|---|
| ADT | 4245 |
| ADTT | 457 |
| %Trucks | 10.8% |
| ATHWLDs | 10.4 |
| 20-Yr 18-kip ESALs (Million) | 5.51 |
| C5/C9 Ratio | 0.32 |

| Speed | US 190 EB Lane |
|---|---|
| Avg(All) | 64 |
| Avg(Trucks) | 63 |
| Max(All) | 88 |
| Max(Trucks) | 88 |
| Speed Limit(mph) | 70 |
| %age of Vehicles Over Speed Limit(All) | 2.55% |
| %age of Trucks Over Speed Limit(Trucks) | 0.04% |



(a)



| Volume | US 190 WB Lane |
|---|---|
| ADT | 4320 |
| ADTT | 479 |
| %Trucks | 11.1% |
| ATHWLDs | 10.2 |
| 20-Yr 18-kip ESALs (Million) | 5.41 |
| C5/C9 Ratio | 0.35 |

| Speed | US 190 WB Lane |
|---|---|
| Avg(All) | 64 |
| Avg(Trucks) | 62 |
| Max(All) | 94 |
| Max(Trucks) | 94 |
| Speed Limit(mph) | 70 |
| %age of Vehicles Over Speed Limit(All) | 2.30% |
| %age of Trucks Over Speed Limit(Trucks) | 0.04% |



(b)

**Figure 32. Example of Traffic Volume and Vehicle Speed Data from US 190, Bryan District: (a) Eastbound Lane and (b) Westbound Lane.**

| | | Value | Comment |
|---|---|---|---|
| Design Life (Years) | | 20 | Can be changed as desired (typical = 20 years) |
| Annual Growth Rate (%) | | 3.0 | Can be changed as desired (typical range = 2.5 to 5.0%) |

**FPS Input Parameters**

| Parameter | | Value | Comment |
|---|---|---|---|
| ADT-Beginning | | 8565 | ADT (Both directions) at the beginning of the design period |
| ADT-END | 20 Yrs | 15469 | ADT (Both directions) at the end of the design period |
| 18 kip ESALs (million) | 20 Yrs | 5.51 | Design lane ESALs |
| Avg. vehicle speed (mph) | | 64.26 | Approach speed assumed to be equal to operational speed |
| % trucks in ADT | | 10.8% | |
| ATHWLD | | 10.35 | Kips |
| % Tandem Axles | | 37.50% | |

(a)

| | | Value | Comment |
|---|---|---|---|
| Design Life (Years) | | 20 | Can be changed as desired (typical = 20 years) |
| Annual Growth Rate (%) | | 3.0 | Can be changed as desired (typical range = 2.5 to 5.0%) |

**FPS Input Parameters**

| Parameter | | Value | Comment |
|---|---|---|---|
| ADT-Beginning | | 8565 | ADT (Both directions) at the beginning of the design period |
| ADT-END | 20 Yrs | 15470 | ADT (Both directions) at the end of the design period |
| 18 kip ESALs (million) | 20 Yrs | 5.41 | Design lane ESALs |
| Avg. vehicle speed (mph) | | 64.14 | Approach speed assumed to be equal to operational speed |
| % trucks in ADT | | 11.1% | |
| ATHWLD | | 10.25 | Kips |
| % Tandem Axles | | 36.53% | |

(b)

**Figure 33. Example of FPS Inputs from US 190, Bryan District: (a) Eastbound Lane and (b) Westbound Lane.**

## SUMMARY

This chapter presented and discussed the type of traffic data measured, collected, and generated by the portable WIM system as well as portable WIM systems installed on Texas highways. The type of traffic data measured, collected, and generated by the portable WIM system include traffic volume counts, vehicle classification, vehicle speed, and weight data. Once raw traffic data are obtained from portable WIM system, the data are processed and analyzed using portable WIM macro to generate general traffic output parameters and ME traffic inputs for pavement design, which include FPS, TxME, TxCRCP-ME (concrete), and AASHTOWare.

Portable WIM systems have been installed on various highways across the State, Districts, and major critical traffic routes for measurement, collection, and analysis of site-specific traffic data where permanent WIM stations are unavailable. Like permanent WIM stations, the portable WIM measures traffic volume counts, vehicle classification, vehicle speed, vehicle weight data. Key aspects to obtaining good-quality, repeatable, and reliable portable WIM data with low variability is proper site selection, installation, calibration, and maintenance practices. In total, there are over 66 portable WIM highway sites around the state.

# CHAPTER 5. EXPERIMENTATION, TRAINING, AND DEMONSTRATION STATION

This chapter provides a summary review of establishment of long-term portable WIM experimentation stations at several potential locations including TTI RELLIS Campus and in-service highways such as US 87 in Austin District, SH 21 in Bryan District, and SH 6 in Bryan District. The purpose of the establishment of these experimentation stations are for demonstration, training, system calibration, system information, and portable WIM technical support.

## THE EXPERIMENTATION TEST SITE (TTI)

As shown in Figure 34 and Figure 35, a portable WIM experimentation test site has been established at the TTI RELLIS campus to serve the following key functions: (a) pre-checking and testing the sensors prior to any field installation works; (b) pre-calibration of the portable WIM units prior to any field installation works; (c) general diagnostic testing and evaluation of the portable WIM systems; (d) testing and verification of any new system improvements and enhancements; (e) technical support and general advancement of the portable WIM systems; and (f) general demonstration and training purposes. Prior to any field installations works, the portable WIM systems, including the sensors, are pre-checked and pre-calibrated. Any diagnostic and/or trouble shooting works, prior to or after field work, are conducted at this experimentation station.

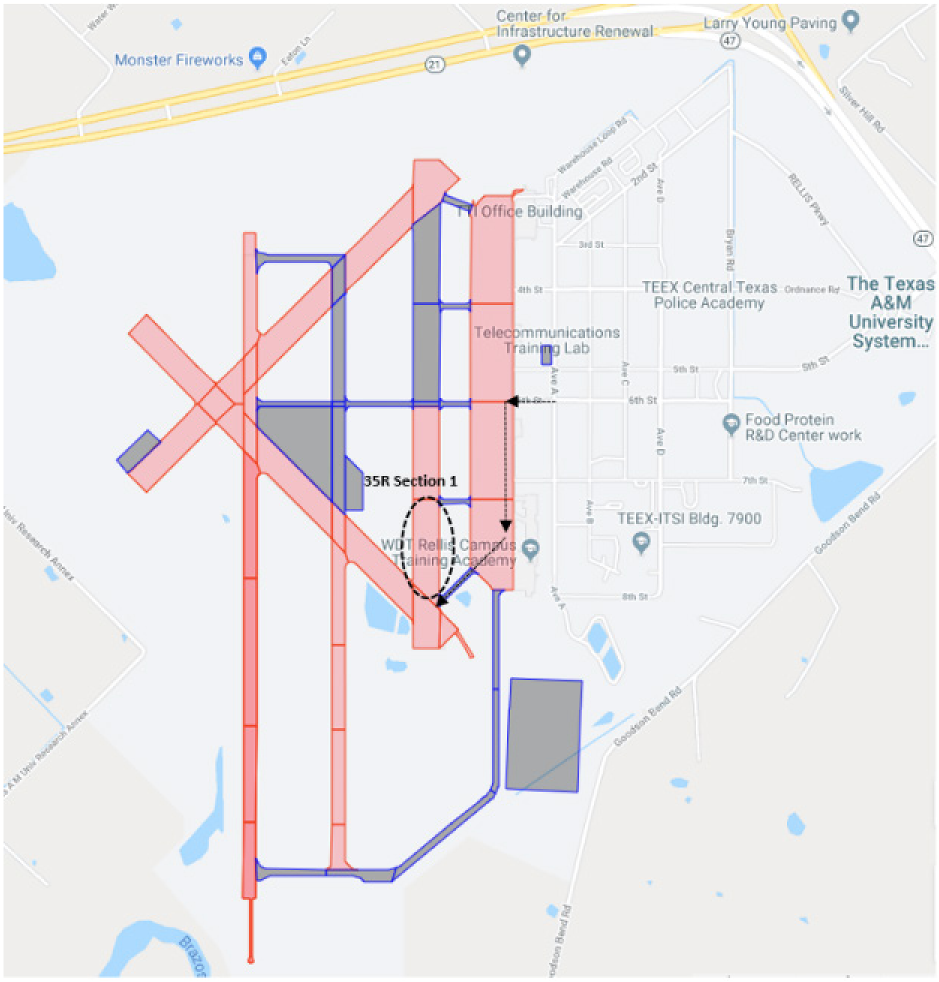



**Figure 34. Schematic Location Map of the TTI Experimentation Test Site.**

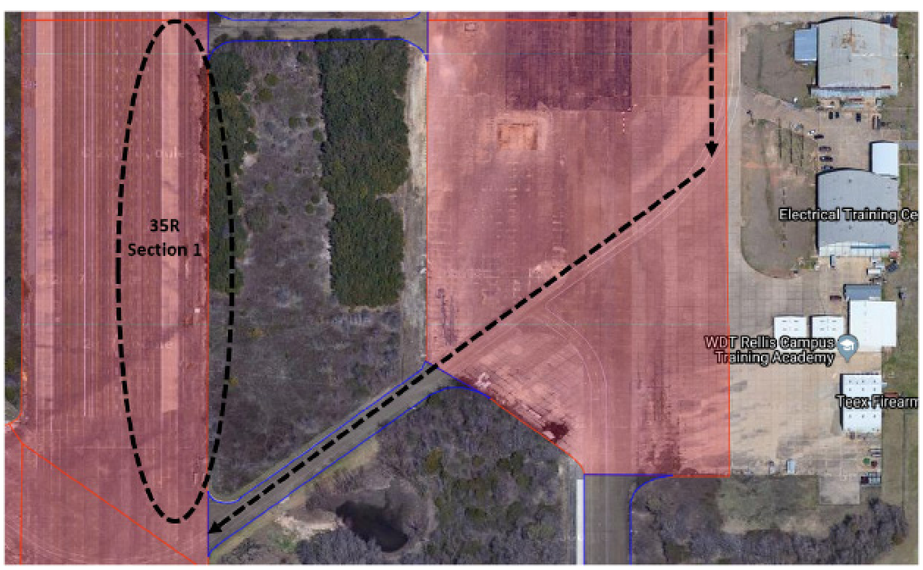



**Figure 35. Satellite View of the TTI Experimentation Test Site.**

Figure 36 and Figure 37 show some examples of sensor pre-checking and pre-calibration at TTI's portable WIM experimentation test site (RELLIS Campus). The test setup comprises of both pocket-tape and metal-plate sensor installation methods. In general, it is a mandatory requirement to always pre-check and pre-calibrate the portable WIM system and sensors before heading out for field installations. This not only ensures that only functional equipment is carried to the site, but also optimizes efficiency both in terms of field installation and onsite calibration.


**Figure 36. Sensor Checking, Testing, and Pre-calibration at the TTI Portable WIM Experimentation Test Site (Pocket-Tape).**


**Figure 37. Sensor Checking, Testing, and Pre-calibration at the TTI Portable WIM Experimentation Test Site (Metal-Plates).**

Specifically, the pre-checking and pre-calibration works at the TTI portable WIM experimentation test site include the following activities: (a) *speed checks* (checked against speedometer and speed gun readings at multiple vehicle speeds), (b) *axle spacing* (verified with physical tape measurements), (c) *vehicle classification* (compared against FHWA classification), and (d) *axle/GVW weights* (verified with static scales) measurements system – see Appendix IV. As exemplified in Appendix IV, both TTI vehicles as well rented Class 9 trucks are typically used for pre-checking and pre-calibrating the portable WIM systems and sensors.

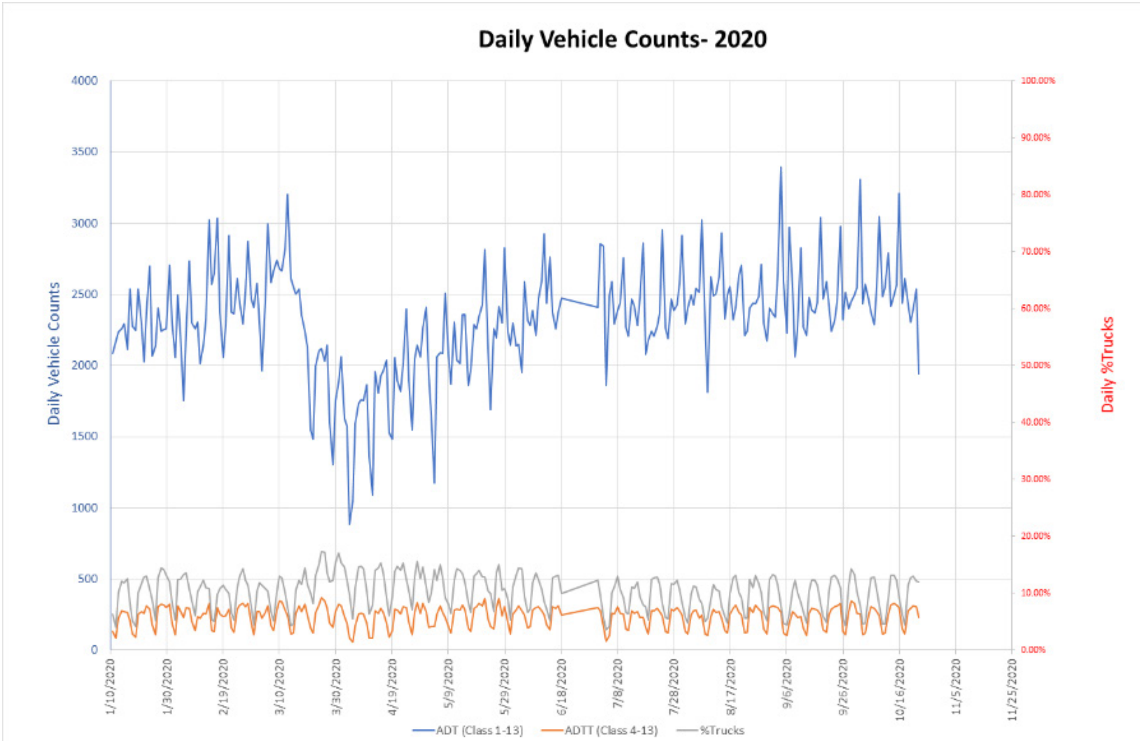
## THE IN-SERVICE DEMO-MONITORING STATION IN US 87 AUSTIN DISTRICT

Another portable WIM monitoring site was also established on an in-service highway US 87 (NB lane) in Austin District (near Frederiksberg, Gillespie County) to monitor and evaluate the sensor sensitivity, accuracy over time, endurance, site maintenance needs, and frequency of unit re-calibration (See Figure 38).

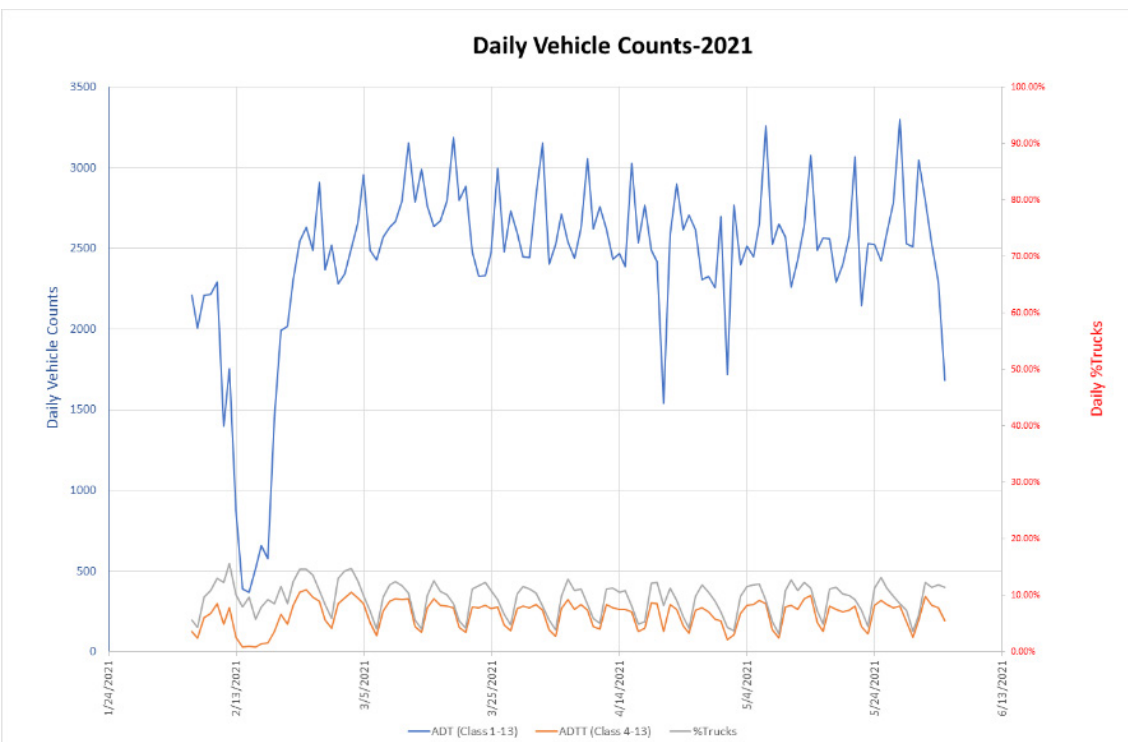
**Figure 38. Active Portable WIM Site – US 87 (Austin District)**

**Thus far, the site has been in satisfactory operation for over one year (since December 2019) with minimum maintenance (i.e., adding more tapes) and only one re-calibration**

**check. As exemplified in**

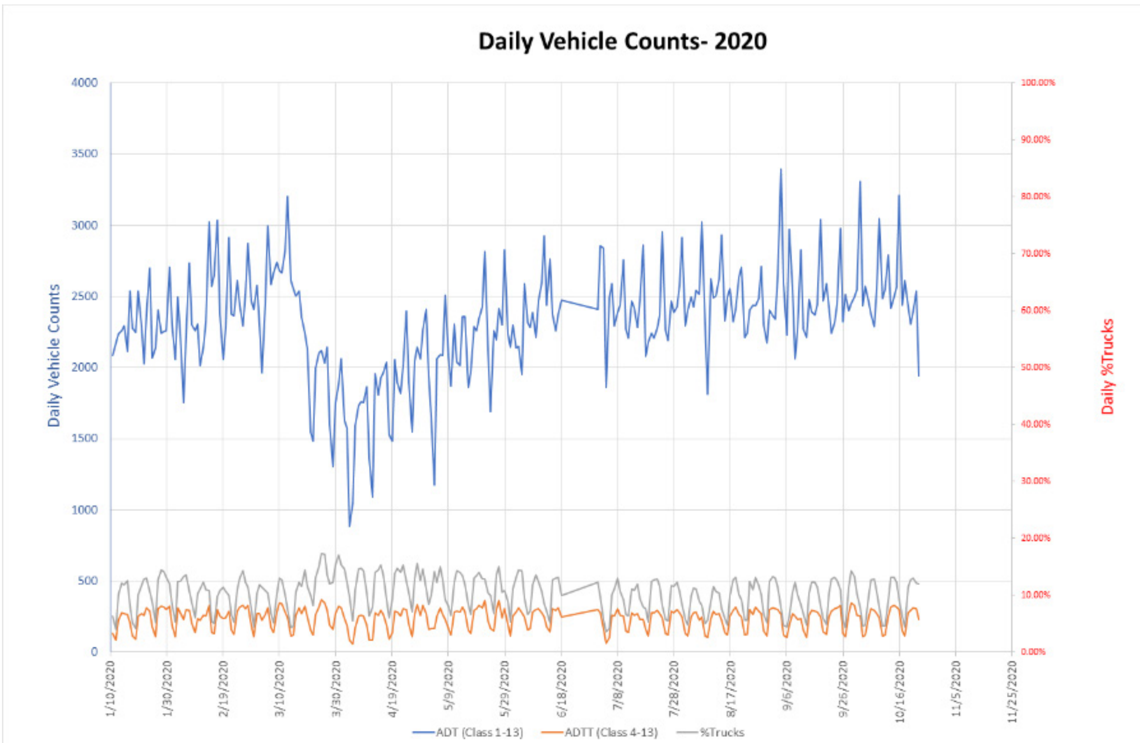



(a)

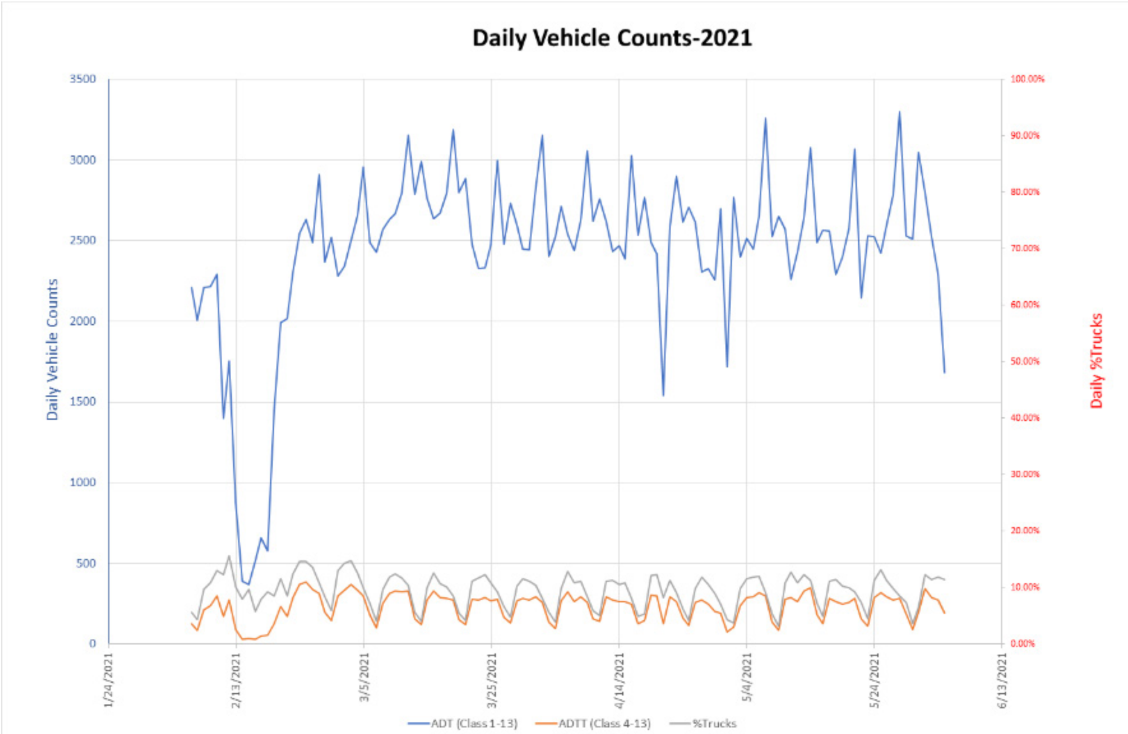



(b)

Figure 39, US 87 traffic data, which is being monitored and downloaded regularly, is still satisfactory. However, it is to be observed from Figure 39 that from November 2020 to January 2021, traffic data measurement was not performed due to a few technical issues and traffic data collection was continued in February 2021.




(a)




(b)

**Figure 39. Portable WIM System Volume Data on US 87 (NB), Austin District: (a) 2020 Data and (b) 2021 Data**

## THE IN-SERVICE DEMO-MONITORING STATION IN SH 21 BRYAN DISTRICT

The researchers have also established a long-term demo-monitoring station on an in-service highway SH 21 (see Figure 40 and Figure 41) in Bryan District near TTI by deploying multiple traffic data collection systems including the following:

- Portable WIM system
- Pneumatic tube counters
- Wavetronix (only in eastbound direction)
- Road Scanner (only in eastbound direction)
- Manual (visual) vehicle counts (two-hour random count periods on randomly selected days)


**Figure 40. Portable WIM Demo-Monitoring Testing Station in SH 21 (WB), Bryan District.**

**Figure 41. Portable WIM Demo-Monitoring Testing Station in SH 21 (EB), Bryan District.**

The SH 21 demo-monitoring testing station is subjected to real-time conventional traffic loading. Therefore, comparison of multiple traffic measurement devices under real traffic loading was performed for system comparisons, calibrations, verification, improvements, enhancements, demonstration, training, and traffic data evaluation purposes. In westbound direction, only portable WIM system and pneumatic tubes were deployed for comparative evaluation. As for eastbound direction, portable WIM system, Wavetronix system (radar-based traffic counter), and Road Scanner (LiDAR-based traffic counter) were installed side-by-side for comparative evaluation study between systems. Some of the goals of the side-by-side installation with the portable WIM include the following:

- Vehicle counts and traffic volume data comparisons between the two systems including the manual (visual) counts. In particular, comparison with the manual (visual) vehicle counts at the SH 21 demo-monitoring will aid to calibrate the systems for accuracy enhancement.
- Continued refinement and calibration of the analysis macro for converting Wavetronix and Road Scanner data to FHWA Class 1-13 system and other TxDOT/FHWA classification schemes.
- Development/validation of some correlative models for relating, estimating, and predicting load spectra data including TF and ESALs from the Wavetronix and Road Scanner Pro traffic volume data.

A comparative study was performed on portable WIM system and Wavetronix system with manual vehicle counts as a reference to check system accuracy of both systems. Since both Wavetronix (and Road Scanner) is only able to classify vehicles based on length, FHWA vehicle classification data is not possible to obtain through these systems. However, a classification macro, namely “Length-Based Vehicle Classification macro” was developed and used to obtain ADTT and truck percentage data from Wavetronix (See Figure 42). The macro basically predicts the class of the vehicles based upon the FHWA vehicle classifications using machine learning algorithm K-Nearest Neighbors (KNN). The data obtained from Wavetronix and portable WIM were joined based on timestamp and then used for training the prediction model. At this point, satisfactory performance is obtained and as more data is obtained, the performance of the macro will be refined and improved.

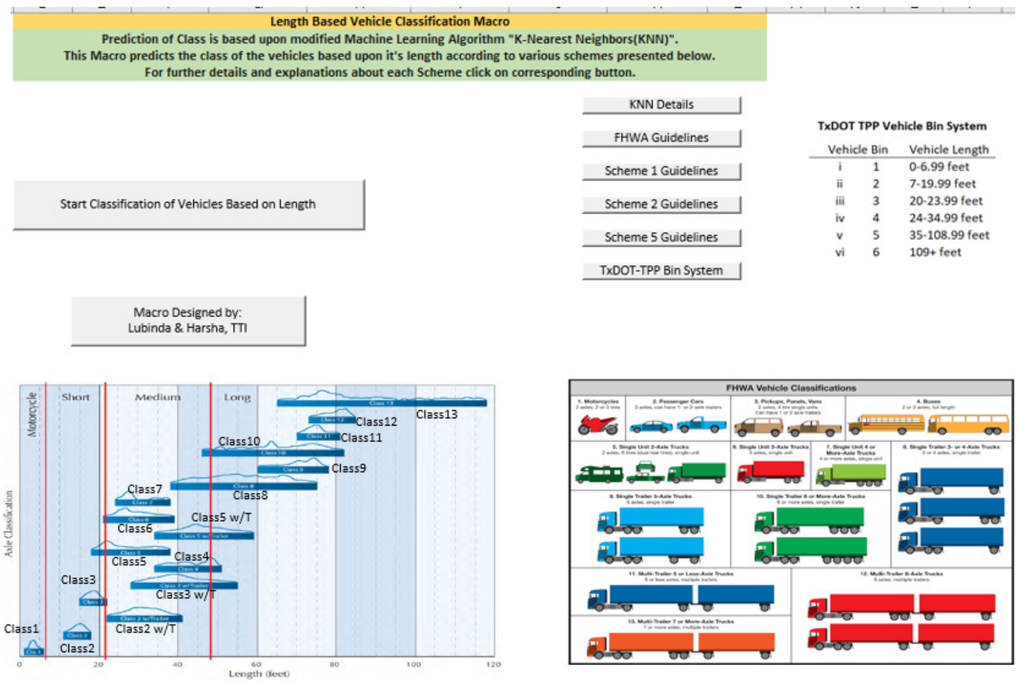
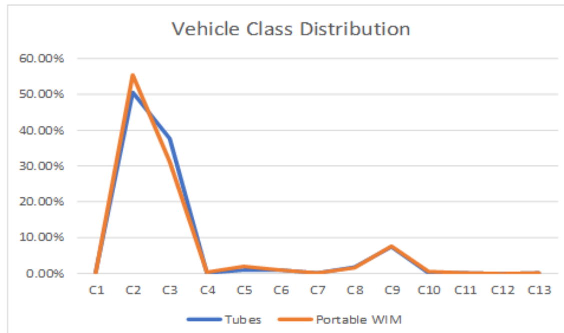



**Figure 42. KNN Length-based Vehicle Classification Macro**

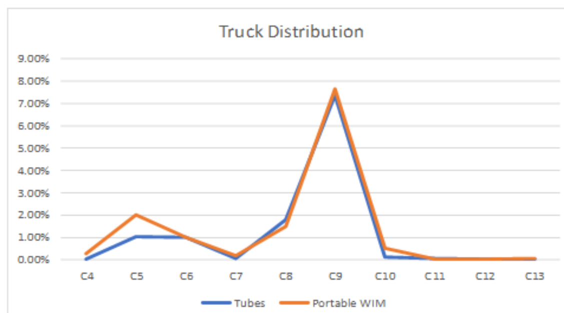
In this initial stage, Road Scanner was not included in the comparative analysis indicated due to several technical issues on the system. System comparisons data which was performed three times on a different day and time indicated that both portable WIM system and Wavetronix system which installed side-by-side is fairly comparable with manual vehicle counting used as a datum reference in terms of ADT, ADTT, and percentage of trucks. The results indicate the average deviation error from manual counts is within 5% in average and able to provide truck distribution percentage accuracy of about 94% in average for both system. However, it is to be observed from this comparative evaluation that only portable WIM system can generate FHWA vehicle classification data, GVW data, axle weight data, axle spacing data. Length-based vehicle classification macro is needed to generate FHWA vehicle classification data from Wavetronix and it is not possible to generate GVW, axle weight, and axle spacing data from Wavetronix. The comprehensive results of portable WIM and Wavetronix system comparison study with manual vehicle counts reference can be found on Appendix VI.

Additionally, system comparisons between portable WIM and pneumatic tubes were performed for seven days as well to evaluate both volume and speed accuracy. The traffic data (ADT, ADTT, percentage of trucks, and speed) obtained from both systems is fairly similar, with average accuracy of 95.25% (See Figure 43). The drawbacks of the pneumatic tubes system are the system requires same amount of installation efforts as portable WIM system and does not provide GVW and axle weight data.

| TUBES Vs PORTABLE WIM | | |
|---|---|---|
| Start date | 31st July 2020 | |
| End date | 6th August 2020 | |
| Total | 7 Days | |
| Factor | Tubes | Portable WIM |
| VCD Data | | |
| ADT | 6387 | 6349 |
| ADTT | 733 | 801 |
| %Trucks | 11.5% | 12.6% |
| C5/C9 Ratio | 0.14 | 0.26 |
| Speed Data (mph) | | |
| Avg(All) | 69 | 70 |
| Avg(Trucks) | 64 | 67 |
| Max(All) | 103 | 98 |
| Max(Trucks) | 93 | 95 |
| Speed Limit(mph) | 75 | 75 |
| %age of Vehicles Over Speed Limit(All) | 19.23% | 11.90% |
| %age of Trucks Over Speed Limit(Trucks) | 0.23% | 0.26% |




| VCD Data | | |
|---|---|---|
| % in ADT | Tubes | Portable WIM |
| C1 | 0.25% | 0.17% |
| C2 | 50.59% | 55.47% |
| C3 | 37.69% | 31.20% |
| C4 | 0.02% | 0.28% |
| C5 | 1.02% | 2.00% |
| C6 | 0.99% | 1.01% |
| C7 | 0.05% | 0.16% |
| C8 | 1.80% | 1.49% |
| C9 | 7.37% | 7.63% |
| C10 | 0.13% | 0.50% |
| C11 | 0.04% | 0.03% |
| C12 | 0.01% | 0.02% |
| C13 | 0.04% | 0.05% |
| Total | 100.00% | 100.00% |
| C1-3 | 88.53% | 86.84% |
| C4-13 | 11.47% | 13.16% |




| Truck Percentage Data | | | | |
|---|---|---|---|---|
| Avg | Min | Max | Deviation Error from Avg | Accuracy q.r.t Avg |
| 12.0% | -4.75% | 4.75% | ± 4.75% | 95.25% |

| Unit | Deviation Error | Accuracy (Target ≥ 85%) |
|---|---|---|
| Tubes = | 4.75% | **95.25%** |
| Portable WIM = | 4.75% | **95.25%** |

**Figure 43. Side-by-Side System Comparisons of Portable WIM System and Pneumatic Tubes (August 6th, 2020)**

## THE IN-SERVICE DEMO-MONITORING STATION IN SH 6 BRYAN DISTRICT

The researchers have also established a long-term demo-monitoring station on an in-service highway SH 6 (see Figure 44) in Bryan District near permanent WIM station W554 by deploying multiple traffic data collection systems including the following:

- Portable WIM system
- Wavetronix
- Road Scanner

- Manual (visual) vehicle counts (two-hour random count periods on randomly selected days)

**Figure 44. Portable WIM Demo-Monitoring Testing Station in SH 6 (SB), Bryan District.**

The SH 6 demo-monitoring testing station is subjected to real-time conventional traffic loading. Therefore, comparison of multiple traffic measurement devices under real traffic loading with permanent WIM system W554 will continuously be performed for system comparisons, calibrations, verification, improvements, enhancements, demonstration, training, and traffic data evaluation purposes. The demo-monitoring station will also serve as an ongoing advancement of the portable WIM technology including assessment of the long-term repeatability, sensitivity, and endurance of the WIM sensors for improved accuracy and data quality. Furthermore, the station will also serve as a reference datum for continued development and refinement of the traffic data analysis macros/algorithms for accuracy optimization.

A comparative study was performed on portable WIM system, permanent WIM system W554, Wavetronix system, and Road Scanner with manual vehicle counts as a reference for all the systems. The result of the system comparative evaluation of ADT, ADTT, and trucks percentage which was performed three times on different day and time for two hours can be found in Table 4.

**Table 4. Comparison of Volume and Classification Data Obtained from Different System**

| | Data | Manual Vehicle Counting | Permanent WIM Station W554 | Portable WIM System | Wavetronix System | Road Scanner |
|---|---|---|---|---|---|---|
| Case 01 4/20/2021 7am – 9am | ADT | 1088 | 1378 | 1068 | 1116 | 1023 |
| | ADTT | 252 | 461 | 254 | 260 | 279 |
| | % Trucks | 23.16 | 33.45 | 23.78 | 23.30 | 27.27 |
| Case 02 4/22/2021 4pm – 6pm | ADT | 1505 | 1478 | 1492 | 1546 | 1413 |
| | ADTT | 214 | 436 | 200 | 225 | 237 |
| | % Trucks | 14.21 | 29.49 | 13.4 | 14.6 | 16.8 |
| Case 03 4/23/2021 10am – 12pm | ADT | 1218 | 1325 | 1199 | 1242 | 1319 |
| | ADTT | 276 | 482 | 263 | 287 | 329 |
| | % Trucks | 22.66 | 36.37 | 21.93 | 23.10 | 24.94 |

The results of the system comparison are summarized in Table 5. Portable WIM system and Wavetronix have the least deviation from manual counts compared to other systems. A very low deviation error from manual counts means that portable WIM system and Wavetronix can obtain very high accuracy (more than 95%) with respect to ADT, ADTT, and percentage of trucks. As for Road Scanner, the system accuracy is fairly comparable with average deviation error of 7%, 14%, and 15% for ADT, ADTT, and percentage of trucks, respectively. The performance of Road Scanner can be attributed to various factors like weather conditions. As mentioned previously, both Wavetronix and Road Scanner are not capable to generate FHWA vehicle classification data; therefore, ADTT and percentage of trucks data of these systems are predicted through length-based vehicle classification macro. From our comparative evaluation, we found that permanent WIM station W554 provides accuracy of 88% in terms of ADT. However, the average deviation error of ADTT and percentage of trucks of permanent WIM station W554 are unexpectedly very high (about 87% and 70%, respectively), indicating a very low vehicle classification accuracy.  Based on the result, maintenance of the system components that include re-calibration of the sensors, troubleshooting, and performing advanced configuration, may be required to increase the system accuracy on permanent WIM station W554. Additional information of comparative evaluation performed in SH 6 demonstration testing site can be found in Appendix VI.

**Table 5. Average Deviation Error from Manual Vehicle Counts**

| Data | Manual Vehicle Counting | Permanent WIM Station W554 | Portable WIM System | Wavetronix System | Road Scanner |
|---|---|---|---|---|---|
| ADT | Reference | 12.41% | 1.42% | 2.41% | 6.79% |
| ADTT | | 87.10% | 4.01% | 4.09% | 13.54% |
| % Trucks | | 70.81% | 3.87% | 1.65% | 15.24% |

## SUMMARY

This chapter presented and discussed the establishment of experimentation testing site at the TTI RELLIS campus and in-service demonstration testing site at the US 87 (Austin District), SH 21 (Bryan District), and SH 6 (Bryan District). Thus far, the TTI portable WIM experimentation testing site (RELLIS Campus) is fully operational and has been very instrumental in providing technical support for the ongoing portable WIM traffic measurements and data collection to routinely provide the TxDOT Districts with site-specific traffic data for pavement design, maintenance and rehabilitation, pavement damage analysis/evaluation, and planning purposes. Various activities such as pre-checking the sensors and TRS unit prior to any field installation works, pre-calibration of the system. General diagnostic testing, verification of any new system, and general technical support can be performed at the TTI portable WIM experimentation testing site at TTI RELLIS campus. Demo-monitoring testing site at US 87, Austin District is also still in operational and thus far, the site has been in satisfactory operation for more than one year with minimum maintenance and only one re-calibration check.

Demo-monitoring testing site at SH 21 and SH 6 were also established to perform comparative evaluation between portable WIM system and other traffic counter system, such as pneumatic tubes (only in SH 21 highway), Wavetronix (radar-based system), and Road Scanner (LiDAR-based system). Additionally, verification and evaluation study of permanent WIM station W554 in Bryan District was also performed by deploying portable WIM system, Wavetronix, and Road Scanner side by side at SH 6 highway. Manual vehicle counts were conducted during the evaluation process as a datum reference for the system comparison. The results indicated that pneumatic tubes, portable WIM system, and Wavetronix system are fairly comparable with a very high accuracy of more than 95% in terms of ADT, ADTT, percentage of trucks, and speed. Since both Wavetronix and Road Scanner are not capable to generate FHWA vehicle classification data, length-based vehicle classification macro was developed and used to predict the ADTT and percentage of trucks. Table 6 provides a summary of traffic data measurement capabilities of each system. Additional pictures of Wavetronix and Road Scanner system can be found in Appendix V and summary of various system comparisons can be found in Appendix VI.

**Table 6. Various System Characteristics**

| Measurements | Manual Vehicle Counting | Permanent WIM Station | Portable WIM System | Pneumatic Tubes | Wavetronix System | Road Scanner |
|---|---|---|---|---|---|---|
| Vehicle counts (ADT) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Vehicle and axle weight | ✗ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Vehicle speed | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| FHWA Classification | ✓ | ✓ | ✓ | ✓ | Prediction | Prediction |
| Axle spacing and wheelbase | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Vehicle length | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ |
| Vehicle width | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ |
| Vehicle height | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ |

# CHAPTER 6. THE ME TRAFFIC DATABASE

In practice, the MS Access is a platform, which enables the management and exploitation of large size database. Various traffic data were collected, processed, and analyzed to generate useful inputs values for pavement design. The outcomes were synthetized and stored as a MS Access database. The Access format developed for this traffic database grants access to data and files as it provides a relational database management interface. Furthermore, the MS Access provides the option of exporting filtered or partial data as directly usable MS supported format (e.g., MS Word, Excel, portable document format, etc.).

## STRUCTURE OF T-DSS

The MS Access is a user-friendly interface for database management and is therefore, considered as a platform for the T-DSS. The MS Access is in general available on most computers as par the MS package available on most computers. Hence, the T-DSS is a convenient data management system which will assist TxDOT engineers and general stakeholders to easily access traffic analysis results of highways across the State of Texas. Figure 45 presents the main menu of the T-DSS.

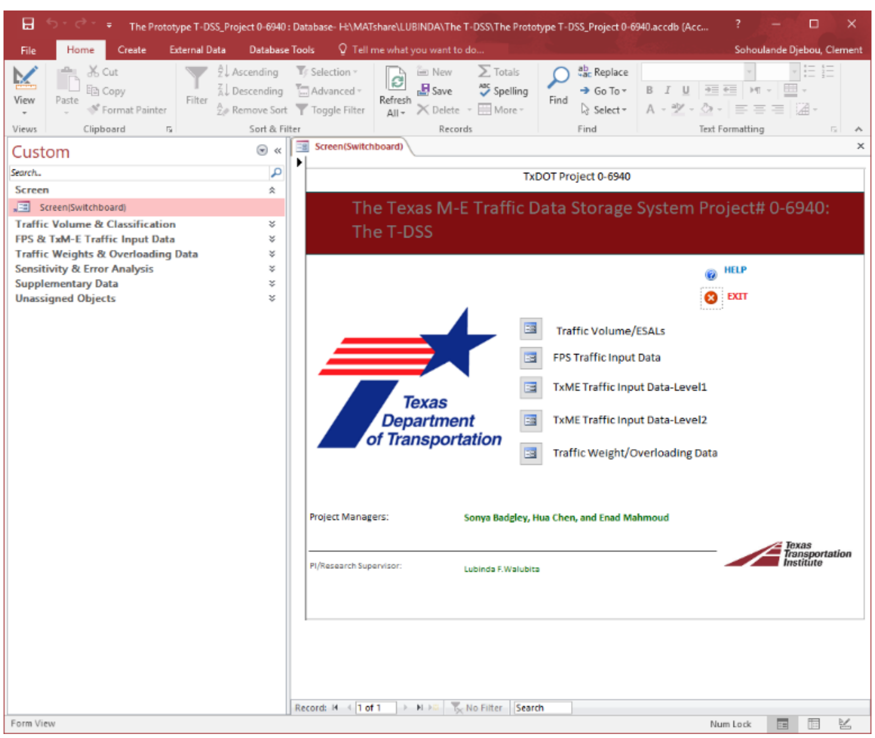


**Figure 45. The T-DSS Main Screen.**

The structuration of the T-DSS enables interrelations between the groups which data can be easily populated upon users' quests. The data constituting the T-DSS include the following:

- Traffic volume and vehicle classification parameters
- FPS and ME traffic inputs
- Input parameters for TxME, AASHTOWare, TxACOL, and TxCrackPro
- Axle load distribution
- Overweigh traffic statistics
- Cumulative 20-year 18-kip Equivalent single axle loads (ESALs) for flexible pavements and 30-year 18-kip ESALs for concrete pavements

The T-DSS is a collection of traffic parameters, ready to use for pavement design and transportation planning.

## TRAFFIC VOLUME AND CLASSIFICATION

As shown in Figure 46, the group of traffic volume and classification contains three tables, namely, Table 01, 02 and 03. The Table 01 contains traffic volume data, estimated ESALs values, and statistics on vehicle speed. The Table 02 contains the traffic volume parameters including average daily traffic (ADT), average daily truck traffic (ADTT), vehicle classification (i.e., percentage of each class of vehicle/truck in the ADT and ADTT). Table 03 contains detailed data of hourly and daily traffic volume distribution. The hourly volume is reported as percentages of ADT corresponding to the different hours of the day (i.e., 00 am through 11:59 pm). The daily distribution is reported as the average absolute value of daily traffic corresponding to each day of week (i.e., Monday through Sunday).

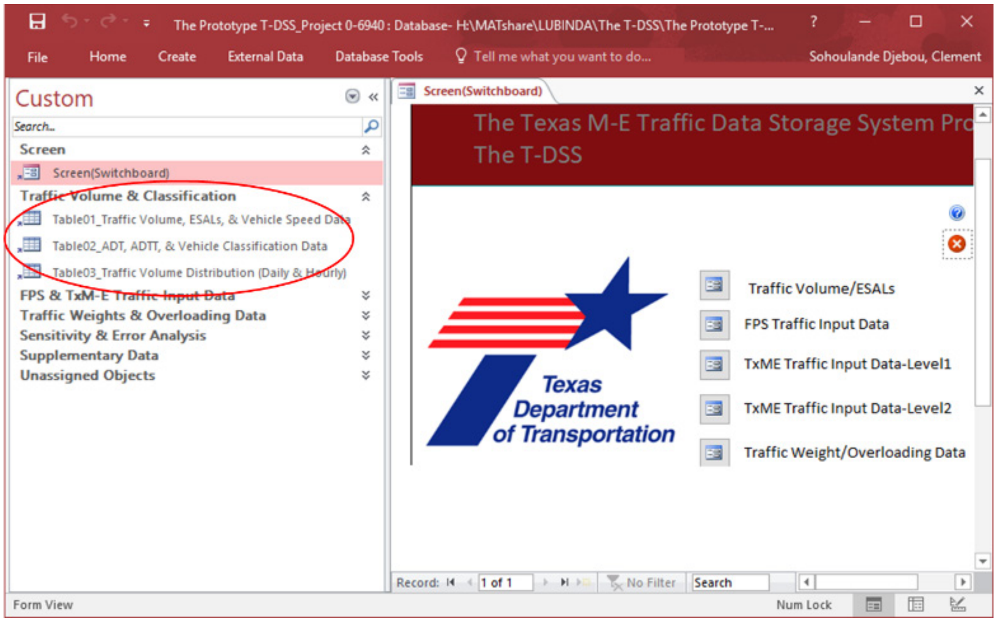



**Figure 46. The Traffic Volume and Classification Interface.**

## FPS AND TXME TRAFFIC INPUT DATA

Figure 47 presents a screenshot of the FPS and TxME input data group. The interface is made of seven different tables, namely Tables 04, 05a, 05b, 05c, 06, 07a and 07b.

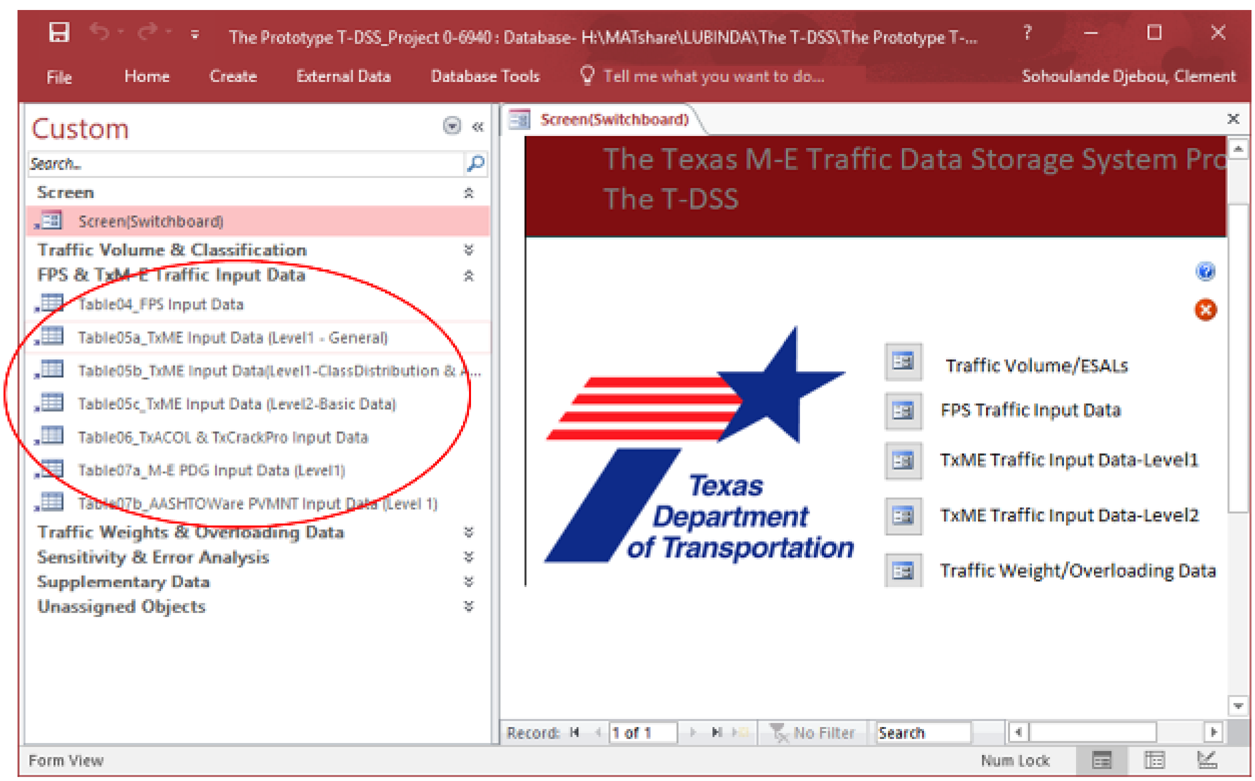



**Figure 47. FPS and TxME Traffic Input Data Interface.**

As shown in Figure 48, Table 04 recaps the FPS input data which include the computed ADT, the projected 20-year ADT, the 20-year cumulative 18 kips ESALs, the average speed, the percentage truck in ADT, the average tenth highest wheel load (ATHWLD), and the percentage of tandem axles.

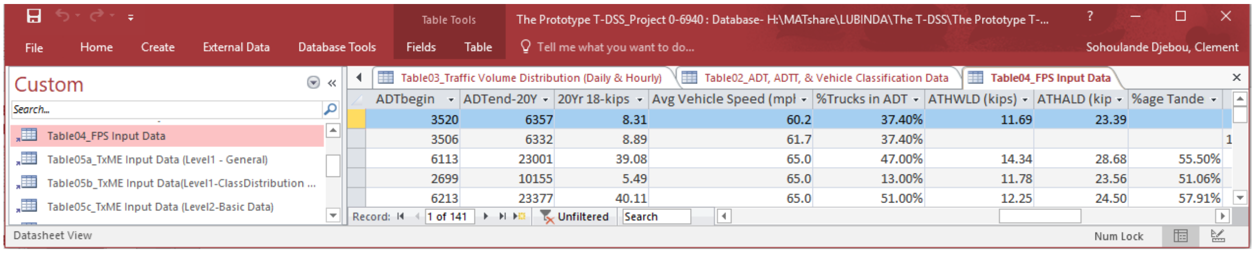



**Figure 48. FPS Input Data in the T-DSS.**

Table 05a summarizes the TxME input data (Level 1) which include the computed two-way Average annual daily truck traffic (AADTT), the number of lanes in the design direction, the percentage of trucks in the design direction, and the percentage of trucks in the design lane. The remaining TxME input data (Level 1) are summarized in the Table 05b which contains data on vehicle class distribution, traffic growth rate, and average single, tandem, tridem, quad axles per truck. Figure 49 illustrates Tables 05a and 05b including the traffic data required for the TxME.

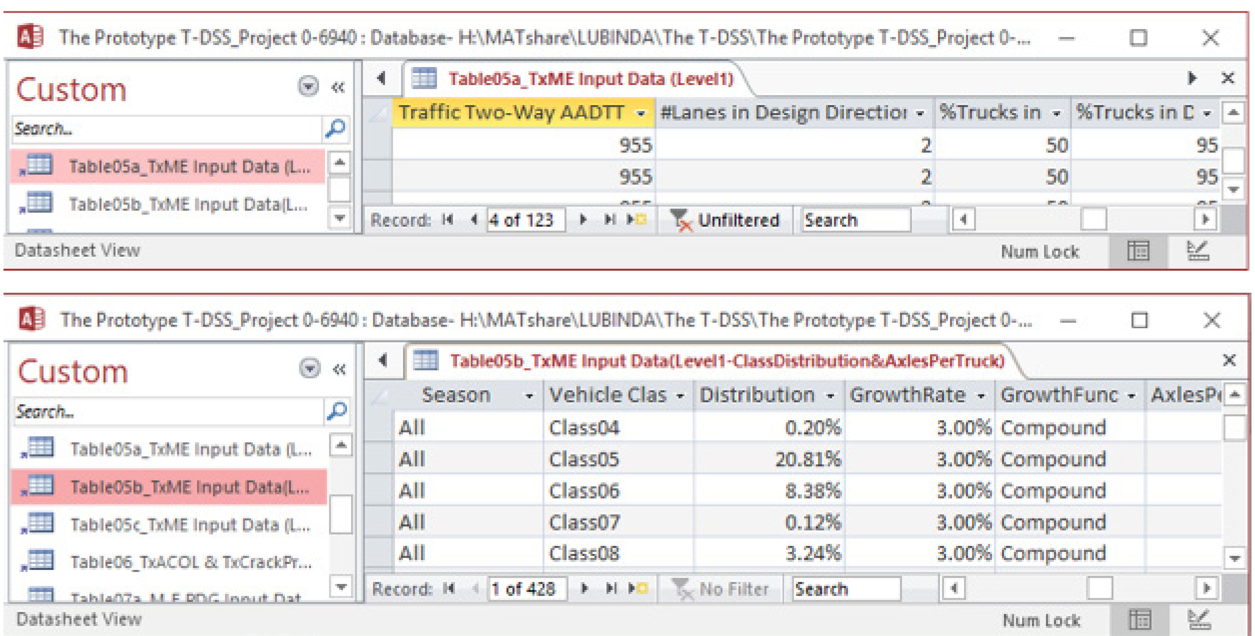



**Figure 49. TxME Input Data (Level 1 data) in the T-DSS.**

As displayed in Figure 50, the Table 05c is structured for compiling Level 2 TxME Input data computed for the different highway sections. Each highway section corresponds to a location were a permanent or portable WIM system is installed for traffic data collection. These data include the standard tire pressure value, the ADT at beginning, the projected 20-year ADT, the 20-year cumulative 18 kips ESALs, and the operational speed for each highway section.

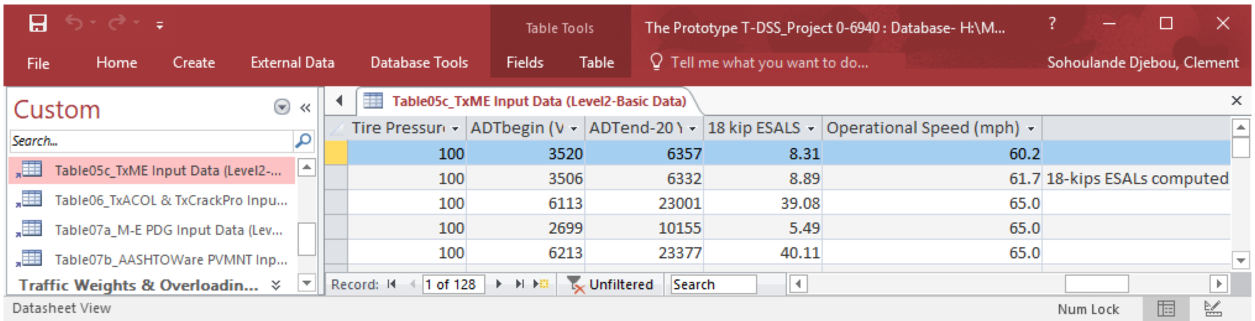



**Figure 50. TxME Input Data (Level 2 data) in the T-DSS.**

Table 06 contains the input traffic parameter needed for TxACOL and TxCrackPro. As shown by Figure 51, these traffic parameters include the ADT at beginning, the projected 20-year ADT, the 20-year cumulative 18 kips ESALs and the operational speed associated with the highway.

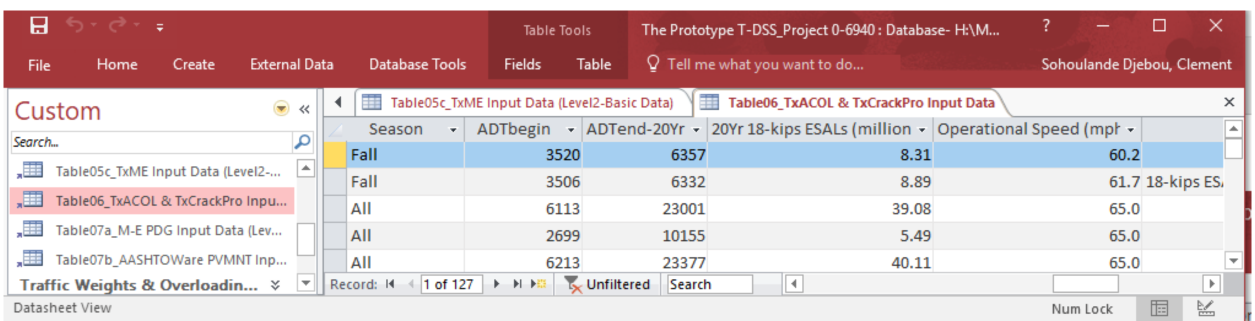



**Figure 51. TxACOL and TxCrackPro Input Data in the T-DSS.**

As indicated in Figure 52, Tables 07a and 07b report the input needed for AASHTOWare Pavement design software, respectively. These inputs are essentially the monthly adjustment factors (MAF) and the axle load distribution (ALD) files. The MAF and ALD files are uploaded in the appropriate format in the corresponding tables.

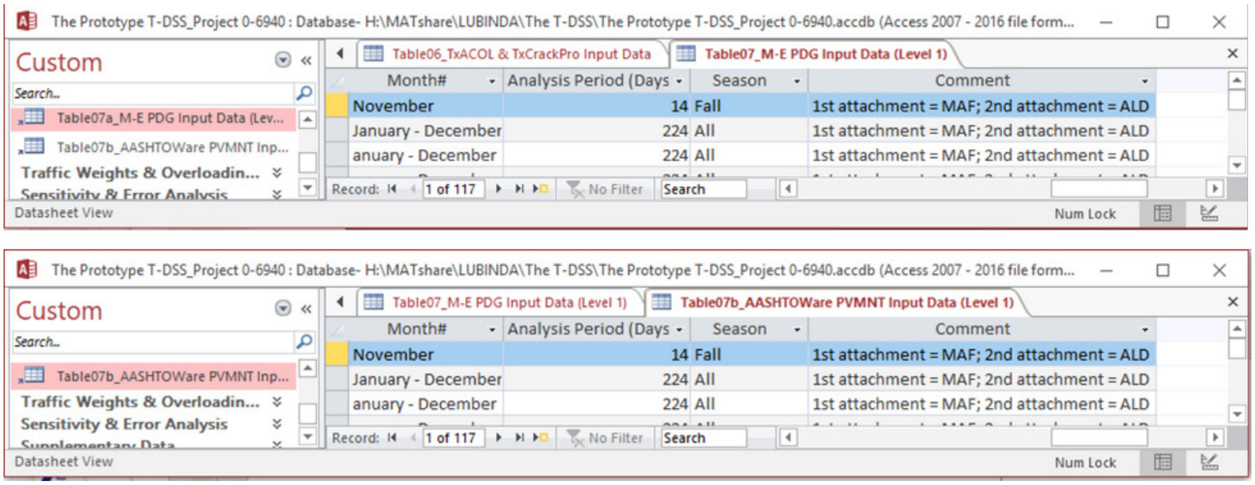



**Figure 52. AASHTOWare Input Data in the T-DSS.**

## TRAFFIC WEIGHTS AND OVERLOADING DATA

Figure 53 presents the traffic weights and overloading data interface as it is in the T-DSS. This interface contains eight different tables including Tables 08, 09a, 09b, 09c, 09d, 09e, 09f and 10. These tables summarize different levels of traffic load spectra analyses.

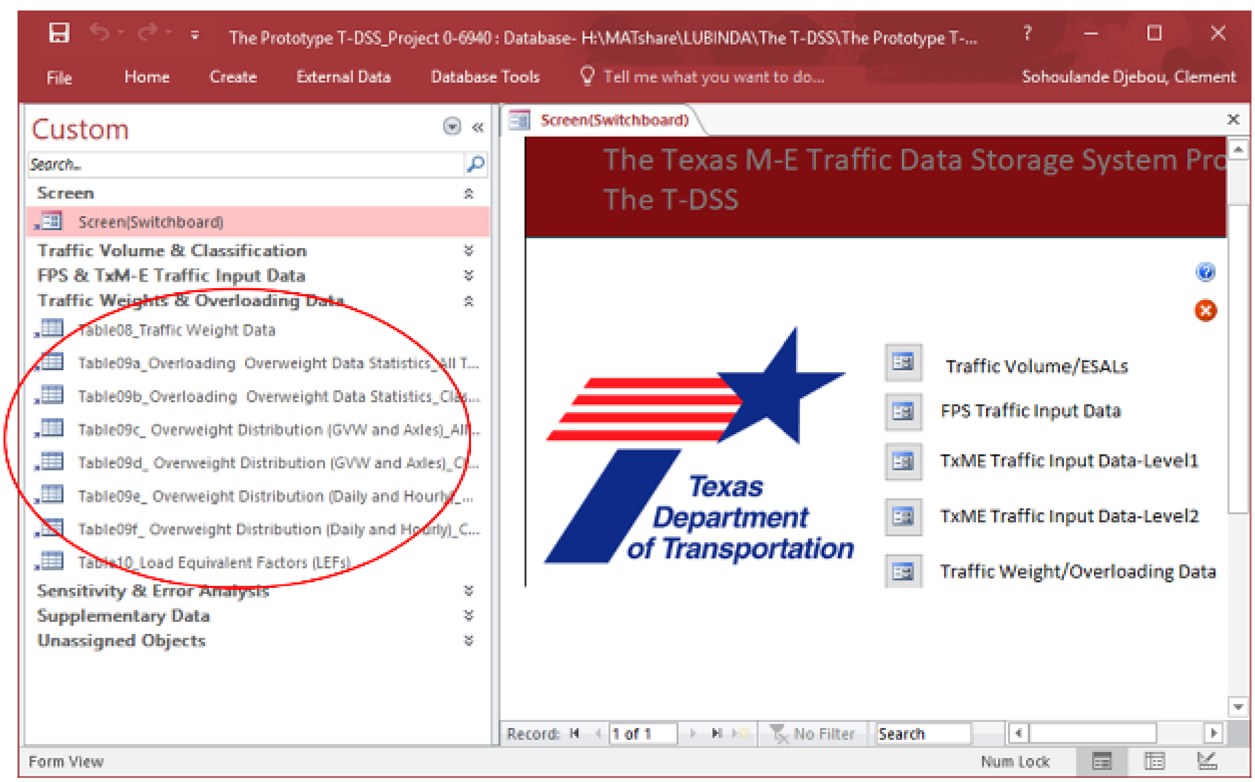



**Figure 53. Traffic Weights and Overloading Data Interface.**

In the T-DSS, Table 08 summarizes the general location data of the highway sections. Tables 9a, 9b, 9c and 9d summarize different types of overload statistics. As shown by Figure 54, these overload statistics include the gross vehicles weight (GVW), daily overload count, single axle overload statistics, tandem overload statistics, tridem overload statistics, and quad overload statistics.

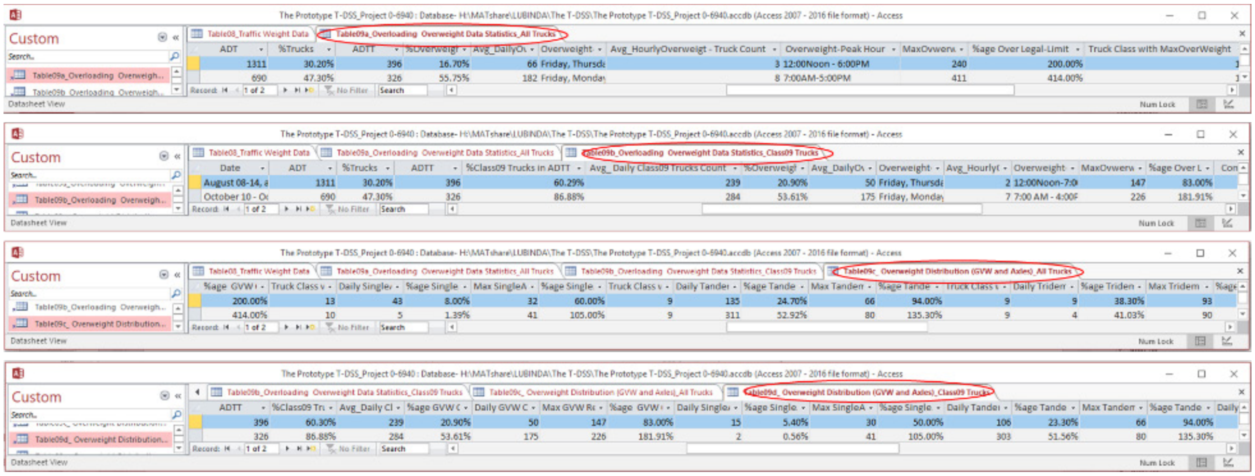


**Figure 54. Interface of Overweight Analysis in the T-DSS.**

Figure 55 presents the interface for daily and hourly overload statistics. It is noted that Table 09e reports the daily and hourly overload statistics for all trucks while Table 09f reports the statistics only for class 9 truck that is the most represented truck on all the highways analyzed.

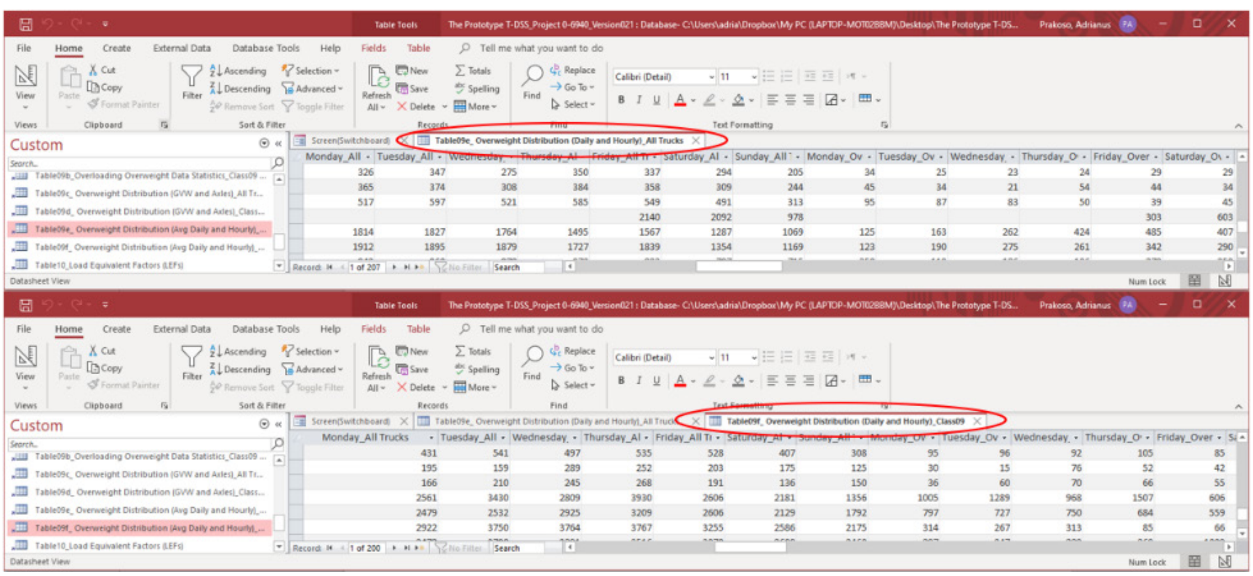


**Figure 55. Interface of Daily and Hourly Overweight Analysis in the T-DSS.**

## T-DSS DATA ACCESS, EXPORTING, EMAILING, AND DOWNLOADS

Accessing the T-DSS data is typically achieved through the MS Access External Data function that exports the data (selected table and/or data) into various desired formats, including MS Excel, text, and PDF. MS Access also provides direct emailing of the T-DSS data once the desired table or set of data is selected. This is exemplified in Figure 56 through Figure 58. The zipped attachments can simply be downloaded by double-clicking the attachment icon on any table that has the zipped attachments.

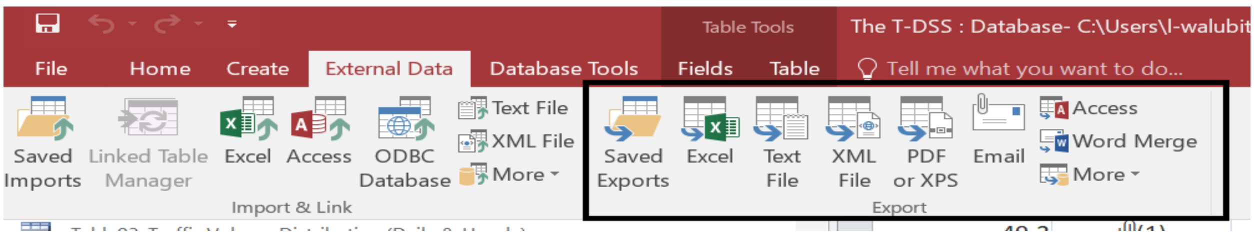



Figure 56. MS Access Tools for T-DSS Data Export.

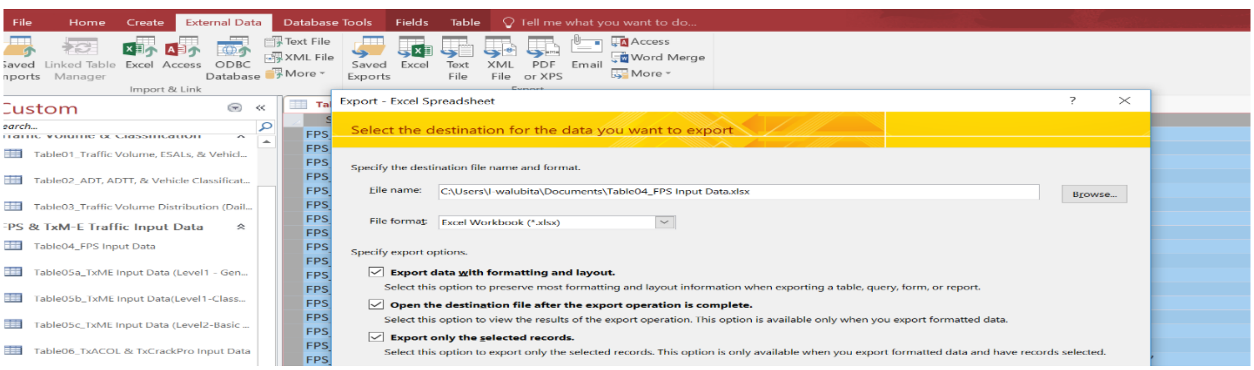



Figure 57. T-DSS Data Export (External Data ⇒ Excel).

| HWY | LaneDirection | ADTbegin | ADTend-20Yr | 20Yr 18-kips ESALs (millions) | Avg Vehicle Speed (mph) | %Trucks in ADT | ATHWLD (kips) | %age Tandem Axles (%) |
|---|---|---|---|---|---|---|---|---|
| IH 35 | NB | 6113 | 23001 | 39.08 | 65.00 | 47.00% | 14.34 | 55.50% |
| IH 35 | NB | 2699 | 10155 | 5.49 | 65.00 | 13.00% | 11.78 | 51.06% |
| IH 35 | SB | 6213 | 23377 | 40.11 | 65.00 | 51.00% | 12.25 | 57.91% |
| IH 35 | SB | 2656 | 9994 | 5.76 | 65.00 | 14.00% | 12.74 | 54.87% |
| US 281 | NB | 2124 | 6473 | 1.79 | 65.00 | 14.00% | 13.03 | 46.84% |
| US 281 | SB | 2150 | 6552 | 1.69 | 65.00 | 17.00% | 12.86 | 46.73% |
| FM 3129 | SB | 504 | 910 | 0.44 | 65.00 | 33.00% | 12.8 | 60.12% |
| SH 7 | WB | 1902 | 3435 | 5.31 | 67.10 | 20.50% | 15.5 | 49.12% |
| FM 468 | EB | 1977 | 3571 | 12.74 | 64.80 | 54.00% | 15.5 | 57.78% |
| US 281 | NB | 1354 | 2445 | 37.31 | 33.70 | 77.00% | 20.51 | 56.42% |
| US 281 | SB | 3801 | 6865 | 18.90 | 35.20 | 32.00% | 15.29 | 56.15% |
| SH 6 | NB | 2118 | 3825 | 2.25 | 69.00 | 22.40% | 12.68 | 45.61% |
| IH 35 | NB | 6113 | 23001 | 39.08 | 65.00 | 47.00% | 14.34 | 55.50% |
| IH 35 | NB | 2699 | 10155 | 5.49 | 65.00 | 13.00% | 11.78 | 51.06% |
| IH 35 | SB | 6213 | 23377 | 40.11 | 65.00 | 51.00% | 12.25 | 57.91% |
| IH 35 | SB | 2656 | 9994 | 5.76 | 65.00 | 14.00% | 12.74 | 54.87% |

Figure 58. Example Data Export from The T-DSS (FPS Input Data).

## THE HELP FUNCTION

The Help function comprises, in zipped and PDF file formats, documents designed to help users navigate the T-DSS. The information and documents include the user's manual, MPRs, tech memos, project deliverables, research reports, and the ME software associated with the T-DSS data. Specifically, users are recommended to read the user's manual for easy T-DSS navigation and data access.

## SUMMARY

This chapter provided an overview of the user-friendly MS Access platform, namely T-DSS, which is used to store and manage the ME traffic data. For continued population and update of the T-DSS, traffic data collection through statewide deployment of the portable WIM system on selected highway sites, particular FM roads without permanent WIM stations, energy sector developmental areas, heavy haul routes/roads, port corridors, and border routes, is strongly recommended.

# CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The portable WIM system technology is an optimal and cost-effective tool to measure and quantify site-specific traffic loading for any given highway site. In research project 0-6940, Develop Systems to Render Mechanistic-Empirical Traffic Data for Pavement Design, portable WIM technology has been successfully explored to accurately measure site-specific traffic data for pavement designs and maintenance or rehabilitation purposes. With proper site selection, installation, calibration, and maintenance, data accuracy of up to 93.5% can be achieved with the portable WIM; therefore, the system can be a practical alternative to be implemented throughout the state of Texas.

This technical report presented and documented the two-year work done to implement portable WIM technology on Texas highways. The scope of work included development of standardized procedures and guidelines for portable WIM installation and data analysis, establishment of demonstration, experimentation, and training portable WIM stations, and deployment of portable WIM systems for site-specific traffic data collection on selected highway sites to support TxDOT districts in their need for pavement design, maintenance, and rehabilitations. This chapter summarizes the overall findings and conclusions drawn from this study.

## STANDARD GUIDELINES FOR PORTABLE WIM DEPLOYMENT

A comprehensive and detailed standardized procedures and guidelines for portable WIM system installation and data analysis has been developed to assist the Maintenance Division (MNT), Materials and Testing Division (MTD), Receiving Agency districts, and other stakeholders to implement and readily use the new system. The guideline covers the following key aspects:

- Description of the portable WIM system components and required accessories
- Portable WIM site selection, preparation, and management
- Guidelines and procedures for portable WIM installation, setup, removal, and calibration
- Guidelines and procedures for portable WIM troubleshooting and maintenance
- Standardized procedures and automated macros for general processing and analysis of the portable WIM traffic data
- Standardized procedures and automated macros for generating FPS and ME (TxME) traffic input data.

## PORTABLE WIM SYSTEM IMPLEMENTATION

Like permanent WIM stations, the portable WIM system is able to measure traffic volume counts, vehicle classification, vehicle speed, vehicle weight data, and so forth. To date, portable WIM systems have been installed in more than 66 highway sites across Texas. The portable WIM data are collected through short-term deployment (minimum seven days) as well as long-term deployment (with routine periodic service maintenance). Using the developed macro, these data were analyzed to generate general traffic parameters and ME traffic inputs, which later then can be stored in the T-DSS. The key findings can be summarized as follows:

- Portable WIM is a cost-effective and practical alternative tool used for site-specific traffic data collection (volume counts, speed, VCD, and vehicle weight measurements).
- The developed portable WIM data analysis macros and algorithms are satisfactorily able to compute and generate general traffic input parameters and ME traffic inputs for both flexible and concrete pavements.
- The T-DSS is a viable, user-friendly, and readily accessible MS Access storage platform for the storage and management of ME traffic data.

## THE EXPERIMENTATION AND DEMONSTRATION TESTING SITES

The experimentation and demonstration testing sites have been successfully established at the TTI RELLIS campus and in-service highways such as US 87 (Austin District), SH 21 (Bryan District), and SH 6 (Bryan District). Various system such as portable WIM systems, pneumatic tubes, Wavetronix system, and Road Scanner have been deployed for comparative evaluation study at SH 21 and SH 6 highways. The key findings are listed below:

- The portable WIM experimentation testing site at TTI RELLIS Campus is fully operational for various activities such as pre-checking and calibration of sensors prior to any field installation works, diagnostic and/or troubleshooting prior to or after field work, and technical support and general advancement of the portable WIM systems.
- The deployment of portable WIM system in US 87 site has been in satisfactory operation for over one year (since December 2019) with minimum maintenance and only one re-calibration check.

- The portable WIM systems, pneumatic tubes, and Wavetronix system deployed at the in-service demonstration testing sites are fairly comparable with a very high accuracy of more than 95% in terms of ADT, ADTT, percentage of trucks, and speed. However, only portable WIM system is capable to capture weight data such as GVW and axle weight.
- Since Wavetronix and Road scanner are not capable to generate FHWA vehicle classification data, length-based vehicle classification macro was developed and needed to process the vehicle length data obtained from these systems and predict the FHWA vehicle classification data.

## RECOMMENDATIONS

Based on the portable WIM implementation across the state of Texas through this project, the following recommendations are made:

- Continued statewide traffic data collection with the portable WIM systems where permanent WIM stations are not available, particularly in the energy sector developmental areas, heavy haul routes/roads, port corridors, and border routes, is strongly recommended to aid TxDOT Districts in pavement design, maintenance, and rehabilitations and population of the TxDOT traffic database. In addition, more traffic data can significantly contribute to the development of a statewide map of truck factors per district per highway functional class.
- Continued improvements, refinement, and enhancements of the portable WIM data analysis macro to make the macro more robust, accurate, and user friendly.
- More side-by-side deployment of Wavetronix along with portable WIM systems to obtain more traffic data that can be used to improve and calibrate the vehicle classification macro.
- Continued refinement and calibration of the length-based vehicle classification macro to enhance the classification accuracy.

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Walubita, L., Prakoso, A., Aldo, A., Lee, S., & Djebou, C. (2019). *Using WIM Systems and Tube Counters to Collect and Generate ME Traffic Data for Pavement Design and Analysis: Technical Report.* College Station, TX: Texas A&M Transportation Institute.

## APPENDIX I: PORTABLE WIM UNIT INSTALLATION AND SETUP


**Figure I-1. Three-Channel TRS Portable WIM Unit.**
(Piezo-electric Channel (2nd channel) = 8 Sensors or 4-Lanes).


**Figure I-2. TRS Piezo-electric Channel Connector with Eight Sensors Capacity, i.e., 4-Lane Setup.**

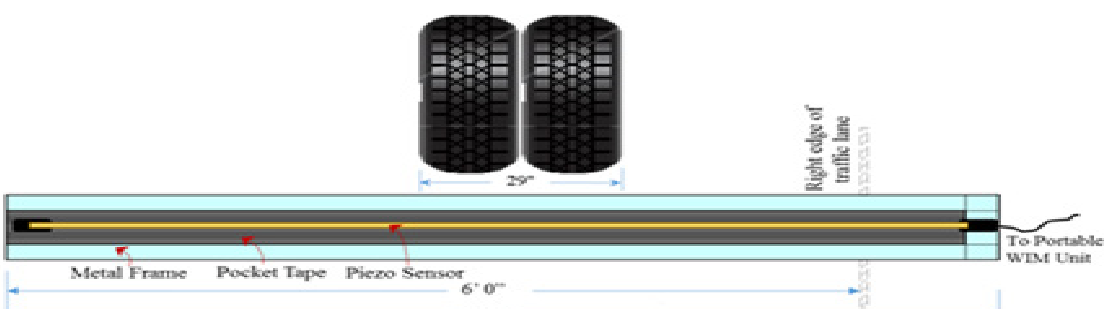



**Figure I-3. Schematic View of the Metal-Plate and Sensor Setup.**


**Figure I-4. Portable WIM System Main Components.**

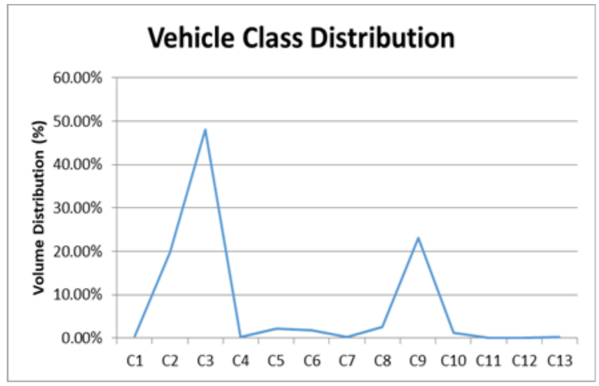

**Figure I-5. Modem Communication System for the Portable WIM.**

# APPENDIX II: GENERAL TRAFFIC OUTPUT RESULTS

| Traffic Volume | SH 302 EB |
|---|---|
| ADT | 5581 |
| ADTT | 1768 |
| %Trucks | 31.7% |
| ATHWLDs | 13.5 |
| 20-Yr 18-kip ESALs (Million) | 26.83 |
| C5/C9 Ratio | 0.10 |

| Vehice Speed Data | SH 302 EB |
|---|---|
| Avg(All) | 57 |
| Avg(Trucks) | 56 |
| Max(All) | 94 |
| Max(Trucks) | 80 |
| Speed Limit at Site Location (mph) | 65 |
| %age of Vehicles Over Speed Limit(All) | 2.25493% |
| %age of Trucks Over Speed Limit(Trucks) | 0.16381% |

Vehicle Class: C2
Truck Type/Class: C5




| Traffic Peak Statistics (SH 302 EB) | | | | |
|---|---|---|---|---|
| Peak hour (all Vehicles) | 5:00 PM | Peak day (all Vehicles) | Tuesday | |
| Peak hour (Trucks only) | 5:00 PM | Peak day (Trucks only) | Tuesday | OW = overweight |
| Peak hour (OW Trucks) | 3:00 PM | Peak day (OW Trucks) | Wednesday | |

**Figure II-1. Traffic Volume and Vehicle Speed Data (SH 302 EB, Odessa District).**

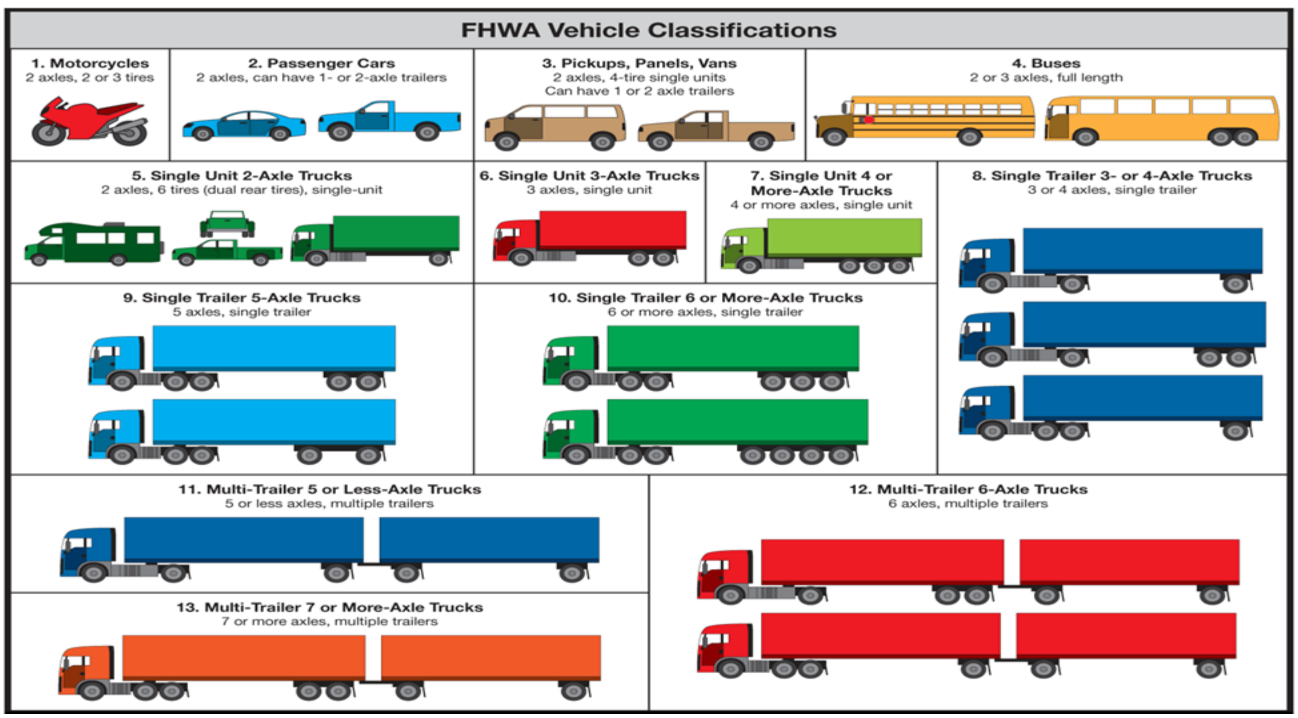



**Figure II-2. FHWA Vehicle Classification.**

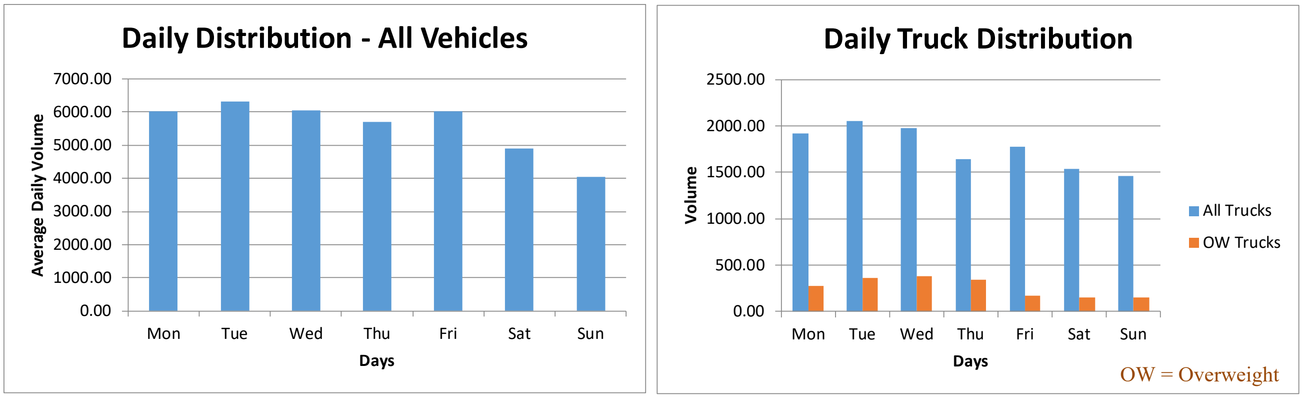



**Figure II-3. Vehicle Daily Distribution (SH 302 EB).**

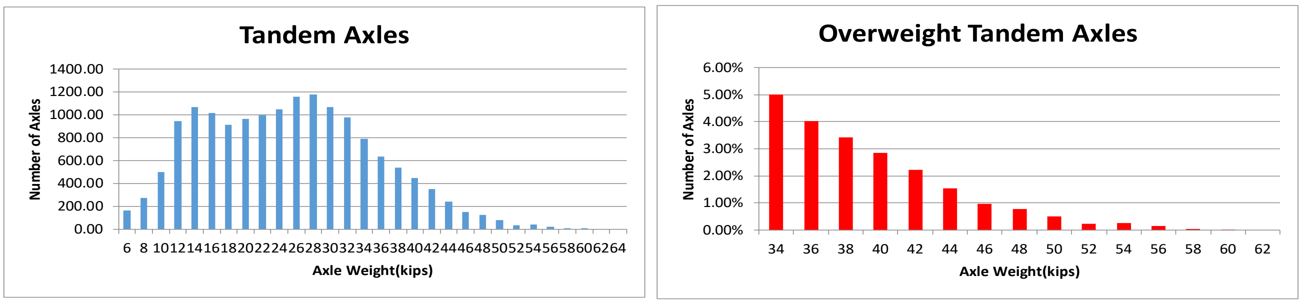



**Figure II-4. Example of Tandem Axle Weight Distribution (SH 302 EB).**

Truck GVW Overweight (SH 302 EB)

| | All Trucks (C4-13) | Class9 (C9) Trucks Only | Comment |
|---|---|---|---|
| ADTT | 1768 | 1290 | |
| ADTT | 1768 | 1290 | |
| %Overweight-Trucks (>80 kips) | 14.87% | 15.97% | |
| Avg_Daily Overweight-Truck Count | 263 | 206 | |
| Most Overweight-Peak Day (s) | Wed | Thu | |
| | | | |
| Average Hourly Truck Count | 74 | 54 | |
| Average Hourly Truck Count | 74 | 54 | |
| Avg_Hourly Overweight - Truck Count | 11 | 8 | |
| Most Overweight-Peak Hour | 3:00:00 PM | 5:00:00 PM | |
| | | | |
| Mostly Occurring Overweight GVW Value | 81 | 81 | Mode |
| %age Over Legal-Limit (>80 kips) | 1.25% | 1.25% | |
| %age of Overweight Trucks with this GVW Value | 4.78% | 5.35% | |
| | | | |
| Max Overweight Recorded (kip) | 207.073125 | 142.0875 | |
| %age Over Legal-Limit (>80 kips) | 158.8% | 77.6% | |
| Truck Class with Max Overweight Recorded | C13 | C9 | |

Axle Overweight - All Trucks(C4-C13) (SH 302 EB)

| | Daily Count | Daily Overweight Count | %age Overweight | Max Weight Recorded (kips) | %age Overweight |
|---|---|---|---|---|---|
| GVW(> 80 kips) | 1768 | 263 | 14.87% | 207.073125 | 158.84% |
| Single(>20 kips) | 3119 | 108 | 3.46% | 30.97 | 54.85% |
| Tandem(>34 kips) | 2250 | 383 | 17.02% | 61.56 | 81.06% |
| Tridem(>42 kips) | 90 | 41 | 45.48% | 84.65625 | 101.56% |
| Quad(>50 kips) | 15 | 6 | 40.00% | 99.945 | 99.89% |

Axle Overweight - Class9 (C9)Trucks Only (SH 302 EB)

| | Daily Count | Daily Overweight Count | %age Overweight | Max Weight Recorded (kips) | %age Overweight |
|---|---|---|---|---|---|
| GVW(> 80 kips) | 1290 | 206 | 15.97% | 142.0875 | 77.61% |
| Single(>20 kips) | 2266 | 70 | 3.09% | 29.79 | 48.95% |
| Tandem(>34 kips) | 2031 | 313 | 15.41% | 61.56 | 81.06% |
| Tridem(>42 kips) | 0 | 0 | 0.00% | 0 | 0.00% |
| Quad(>50 kips) | 0 | 0 | 0.00% | 0 | 0.00% |

**Figure II-5. Truck Overweight Statistics (SH 302 EB, Odessa District).**

# APPENDIX III: PORTABLE WIM HIGHWAY SITE LOCATIONS

## Table III-1. Portable WIM Highway Site Locations throughout Texas

| District | County | Highway | Direction | GPS Coordinates |
|---|---|---|---|---|
| Abilene | Jones | US 277 | NB | 32°48'26.7"N 99°52'17.4"W (32.807417, -99.871500) |
| | | | SB | 32°48'27.4"N 99°52'19.0"W (32.807611, -99.871945) |
| Amarillo | Moore | FM 281 | WB | 36°01'32.9"N 102°06'15.3"W (36.025806, -102.104250) |
| | | | EB | 36°01'32.2"N 102°06'21.6"W (36.025611, -102.106000) |
| Atlanta | Harrison | IH 20 | WB | 32°29'07.5"N 94°29'58.4"W (32.485421, -94.499557) |
| | | | EB | 32°29'06.8"N 94°29'58.3"W (32.485209, -94.499536) |
| | Panola | US 59 | SB | 32°12'05.4"N 94°20'35.4"W (32.201491, -94.343165) |
| Austin | Travis | IH 35 | NB | 30°15'34.1"N 97°44'11.9"W (30.259472, -97.736639) |
| | | | SB | 30°15'41.1"N 97°44'11.3"W (30.261417, -97.736472) |
| | | SH 130 | SB | 30°19'33.6"N 97°34'57.6"W (30.326000, -97.582667) |
| | | US 290 | WB | 30°14'02.9"N 97°52'05.1"W (30.234139, -97.868083) |
| | | | EB | 30°14'02.1"N 97°52'00.9"W (30.233917, -97.866917) |
| | | IH 35 | NB | 30°22'08.0"N 97°40'52.3"W (30.368879, -97.681181) |
| | | | SB | 30°21'47.3"N 97°41'06.2"W (30.363141, -97.685063) |
| | Blanco | US 281 | NB | 30°11'28.8"N 98°22'37.7"W (30.191333, -98.377139) |
| | | | SB | 30°11'37.4"N 98°22'34.9"W (30.193722, -98.376361) |
| | Gillespie | US 87 | NB | 30°19'19.2"N 98°54'38.6"W (30.322000, -98.910722) |
| | | | SB | 30°19'16.3"N 98°54'38.1"W (30.321186, -98.910591) |
| Bryan | Madison | US 190 | EB & WB | 30°53'09.3"N 96°10'25.0"W (30.885922, -96.173614) |
| | Brazos | SH 6 | NB | 30°37'03.9"N 96°17'40.2"W (30.617754, -96.294495) |
| | | | SB | 30°36'60.0"N 96°17'39.3"W (30.616652, -96.294258) |
| | | SH 21 | WB | 30°38'50.8"N 96°29'14.4"W (30.647441, -96.487342) |
| | | | EB | 30°38'56.6"N 96°28'29.6"W (30.649056, -96.474889) |
| | | FM 974 | NB & SB | 30°49'03.7"N 96°20'50.5"W (30.817694, -96.347361) |
| | Robertson | SH 7 | EB & WB | 31°15'27.0"N 96°21'09.6"W (31.257500, -96.352667) |
| | Leon | SH 7 | WB | 31°20'07.4"N 95°42'16.5"W (31.335389, -95.704583) |
| Brownwood | Comanche | SH 6 | NB | 32°08'25.2"N 98°34'31.4"W (32.140324, -98.575376) |
| El Paso | Culberson | RM 652 | WB & EB | 31°55'54.6"N 104°29'20.8"W (31.931833, -104.489111) |
| | | | | 31°51'10.2"N 104°14'08.9"W (31.852833, -104.235806) |
| | | | | 31°50'14.7"N 104°10'15.1"W (31.837417, -104.170861) |
| Fort Worth | Wise | SH 114 | EB | 33°02'12.0"N 97°25'28.7"W (33.036667, -97.424639) |
| Laredo | Webb | IH 35 | NB | 27°40'04.0"N 99°28'12.3"W (27.667786, -99.470079) |
| | | IH 35 | SB | 27°40'35.9"N 99°28'03.9"W (27.676638, -99.467738) |
| | | IH 35 FR | NB | 27°40'31.6"N 99°28'03.1"W (27.675448, -99.467537) |
| | | IH 35 FR | SB | 27°40'31.1"N 99°28'06.3"W (27.675308, -99.468420) |

| | | | | |
|---|---|---|---|---|
| | | FM 1472 | WB | 27°36'35.5"N 99°31'13.6"W (27.609873, -99.520432) |
| | | FM 1472 | EB | 27°36'35.5"N 99°31'14.7"W (27.609869, -99.520740) |
| | | US 83 | NB | 28° 02’ 37.4”N 099° 32’ 59.8”W (28.043722, -99.549944) |
| | Dimmit | FM 468 | EB | 28°33'01.0"N 99°30'09.6"W (28.550290, -99.502679) |
| Odessa | Midland | SH 349 | NB | 31°56'08.6"N 102°13'43.8"W (31.935722, -102.228833) |
| | | SH 349 | SB | 31°56'14.3"N 102°13'53.3"W (31.937308, -102.231479) |
| | Reeves | RM 652 | WB & EB | 31°51'40.0"N 103°51'21.8"W (31.861098, -103.856055) |
| | Loving | SH 302 | WB | 31°42'56.8"N 103°35'19.3"W (31.715778, -103.588694) |
| | Reeves | US 285 | WB & EB | 31°38'58.7"N 103°40'51.6"W (31.649639, -103.681000) |
| | Midland | SH 349 | NB & SB | 31°43'16.5"N 102°00'43.9"W (31.721250, -102.012194) |
| | | FM 1787 | WB | 31°41'17.1"N 102°07'13.9"W (31.688093, -102.120526) |
| | Winkler | SH 302 | WB | 31°53'14.9"N 102°52'55.4"W (31.887472, -102.882056) |
| | | SH 302 | EB | 31°53'20.7"N 102°52'25.8"W (31.889083, -102.873833) |
| | | SH 302 | WB & EB | 31°51'19.9"N 103°03'25.8"W (31.855528, -103.057167) |
| San Angelo | Glasscock | SH 137 | NB | 31°47'17.0"N 101°40'38.4"W (31.788056, -101.677330) |
| | | | SB | 31°47'37.1"N 101°40'45.7"W (31.793625, -101.679365) |
| Waco | Hamilton | SH 36 | WB | 31°42'19.9"N 98°07'49.0"W (31.705528, -98.130278) |
| | | | EB | 31°42'20.0"N 98°07'49.5"W (31.705556, -98.130417) |
| | | US 281 | NB | 31°42'49.0"N 98°07'12.9"W (31.713611, -98.120250) |
| | | | SB | 31°42'48.6"N 98°07'13.1"W (31.713500, -98.120306) |
| Austin | Travis | IH 35 FR | NB | 30°18'12.1"N 97°42'50.1"W (30.303368, -97.713915) |
| | | | SB | 30°18'16.7"N 97°42'49.7"W (30.304637, -97.713809) |
| Abilene | Callahan | FM 880 | NB | 32°18'34.3"N 99°10'26.4"W (32.309536, -99.173989) |
| | | | SB | 32°18'34.3"N 99°10'26.4"W (32.309536, -99.173989) |
| | | FM 1864 | EB | 32°18'12.0"N 99°10'12.0"W (32.303321, -99.170008) |
| | | | WB | 32°18'12.0"N 99°10'12.0"W (32.303321, -99.170008) |
| Bryan | Brazos | SH 6 | NB | 30°25'12.8"N 96°06'27.7"W (30.420225, -96.107692) |
| | | | SB | 30°27'49.7"N 96°09'09.1"W (30.463806, -96.152528) |
| Odessa | Reeves | SH 17 | NB & SB | 31°09'08.7"N 103°35'14.3"W (31.152419, -103.587299) |
| | Winkler | SH 115 | NB & SB | 31°57'42.6"N 102°57'53.8"W (31.961828, -102.964946) |
| | Martin | SH 137 | NB & SB | 32°18'25.4"N 101°51'35.2"W (32.307041, -101.859773) |

# APPENDIX IV: PORTABLE WIM CALIBRATION

**Figure IV-1. Static Scales for Axle Weight Measurement Calibration and Verification.**

**Figure IV-2. Static Axle Weight Measurement of a TTI Class 03 Truck.**


**Figure IV-3. TTI Class 03 Truck for Portable WIM Calibration**


**Figure IV-4. Class 09 Truck for Portable WIM Calibration**

# APPENDIX V: WAVETRONIX, ROAD SCANNER, AND TRAILER MAST

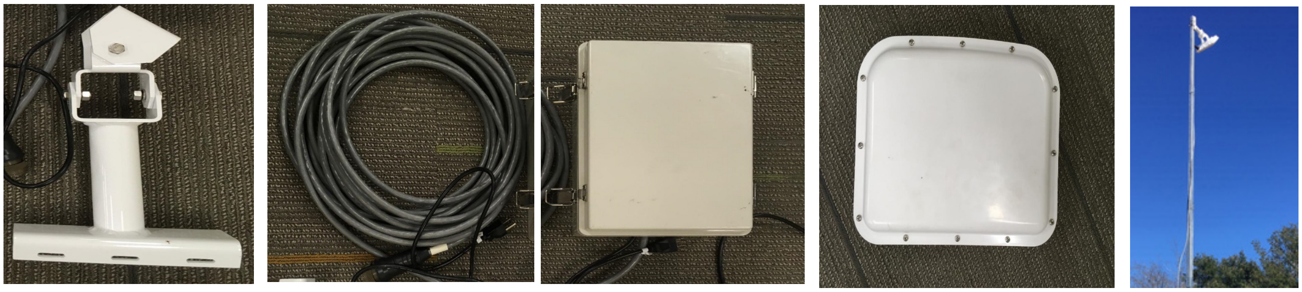


**Figure V-1. Wavetronix System.**


**Figure V-2. Road Scanner System.**

**Figure V-3. Trailer Mast.**

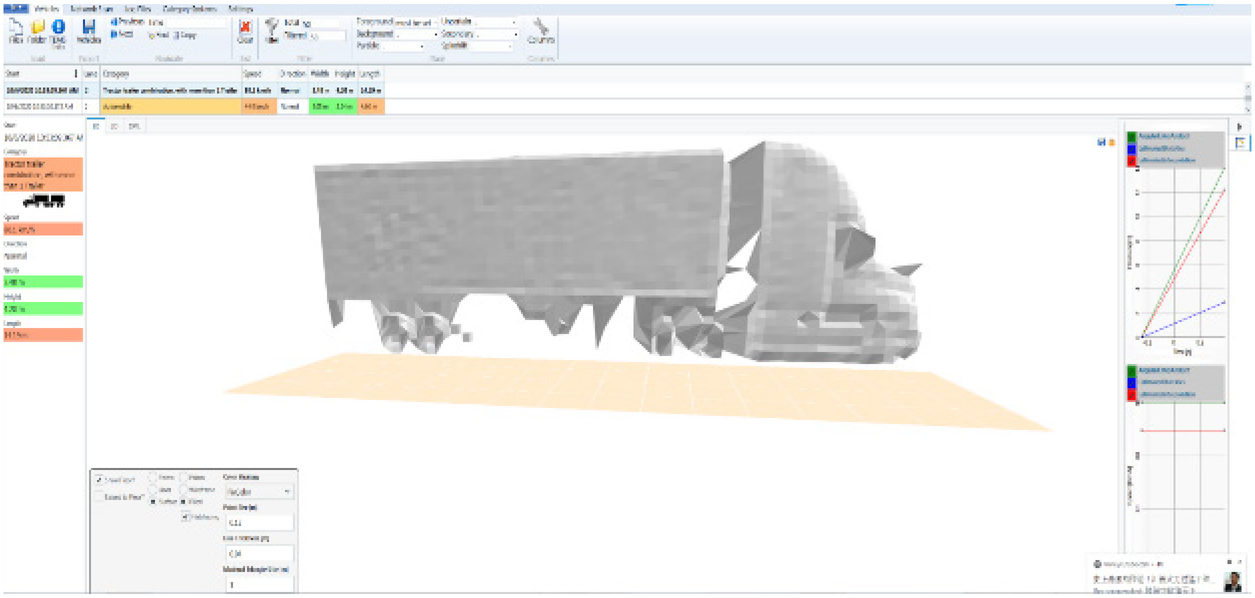


**Figure V-4. Road Scanner 3-D Vehicle Image Projection of 18-Wheeler Truck.**

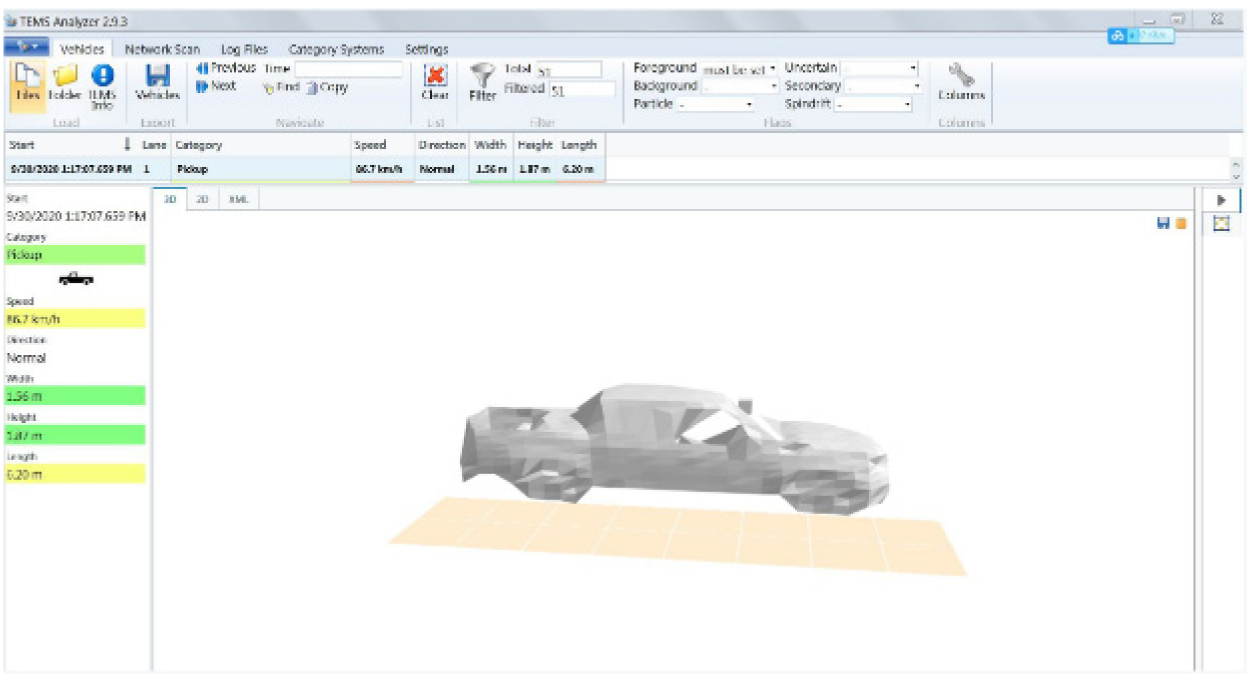



**Figure V-5. Road Scanner 3-D Vehicle Image Projection of Pick-up Truck.**

# APPENDIX VI: COMPARISON STUDY OF VARIOUS SYSTEM IN THE TESTING SITES

| Start Time | 23rd Nov, 2020 3:20 PM | | |
|---|---|---|---|
| End Time | 23rd Nov, 2020 5:20 PM | | |
| Comparision Factor | Manual | Portable WIM | Wavetronix |
| Total Vehicles | 992 | 990 | 1004 |
| Total Trucks | 118 | 100 | 105 |
| ADT | 11904 | 11880 | 12048 |
| ADTT | 1416 | 1200 | 1260 |
| C5/C9 Ratio | 0.768 | 0.207 | 0.176 |
| %Trucks | 11.90% | 10.10% | 10.46% |
| | | | |
| Speed | | | |
| Avg(All) | | 69 | 65 |
| Avg(Trucks) | | 67 | 65 |
| Max(All) | | 82 | 87 |
| Max(Trucks) | | 75 | 79 |
| Speed Limit(mph) | | 75 | 75 |
| %age of Vehicles Over Speed Limit(All) | | 6.76% | 9.20% |
| %age of Trucks Over Speed Limit(Trucks) | | 8.00% | 10.40% |

| Truck Percentage Data | | | | |
|---|---|---|---|---|
| Avg | Min Dev | Max Dev | Deviation Error from Avg | Accuracy w.r.t Avg |
| 11% | 3% | 10% | ±6.5% | 93% |

| Unit | Deviation Error from Avg | Accuracy (Target ≥ 85%) |
|---|---|---|
| Manual = | 9.96% | 90.04% |
| Portable WIM = | 6.63% | 93.37% |
| Wavetronix = | 3.33% | 96.67% |

| Percentage of Classes | | | |
|---|---|---|---|
| Class | Manual | Portable WIM | Wavetronix |
| C1 | 0.10% | 0.00% | 4.88% |
| C2 | 49.80% | 52.83% | 68.23% |
| C3 | 38.21% | 37.07% | 16.43% |
| C4 | 0.00% | 0.00% | 0.00% |
| C5 | 4.33% | 1.21% | 0.90% |
| C6 | 1.31% | 1.41% | 1.29% |
| C7 | 0.20% | 0.20% | 0.00% |
| C8 | 0.40% | 1.41% | 1.89% |
| C9 | 5.65% | 5.86% | 5.08% |
| C10 | 0.00% | 0.00% | 1.29% |
| C11 | 0.00% | 0.00% | 0.00% |
| C12 | 0.00% | 0.00% | 0.00% |
| C13 | 0.00% | 0.00% | 0.00% |
| Sum= | 100.00% | 100.00% | 100.00% |

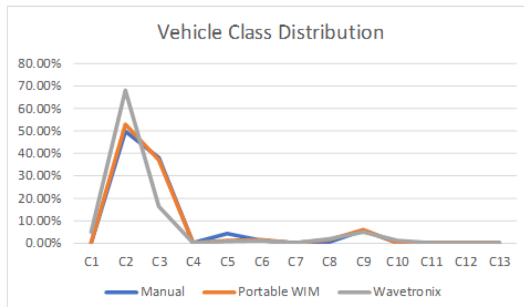



**Figure VI-1. System Comparisons of Portable WIM System and Wavetronix with Manual Vehicle Counting on Nov 23rd, 2020 – SH 21, Bryan District**

| Start Time | 25th Nov, 2020 10:45 AM | | |
|---|---|---|---|
| End Time | 25th Nov, 2020 12:45 AM | | |
| Comparision Factor | Manual | Portable WIM | Wavetronix |
| Total Vehicles | 927 | 927 | 952 |
| Total Trucks | 121 | 113 | 107 |
| ADT | 11124 | 11124 | 11424 |
| ADTT | 1452 | 1356 | 1284 |
| C5/C9 Ratio | 1.022 | 0.457 | 0.353 |
| %Trucks | 13.05% | 12.19% | 11.24% |
| | | | |
| Speed | | | |
| Avg(All) | | 70 | 68 |
| Avg(Trucks) | | 69 | 68 |
| Max(All) | | 84 | 89 |
| Max(Trucks) | | 77 | 79 |
| Speed Limit(mph) | | 75 | 75 |
| %age of Vehicles Over Speed Limit(All) | | 11.11% | 21.21% |
| %age of Trucks Over Speed Limit(Trucks) | | 9.00% | 11.23% |

| Truck Percentage Data | | | | |
|---|---|---|---|---|
| Avg | Min Dev | Max Dev | Deviation Error from Avg | Avg. Accuracy |
| 12% | 8% | 7% | ±7.5% | 92.54% |

| Unit | Deviation Error from Avg. | Accuracy (Target ≥ 85%) |
|---|---|---|
| Manual = | 7.34% | 92.66% |
| Portable WIM = | 0.24% | 99.76% |
| Wavetronix = | 7.58% | 92.42% |

| Percentage of Classes | | | |
|---|---|---|---|
| Class | Manual | Portable WIM | Wavetronix |
| C1 | 0.22% | 0.11% | 3.57% |
| C2 | 56.20% | 51.24% | 64.92% |
| C3 | 30.53% | 36.46% | 20.27% |
| C4 | 0.00% | 0.32% | 0.00% |
| C5 | 5.07% | 2.27% | 1.26% |
| C6 | 2.16% | 2.05% | 1.16% |
| C7 | 0.00% | 0.00% | 0.00% |
| C8 | 0.43% | 2.27% | 2.52% |
| C9 | 4.96% | 4.96% | 3.57% |
| C10 | 0.43% | 0.32% | 2.73% |
| C11 | 0.00% | 0.00% | 0.00% |
| C12 | 0.00% | 0.00% | 0.00% |
| C13 | 0.00% | 0.00% | 0.00% |
| Sum= | 100.00% | 100.00% | 100.00% |

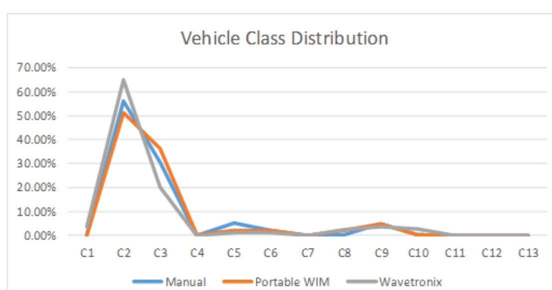



**Figure VI-2. System Comparisons of Portable WIM System and Wavetronix with Manual Vehicle Counting on Nov 25th, 2020 (morning session) – SH 21, Bryan District**

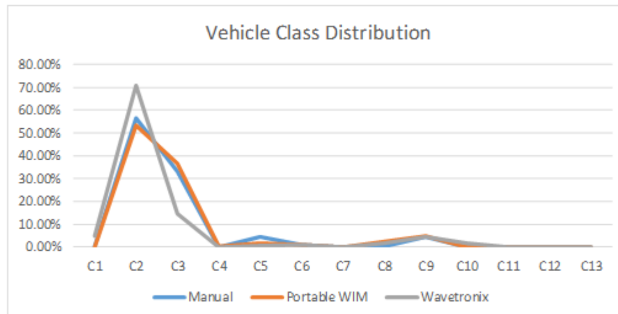
| Start Time | 25th Nov, 2020 2:00 PM | | |
|---|---|---|---|
| End Time | 25th Nov, 2020 3:30 PM | | |
| Comparision Factor | Manual Counting | Portable WIM | Wavetronics |
| Total Vehicles | 849 | 844 | 866 |
| Total Trucks | 86 | 84 | 84 |
| ADT | 10188 | 10128 | 10392 |
| ADTT | 1032 | 1008 | 1008 |
| C5/C9 Ratio | 0.949 | 0.375 | 0.150 |
| %Trucks | 10.13% | 9.95% | 9.70% |
| | | | |
| Speed | | | |
| Avg(All) | | 70 | 68 |
| Avg(Trucks) | | 70 | 67 |
| Max(All) | | 87 | 95 |
| Max(Trucks) | | 79 | 82 |
| Speed Limit(mph) | | 75 | 75 |
| %age of Vehicles Over Speed Limit(All) | | 13.15% | 20.78% |
| %age of Trucks Over Speed Limit(Trucks) | | 8.00% | 9.69% |

| Truck Percentage Data | | | | |
|---|---|---|---|---|
| Avg | Min Dev | Max Dev | Deviation Error from Avg | Accuracy w.r.t Avg |
| 10% | 2% | 2% | ±2.0% | 98% |

| Unit | Deviation Error from Avg | Accuracy (Target ≥ 85%) |
|---|---|---|
| Manual = | 2.04% | 97.96% |
| Portable WIM = | 0.25% | 99.75% |
| Wavetronix = | 2.29% | 97.71% |

**Percentage of Classes**

| Classification | Manual | Portable WIM | Wavetronix |
|---|---|---|---|
| C1 | 0.24% | 0.12% | 4.97% |
| C2 | 56.42% | 53.32% | 70.67% |
| C3 | 33.22% | 36.61% | 14.67% |
| C4 | 0.00% | 0.24% | 0.00% |
| C5 | 4.36% | 1.78% | 0.69% |
| C6 | 0.94% | 0.95% | 1.04% |
| C7 | 0.00% | 0.00% | 0.00% |
| C8 | 0.24% | 2.25% | 1.62% |
| C9 | 4.59% | 4.74% | 4.62% |
| C10 | 0.00% | 0.00% | 1.73% |
| C11 | 0.00% | 0.00% | 0.00% |
| C12 | 0.00% | 0.00% | 0.00% |
| C13 | 0.00% | 0.00% | 0.00% |
| Sum= | 100.00% | 100.00% | 100.00% |




(c)

**Figure VI-3. System Comparisons of Portable WIM System and Wavetronix with Manual Vehicle Counting on Nov 25th, 2020 (afternoon session) – SH 21, Bryan District**

Vehicle Class Distribution

| Class | Manual Counting | Permanent WIM | Portable WIM | Wavetronix | Road Scanner |
|---|---|---|---|---|---|
| Class 1 | 0.18% | 0.36% | 0.09% | 0.27% | 0.59% |
| Class 2 | 44.67% | 38.10% | 43.26% | 39.25% | 36.75% |
| Class 3 | 31.99% | 28.08% | 32.87% | 37.19% | 35.39% |
| Class 4 | 0.46% | 0.22% | 0.19% | 0.00% | 0.20% |
| Class 5 | 3.86% | 17.56% | 4.21% | 2.15% | 6.65% |
| Class 6 | 2.57% | 2.32% | 2.62% | 1.52% | 3.62% |
| Class 7 | 0.28% | 0.15% | 0.19% | 0.00% | 0.00% |
| Class 8 | 1.10% | 1.81% | 1.59% | 1.70% | 2.05% |
| Class 9 | 14.15% | 9.65% | 14.33% | 4.66% | 5.28% |
| Class 10 | 0.55% | 0.15% | 0.47% | 13.17% | 6.94% |
| Class 11 | 0.18% | 0.00% | 0.19% | 0.00% | 0.00% |
| Class 12 | 0.00% | 0.07% | 0.00% | 0.00% | 0.00% |
| Class 13 | 0.00% | 0.07% | 0.00% | 0.09% | 2.54% |
| Class 14 | 0.00% | 1.45% | 0.00% | 0.00% | 0.00% |

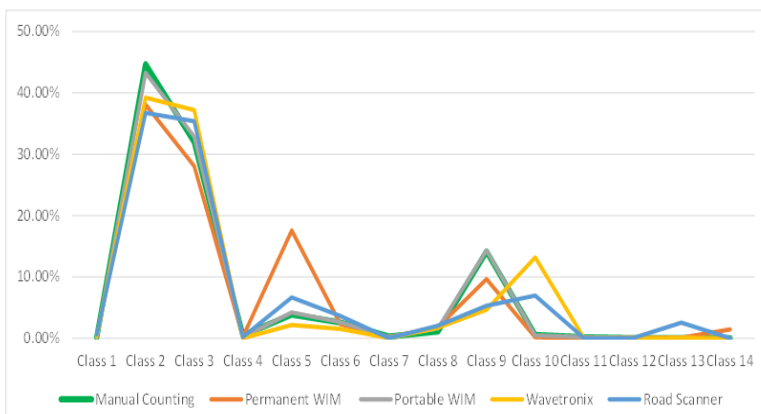



**Figure VI-4. Vehicle Class Distribution of Different Systems with Manual Vehicle Counting on Apr 20th, 2021 – SH 6, Bryan District**

## Vehicle Class Distribution

| Class | Manual Counting | Permanent WIM | Portable WIM | Wavetronix | Road Scanner |
|---|---|---|---|---|---|
| Class 1 | 0.33% | 0.14% | 0.07% | 0.52% | 0.99% |
| Class 2 | 53.16% | 48.58% | 52.41% | 49.87% | 39.42% |
| Class 3 | 32.29% | 21.79% | 34.12% | 35.06% | 42.82% |
| Class 4 | 0.33% | 0.07% | 0.40% | 0.00% | 0.07% |
| Class 5 | 4.32% | 18.47% | 2.95% | 1.81% | 3.82% |
| Class 6 | 1.00% | 0.81% | 0.87% | 0.71% | 2.48% |
| Class 7 | 0.00% | 0.07% | 0.00% | 0.00% | 0.07% |
| Class 8 | 0.20% | 0.61% | 0.80% | 0.91% | 1.13% |
| Class 9 | 8.11% | 7.71% | 7.91% | 3.75% | 4.03% |
| Class 10 | 0.27% | 0.20% | 0.40% | 7.12% | 3.61% |
| Class 11 | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| Class 12 | 0.00% | 0.07% | 0.00% | 0.00% | 0.00% |
| Class 13 | 0.00% | 0.00% | 0.07% | 0.26% | 1.56% |
| Class 14 | 0.00% | 1.49% | 0.00% | 0.00% | 0.00% |
| **Total =** | **100%** | **100%** | **100%** | **100%** | **100%** |

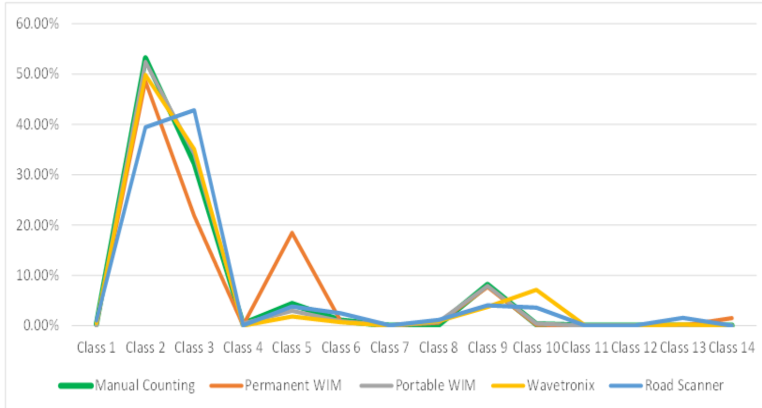



**Figure VI-5. Vehicle Class Distribution of Different Systems with Manual Vehicle Counting on Apr 22nd, 2021 – SH 6, Bryan District**

## Vehicle Class Distribution

| Class | Manual Counting | Permanent WIM | Portable WIM | Wavetronix | Road Scanner |
|---|---|---|---|---|---|
| Class 1 | 0.00% | 0.15% | 0.17% | 0.40% | 0.76% |
| Class 2 | 46.39% | 41.13% | 45.12% | 42.83% | 35.56% |
| Class 3 | 30.95% | 22.34% | 32.78% | 33.66% | 38.74% |
| Class 4 | 0.16% | 0.38% | 0.25% | 0.00% | 0.23% |
| Class 5 | 5.58% | 18.26% | 3.92% | 2.33% | 5.91% |
| Class 6 | 1.72% | 1.66% | 1.58% | 1.37% | 3.87% |
| Class 7 | 0.00% | 0.00% | 0.08% | 0.00% | 0.15% |
| Class 8 | 0.33% | 1.66% | 1.42% | 1.05% | 2.96% |
| Class 9 | 14.29% | 11.47% | 14.18% | 6.04% | 5.00% |
| Class 10 | 0.49% | 0.23% | 0.25% | 11.84% | 5.69% |
| Class 11 | 0.08% | 0.00% | 0.08% | 0.00% | 0.00% |
| Class 12 | 0.00% | 0.08% | 0.00% | 0.00% | 0.00% |
| Class 13 | 0.00% | 0.38% | 0.17% | 0.48% | 1.14% |
| Class 14 | 0.00% | 2.26% | 0.00% | 0.00% | 0.00% |
| **Total =** | **100%** | **100%** | **100%** | **100%** | **100%** |

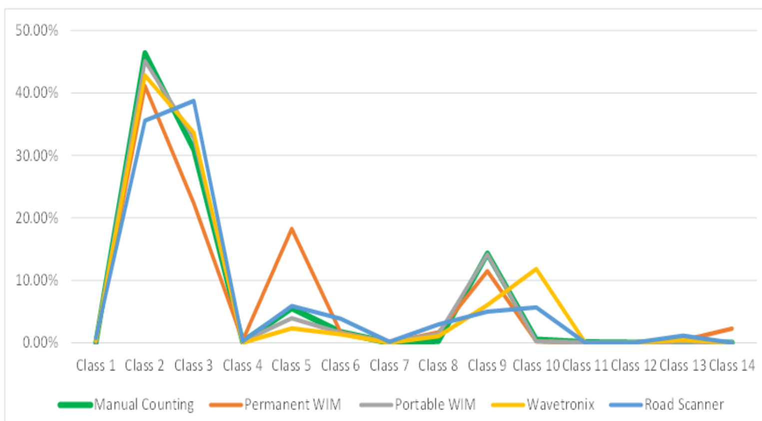



**Figure VI-6. Vehicle Class Distribution of Different Systems with Manual Vehicle Counting on Apr 23rd, 2021 – SH 6, Bryan District**

**Table VI-1. Key Features and Advantages of Different System**

| No | System | Key Features and Advantages |
|---|---|---|
| 1 | Portable WIM System | a) Volume counts, axle spacing, speeding, VCD, & weight<br>b) User-friendliness<br>c) Satisfactory accuracy & reliability<br>d) More than 7-days measurement thru to over 6 months<br>e) Researchers have sound experience with it |
| 2 | Manual Vehicle Counts | a) Used as reference datum.<br>b) Close to actual counts when done by experienced counter. |
| 3 | Tubes | a) Volume Counts, axle spacings, speed, & VCD<br>b) Researchers have sound experience with it |
| 4 | Wavetronix | a) Easy to install<br>b) Volume counts, length and speeds<br>c) Can obtain the occupancy rates of the roads. |
| 5 | Road Scanner | a) Volume counts, length, width, height, and speeds<br>b) Able to generate 3-D image vehicle<br>c) Suitable for oversize vehicle enforcement |

**Table VI-2. Key Challenges and Limitations of Different System**

| No | System | Key Challenges, Limitations, and Disadvantages |
|---|---|---|
| 1 | Portable WIM System | a) Calibration takes up to 250 vehicles, once calibrated gives the best performance.<br>b) Need manual calibration tool for weights for low traffic roads. |
| 2 | Manual Vehicle Counts | a) Difficult to accurately classify some Class 02 -05 vehicles<br>b) Can not obtain speed and weight for all vehicles. |
| 3 | Tubes | a) Accurate for first seven days and then needs to be reinstalled for continued performance.<br>b) Does not capture weight for pavement design |
| 4 | Wavetronix | a) Does not help in FHWA classification – need to use model<br>b) Inbuilt memory is less & needs a dedicated PC to collect per vehicle information – others it collects binned data<br>c) No weight data |
| 5 | Road Scanner | a) Does not help in FHWA classification – need to use model<br>b) Inbuilt memory is less & needs a dedicated PC to collect per vehicle information – others it collects binned data<br>c) No weight data<br>d) At least three LiDAR sensors are needed to generate a very clear 3-D vehicle image |