Final Report

# Commercial Vehicle Inspection Stations

Submitted to

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16. Abstract

The efficient and safe movement of freight over our highways is a vital component of our economy and national security. This research project designed, implemented or evaluated a number of promising technologies that can help in this important endeavor.

The primary objective addressed in this project was the design and implementation of a remotely operated compliance station for commercial vehicles which can automate a multitude of enforcement assistance activities in a cost-effective and efficient manner thereby saving resources and reducing adverse environmental impacts.

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## Executive Summary

Regardless of the principle mode for the movement of freight, whether it is by rail, ship, or plane, all goods consumed are carried by trucks at some point in their journey. According to the U.S. Department of Transportation, freight volume moving within the United States has nearly doubled the rate of population growth over the past three decades. It has even exceeded the growth rates in disposable income and GNP. It is estimated that the volume of goods moved by truck will increase approximately 45 percent between now and 2015.

The primary mission of motor carrier operations in Florida is the safe and efficient movement of goods. Goods are moved by large and heavy trucks, traveling at highway speeds, and often for relatively long distances at a time. Efficiency is assured when there is minimum interference in these operations; only to the degree necessary to ensure the safety of the traveling public.

For any system to function properly there needs to be a set of clear guidelines and regulations which should be consistently enforced. In other words, regulations and enforcement must go hand-in-hand. Regulations cover a large number of parameters that are necessary for both safety, security, and the environment, and include vehicle weight, maximum dimensions, brakes, lights, steering, speed, tires, suspension, exhaust and a multitude of other factors. Other regulations govern commercial drivers such as work hours, and correct licensure.

It is practically impossible to stop, inspect, and test every commercial vehicle that travels through Florida to ensure that trucks meet all safety, security, and environmental regulations. Instead, traditional enforcement mechanisms have centered on selecting a random number of commercial vehicles for inspection at weigh stations. These vehicles are taken out of the traffic flow, and asked to park at the weigh station and wait for an inspector. This model is inefficient for several reasons.

- First, and perhaps most critical, it does not address new safety and security requirements placed on commercial vehicle traffic.
- Second, a substantial amount of time is lost in the inspection process that must be recouped by the carriers. Of course these costs are eventually covered by consumers, not to mention the impact of these delays on interstate commerce.
- Third, queuing commercial vehicles at weigh stations with their associated acceleration and deceleration maneuvers lead to a substantial increase of air pollutants.
- Fourth, large commercial vehicles stopping at weigh stations require substantial space for parking, space that increases by order-of-magnitude the costs for the right of way that needs to be purchased, especially in the vicinity of large urban centers. In some urban areas, space may not be available at any cost.
- And finally, with the current and forecast budgetary shortfalls, states can no longer afford to hire additional enforcement personnel, and must therefore rely on an already overworked workforce.

This research project has the following primary objectives:

1. Design and deployment of the first Florida Remotely Operated Compliance Station (ROCS) (aka Virtual Weigh Station).
2. Field evaluation of several start-of-the art technologies for commercial vehicle compliance.
3. Field evaluation of video, wireless, infrared, internet, database, and sensor technologies.
4. Evaluation of an outdoor "living" lab for commercial vehicle technologies.
5. Development of an on-line database for commercial vehicle technologies.

The research involved a large number of trips to Sneads and the Flagler Weigh station, and the researchers hope that this report will serve as a model for applying advanced technologies in their native operational environments and in the service of our transportation system.

The Sneads ROCS has been an operation for almost one year, and has captured almost 700,000 operational records for various trucks including information related to gross weight, axle weight, speed, and time. The data is invaluable for designing roadway systems, planning for infrastructure developments, and enhancing safety and security.

## Introduction

Overweight trucks pose serious safety and roadway maintenance challenges. For this reason, states have created weigh stations to ensure that truck carriers abide by weight limitations and other regulations. Efficiency is assured when there is minimum interference in these operations; only to the degree necessary to ensure the safety of the traveling public.

Commercial truck safety is a primary focus of every commercial vehicle enforcement agency. The volume of truck traffic is increasing at high rates. As for the relationship between overloading and operating a commercial vehicle with safety deficiencies, a Wisconsin study showed that as many as 70% of overloaded trucks also are in violation of motor carrier safety and driver regulations. This shows that overloaded trucks are three times as likely to be in violation of safety regulations when compared with the estimated safety violation rate for the general truck traffic. (source: The importance of Commercial Vehicle Weight Enforcement in Safety and Road Asset Management. Traffic Technology International 2000. http://www.engr.usask.ca/tc/publications/pdf/irdtraffictechwhyweighv2gfinalpostedpdf.pdf) or (http://www.engr.usask.ca/tc/publications/pdf/irdtraffictechwhyweighv2gfinalpostedpdf.pdf)

## Virtual Weigh-In-Motion Technology

Overweight trucks pose serious safety and roadway maintenance challenges. The concept of "Equivalent Single Axle Loads" (ESAL) was developed to express the expected damage due to any loaded axle expressed in terms of the expected damage from a single standard – namely a commercial truck axle loaded with 18,000 lbs and four tires. A rule of thumb for computing the number of ESALs for any single axle is to determine the ratio of the weight of the axle to 18,000 lbs and raise that ratio to the FOURTH power. For example, for a 36,000 lbs single axle, that ratio would be $(36{,}000/18{,}000)^4$ (=16). This means that doubling the weight from the standard 18,000 lbs causes 16 times more damage. (source: http://training.ce.washington.edu/WSDOT/Modules/04_design_parameters/04-3_body.htm). For this reason, all states have created weigh stations to ensure that truck carriers abide by weight limitations and other regulations.

It is practically impossible to stop, inspect, and test every commercial vehicle that travels through our state to ensure that it meets all safety, security, and environmental regulations. Instead, traditional enforcement mechanisms have centered on selecting a random number of commercial vehicles for inspection at weigh stations. These vehicles are taken out of the traffic flow, and asked to park at the weigh station pending the availability of an inspector.

This model is inefficient for several reasons. First, a substantial amount of time is lost in the inspection process which must be recouped by the carriers. Of course these costs are eventually borne by the tax payers, not to mention the impact of these delays on interstate commerce. Second, queuing commercial vehicles at weigh stations, with their associated acceleration and deceleration maneuvers, lead to a substantial increase of pollutants in the air. Third, large commercial vehicles stopping at weigh stations require substantial space for parking, space that increases by order-of-magnitude the costs for the right of way that needs to be purchased, especially in the vicinity of large urban centers. Here space may not be available at any cost. And fourth, with the current and forecast budgetary shortfalls, the state can no longer afford to hire additional enforcement personnel, and must theretofore rely on an already overworked workforce.

With the expected increase in the number of trucks on our highways, coupled with modern logistic practices and the rapid growth in e-commerce, traffic flow characteristics on highways may change also significantly. This will require the application of new and innovative technologies to expedite the monitoring of commercial vehicle conformance to regulations governing weight, dimensions, and safety, as mandated by Federal and State regulations.

Florida has been a national leader in the deployment of intelligent transportation systems technologies for commercial vehicle operations. The adoption of modern Weigh-in-Motion systems have allowed trucks to avoid stopping at static scales in Weigh Stations leading to large benefits for interstate commerce and the reduction of pollution.

The present environment however poses an additional set of challenges. First, it has long been known that some commercial vehicle operators that exceed safe weight limits often bypass fixed weigh stations. Coupled with an increased need and awareness for enhanced security tempered by the current budgetary limitations, there is now a huge demand for proven advanced compliance technologies to assist law enforcement.

This new technology-reliant architecture will lead to improved enforcement, better security, and a more efficient utilization of enforcement personnel who can plan their activities around areas where violations occur. Efficient enforcement will get unsafe vehicles and operators off the roadways where they can be repaired before being allowed again to travel our roads or expose the public to unnecessary dangers.

Preferably, these technologies should be placed at strategic locations, both on the main line, and at selected bypass routes, to enable law enforcement to plan the optimal use of their resources. Deployment of such stations that can detect attempts to bypass weigh stations, referred to as **virtual weigh stations**, is therefore an extremely valuable goal. These stations will use existing off-the-shelf technologies (COTS) that can monitor and communicate violations.

There is an abundance of vendors marketing technologies and devices to serve these needs. However, there is a dearth of deployment studies that can aid state agencies in the selection of appropriate proven technologies. Several reasons are behind this situation, chief among them is the lack of testing infrastructure for evaluating field performance of these devices. Another problem is the tendency of some groups to purchase devices that may be ill-suited for their intended purpose.

From traffic point of view the WIM station should be installed at an area where there is a huge rate of truck traffic passing through, where truck accidents where reported, in roads/highways/bridges where it is expensive to perform frequent maintenance or rehabilitation, and where there is no other bypass that can be taken by trucks in violation.

WIM stations currently operate in a way where Commercial Vehicle Enforcement (CVE) officers observe images of each truck on a monitor and the information related to that vehicle. An alarm will sound at the weigh station if a truck attempts to by-pass the scales. This means that there must be enough officers that are allocated for such weigh in motion station. A better approach would involve remote monitoring systems where many WIM stations are monitored from one location where once the truck image of the truck is captured, then the truck is recorded and a ticket is sent to the truck owner. With this scenario, the number of officers allocated will be less and the stopping of the vehicles will decrease leading to increased traffic flow in the highways and reduction of damage due to truck stops at the side of the road. In addition there are many bypass roads that the trucks, specifically those in violation of weight, length or both, drive through. The use of sensors that detect weight and trucks dimensions at bypass roads, and are controlled from a weigh station; will help to detect such trucks and consequently provide a safe pavement.

# Thermal Eye Test

This section describes the research work completed on implementation of thermal images in screening commercial vehicles brakes for safety problems. The goal of this research was to test the use of an infrared imaging system, to be installed at a fixed location, in order to screen commercial vehicles brakes. The Infrared system (IR System) consists of two side by side cameras, one is an 8 to 12 micron infrared camera, and the other is a digital camera. The System was housed in a roadside position at the Flagler vehicles weigh station. The IR System camera creates an infrared image of the truck wheels temperature where functional brake appears bright white, indicating that it is "hot" and a non-functioning brake appears dark, or "cold."

## *Scope and Objectives*

The objectives of this study were to evaluate and determine the effectiveness of the IR System in screening of trucks brakes in real-time at the roadside. The IR System was evaluated as a means to:

- Detect problematic trucks brakes conditions.
- Compare the results directly with inspection results.

## *Description of the Test*

The test has designed to screen the trucks brakes before a stop sign inside the weigh station where the trucks had to apply their brakes before entering the static scale but have not yet slowed down or come to a complete stop. Figure 1

Outdoor equipment included, two cameras, housing, circuit board box on a post. The system was deployed directly in line with the truck axles and powered by car battery. Figures 2 and 3.

Indoor equipment, which included, computer, video display, and Joystick controller for manipulating the cameras were powered by regular AC current. Figures 4.

The infrared image is displayed side by side with the digital image to identify the vehicle. The two images are shown on a LCD computer monitor as shown in Figure 5 and 6.

The IR System operator watched the LCD computer monitor and selected vehicles with an indication of the suspected problem area. A wheel was judged as being either problematic or normal. A problematic wheel or brake appeared, according to the IR System operator, significantly colder than the other wheels or brakes on the vehicle. A normal brake did not appear colder than the other brakes on the vehicle.

## *Findings and Results:*

The inspection was performed by officers for the suspected problematic wheels or brakes on the vehicle with prior knowledge from the IR System screening as shown in Figure 7 and 8. Nearly 200 trucks were inspected using the IR System screening in one week.

The major advantage is that the system has the potential of determining if brakes are functioning vs. not functioning. The short observation period for which the system was working showed that hot spots/ areas such as tires, brake discs, and others were clearly shown in the black and white infrared picture as glowing "white" areas.

The disadvantage is that only that problematic vehicles were clear only if the truck was in complete stop mode. Performance of the system was not observed for moving trucks. Also, operators suffered fatigue after watching the screen closely to identify trucks with potential problems.

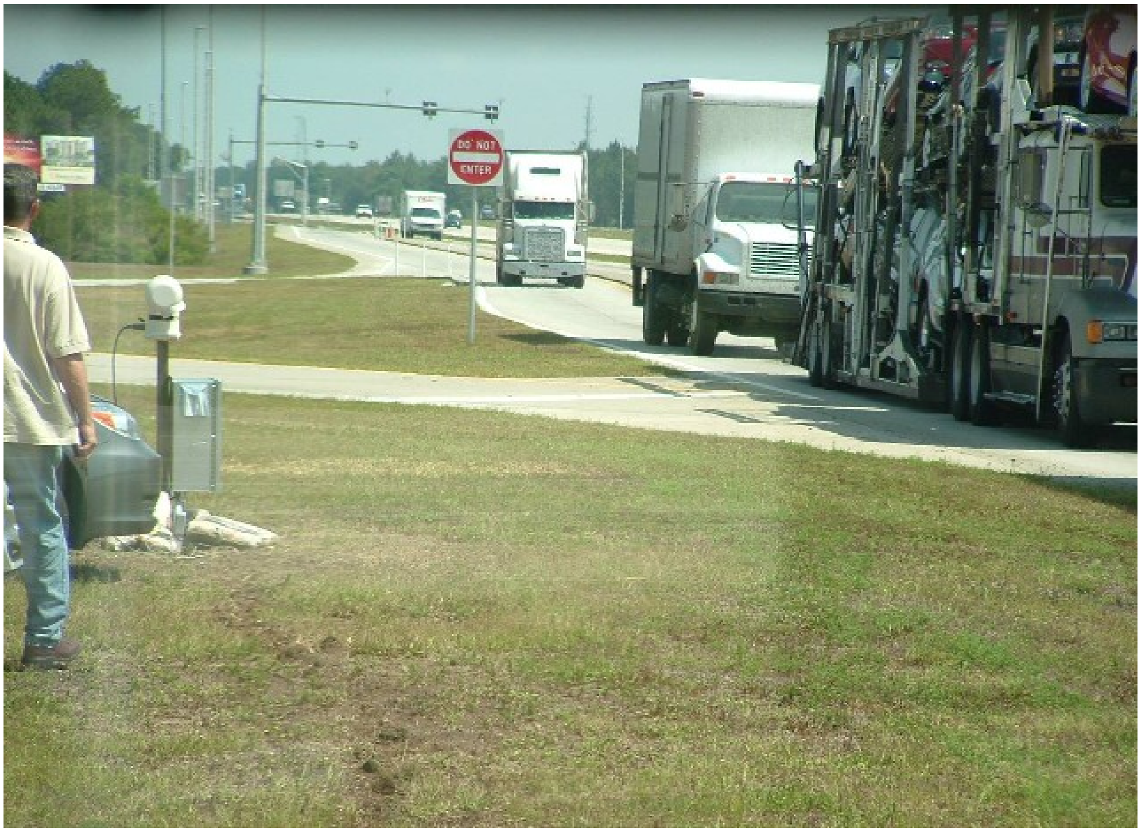



**Figure 1: Camera deployment at the entrance of WIM station**



**Figure 2: The two cameras, housing, and circuit board box on a post**

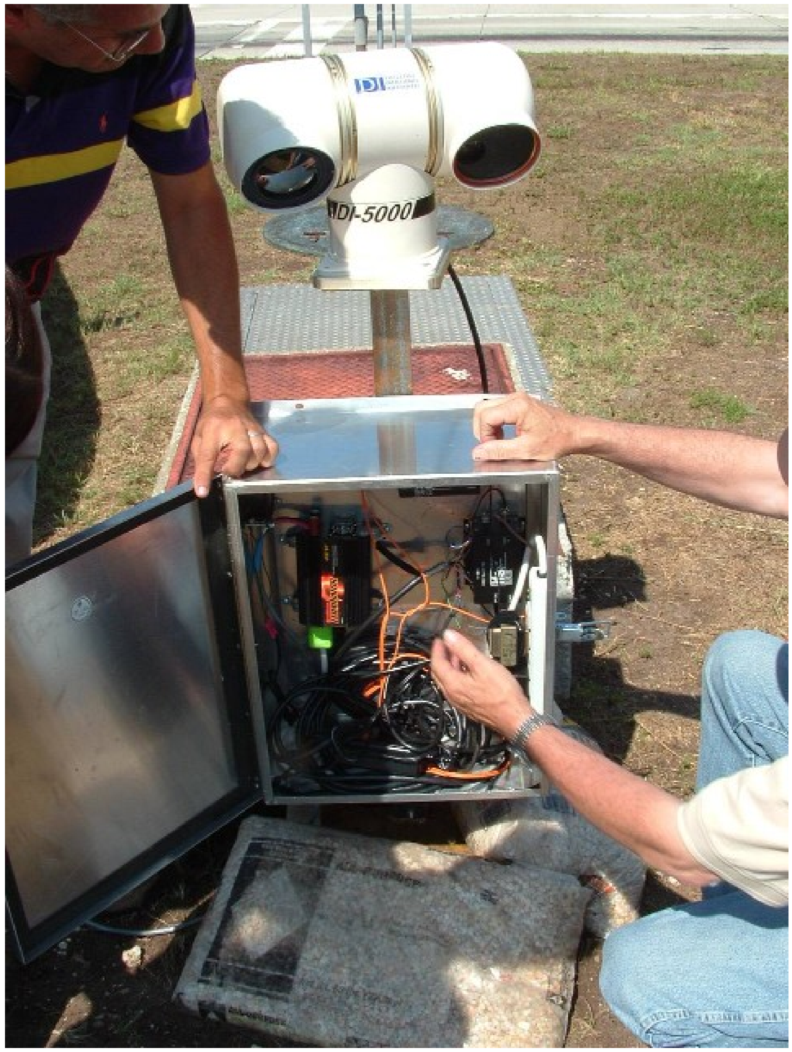



**Figure 3: The Camera and Circuit box**


**Figure 4: The Indoor equipment (computer, video display, and Joy stick for manipulating the cameras)**

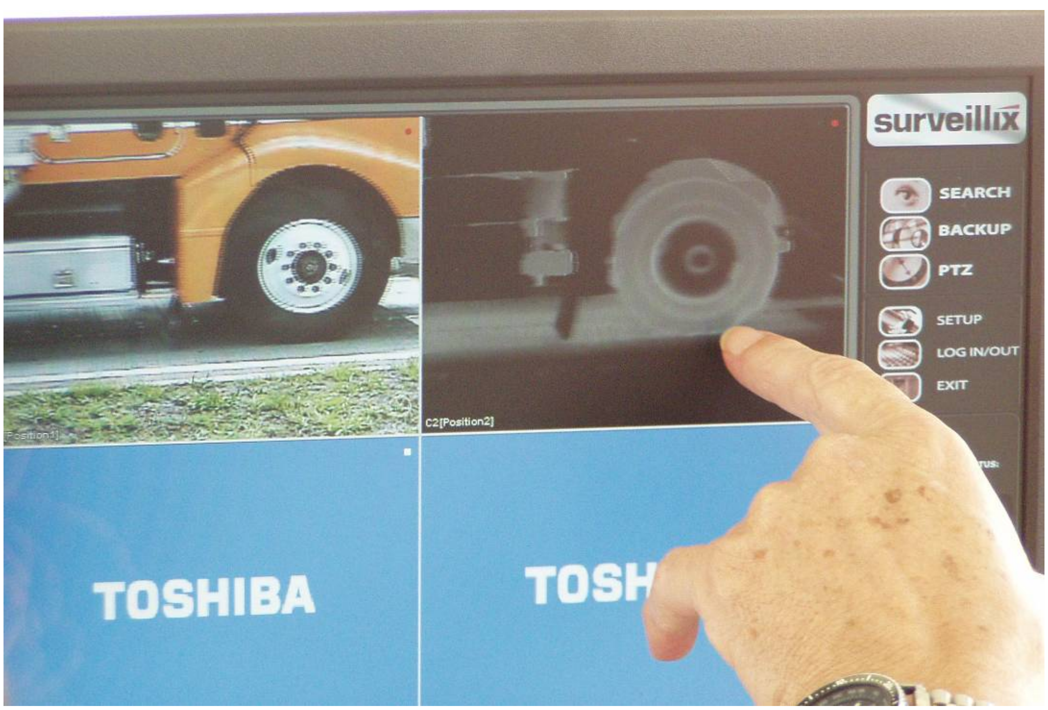



**Figure 5: The two side images on the computer screen**


**Figure 6: Typical truck wheel and brake images**

**Figure 7: Defective brake at inspection station**

**Figure 8: The inspection procedure at the inspection station**

# Mettler Toledo Test at Flagler Weigh Station

This section describes Mettler Toledo's 3D system's test that took place at Flagler Weight Station. There is an essential need to develop an automated technology for screening vehicle dimensions.

This report describes the research work on implementation of a laser scanner provided by the Mettler Toledo Company that provides 3D dimensioning capability of commercial vehicles.

## *Scope and Objectives*

The objectives of this study were to evaluate and determine the effectiveness of using the Mettler Toledo (MT) laser system in scanning and determining the commercial vehicles dimensions. The MT System was evaluated as a means to:

- Scan, sort and identify vehicle dimensions
- Compare the laser scanner results directly with actual measurements from the inspection reports.

## *Description of the Test*

The test has designed based on a patented Mettler Toledo Parallel Infrared Laser Rangefinder (PILAR) as a fan laser measures 100,000+ points per second.

Outdoor equipment included two scanners (SC900 LR), (Figures 9 and 10) connected to two gantries on both sides of the entrance lane of Flagler WIM station. The scanners scanned the cross sections of the vehicle. About 170 sectional scans per second, one scan every 6 milliseconds. Top and both sides of vehicle were scanned to avoid any shadows problem as shown in Figure 9. Laser safety class 1 (unconditionally safe class) was used in the target measurement zone. This type of laser complies with FDA CHDR 1040 and ICE 60825, with 750 nm wave length, not visible to the driver.

Indoor equipment, which included, computer, and printer were attached to the scanner system by a fiber optic cable.

The test deployment was designed that, the two laser scanner were placed 18.6 ft above the road surface, with 18 ft total horizontal distance between them as shown in Figure 10.

The inspection was performed by research team and officers for total of 22 vehicles representing a variety of truck types.  Figures 11 through 32 show the inspected vehicles and both laser scanner and actual measurements.

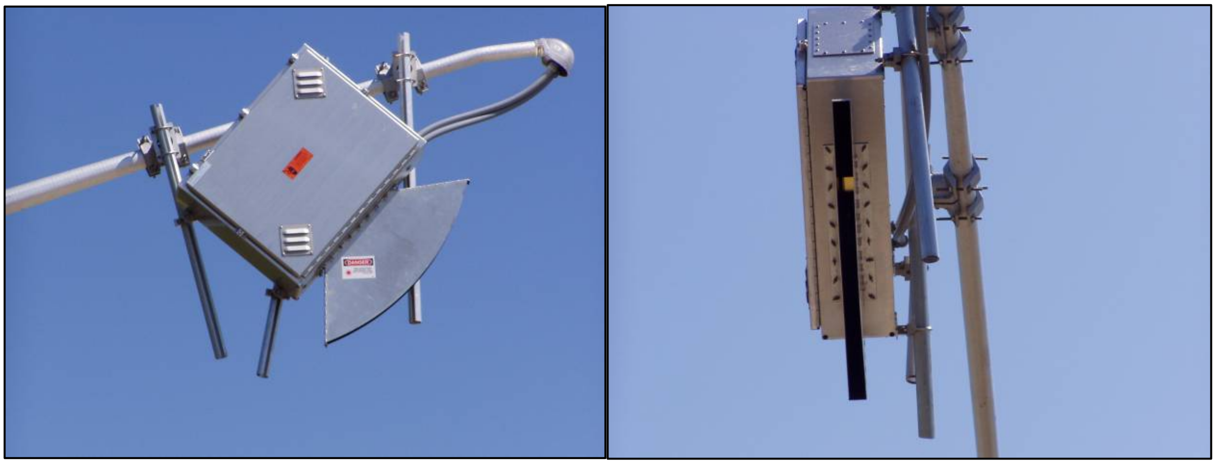


**Figure 9: Laser Scanner (SC900 LR)**

**Figure 10: Laser system deployment at the entrance of WIM**

## *Observation Data Analysis*



| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 1 | 914 | 983 | 69 | 158 | 162 | 4 | 155 | 165 | 10 | |

**Figure 11: Truck No. 1 Data**



| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 2 | 836 | 877 | 41 | 92 | 102 | 10 | 158 | 158 | 0 | |

**Figure 12: Truck No. 2 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 3 | 829 | 871 | 42 | 95 | 103 | 8 | 159 | 161 | 2 | |

**Figure 13: Truck No. 3 Data**


| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 4 | 821 | 851 | 30 | 92 | 102 | 10 | 159 | 161 | 2 | |

**Figure 14: Truck No. 4 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 5 | 924 | 985 | 61 | 77 | 96 | 19 | 75 | 161 | 86 | |

Figure 15: Truck No. 5 Data

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 6 | 707 | 719 | 12 | 117 | 96 | 21 | 119 | 124 | 5 | |

Figure 16: Truck No. 6 Data

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 7 | 760 | 756 | 4 | 86 | 94 | 8 | 127 | 144 | 17 | |

**Figure 17: Truck No. 7 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 8 | 388 | 384 | 4 | 95 | 102 | 7 | 114 | 128 | 14 | |

**Figure 18: Truck No. 8 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Manual w/ Chimney |
| 9 | 374 | 436 | 62 | 90 | 96 | 6 | 122 | 126 | 4 | |

**Figure 19: Truck No. 9 Data**


| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Manual w/ Chimney |
| 10 | 866 | 889 | 23 | 113 | 102 | 11 | 122 | 164 | 42 | 172 |

**Figure 20: Truck No. 10 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 11 | 908 | 1010 | 102 | 93 | 103 | 10 | 165 | 170 | 5 | |

**Figure 21: Truck No. 11 Data**


| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 12 | 791 | 838 | 47 | 166 | 161 | 5 | 173 | 178 | 5 | |

**Figure 22: Truck No. 12 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Manual w/ Chimney |
| 13 | 740 | 776 | 36 | 90 | 95 | 5 | 82 | 122 | 40 | |

**Figure 23: Truck No. 13 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Laser | Manual | ∆ Error | Manual w/ Chimney |
| 14 | 717 | 737 | 20 | 87 | 97 | 10 | 155 | 157 | 2 | |

**Figure 24: Truck No. 14 Data**


| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 15 | 793 | 816 | 23 | 92 | 100 | 8 | 127 | 147 | 20 | |

**Figure 25: Truck No. 15 Data**


| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 16 | 349 | 654 | 305 | 85 | 95 | 10 | 131 | 152 | 21 | |

**Figure 26: Truck No. 16 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 17 | 547 | 687 | 140 | 90 | 102 | 12 | 157 | 158 | 1 | |

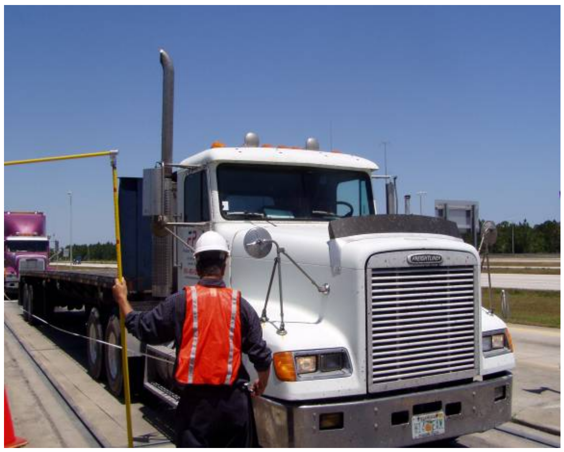
**Figure 27: Truck No. 17 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 18 | 889 | 899 | 10 | 118 | 114 | 4 | 155 | 153 | 2 | |

**Figure 28: Truck No. 18 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 19 | 919 | 986 | 67 | 99 | 103 | 4 | 117 | 156 | 39 | |

**Figure 29: Truck No. 19 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 20 | 704 | 767 | 63 | 85 | 98 | 13 | 106 | 109 | 3 | 157 |

**Figure 30: Truck No. 20 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 21 | 256 | 282 | 26 | 87 | 98 | 11 | 106 | 106 | 0 | 122 |

**Figure 31: Truck No. 21 Data**

| Truck # | Length (Inch) | | | Width (Inch) | | | Height (Inch) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Laser | Manual | Δ Error | Manual w/ Chimney |
| 22 | 373 | 384 | 11 | 90 | 101 | 11 | 116 | 129 | 13 | |

**Figure 32: Truck No. 22 Data**

### *The Findings*

It was found that on average the error for the lengths widths and heights were as follows:

- The Δ Error for the Length was 54.45 inches.
- The Δ Error for the Width was 9.41 inches.
- The Δ Error for the Height was 15.14 inches.

## Remote operations

The locations of the WIM stations are known by the truck drivers, so some truck drivers that may be in violation take bypass roads to avoid being weighed and measured. This results in vast deterioration in the pavements. This section discusses an approach, under testing, aiming to put more stringent control on the bypass roads by installing weight, and dimension sensors at various location and all information be controlled from one WIM station. The test was performed at Palm Coast Bridge, an area close to Flagler WIM station. The following will describe the details of the test:

### *Remote Operations testing Equipment*

The Equipments involved in the testing are:

1. **Sensor:**

   An important component of the system is the sensor made by (ASIM) – where the speed, height, and length of a passing vehicle can be determined. Truck height would trigger other equipment (DVR, and other sensors to send data to a central computer ).

   The TT 298 MW, US & PIR shown in figure (33) is a Triple technology combining Doppler Radar, Ultrasonic and Passive Infrared with intelligent logic that enables the detector to collect the relevant traffic data including vehicle dimensions (Height and length), and its speed.

**Figure 33: ASIM Sensor**

***Passive Infrared (PIR):***

- Detects any changes in thermal radiation emitted by any object or body having a surface temperature above the absolute zero (-273 °C).
- The intensity of the radiation depends on:
    - Surface temperature.
    - Size and structure of a target but not its color or the lighting conditions.
- Two types of sensors used:
    - Dynamic sensor (*react to radiation changes only; a vehicle entering or passing through the field of view activates the output*).
    - Static sensor (*can hold the presence of a vehicle in the field of view for a time of several minutes and are capable of counting*).
    - The use of both sensors is vital as the dynamic detector output will be activated for as long as there is movement in the field of view, if the traffic comes to a stop, even though the traffic is on green, the static detector look at the area in front of the stop line.
    - By combining both sensors, detectors are available for counting, occupancy measurement, presence detection, queue detection, speed measurement and vehicles classification by length.
    - PIR requires very little power and it doesn't use expensive components.

***Doppler Radar / Microwave (MW):***

- Microwave detectors emit focused high frequency signals within a specified frequency band in the GHz region.
- When the vehicle moves into or through the detection area, it reflects the signals back to the detector.
- From the Doppler shift between the emitted and received frequency the direction and speed of a vehicle can be determined very accurately.

***Ultrasonic (US):***

- Ultrasonic detectors emit high frequency acoustic signal bursts beyond the audible range of humans and most animals.
- When the vehicle moves into or through the detection area, it reflects the signals back to the detector.
- Through the travel time of the ultrasonic bursts, the distance to the surface of a vehicle is determined.
- Through such active ranging, a highly reliable presence detection of a standing vehicle for a virtually unlimited time, counting and classification are possible

**2. SMC Wireless Bridge and Amplifier:**

SMC2586w-G (figure 34-amplifier) is a versatile device that can be configured to be in one of the three operational modes: Access point, Bridge Master, and Bridge Slave.

Bridge Master: This mode is designed to work in networks where wireless Bridge Slaves are already installed. The Bridge Master enables the Bridge Slave to automatically associate with it.

If external high-gain directional ability is required, an antenna is needed. The alignments of the antennas is very important. One of the methods used is to determine their location is by using a GPS device.


**Figure 34: SMC Wireless Bridge**

## *Remote Operation Test Location*

The test was performed in two locations:

**Location (A) Flagler Weigh Station:**

This location was chosen for various reasons. More than 213,000 trucks pass each month through the north and southbound lanes of the Flagler weigh station.

About 500 citations are issued monthly for overweight trucks at the Flagler facility, a modern complex with $14 million invested in recent years, said Bruce McDonald, a senior weight inspector at the station.

At Flagler station, computerized scales and other advanced technology weigh trucks, and determine their length, and width. Trucks with weight and dimension exceeding what's allowed on their permits are inspected more thoroughly and are ticketed for violations. Problems arise when as mentioned above, such location is already identified by trucks and there are other bypass roads that can be used by trucks. Thus sensors to detect weight and dimensions violations should be placed at locations, specifically at bypass roads.

The location chosen to place the sensor was Palm Coast Bridge, about 4 miles from the Flagler Weigh Station.

***At Location (A) the following equipment was installed:***

1. SMC 2586W-G wireless bridge set on the Bridge Master mode.
2. A computer connected to the bridge with a cross over Ethernet cable.
3. Antenna placed at the location preset by a GPS device to connect with the Antenna at Palm Coast Bridge.

**<u>Location (B) Palm Coast Bridge:</u>**

***At Location (B) the following equipment were installed as shown in Figure 4:***

1. ASIM Sensor placed at the center of the right hand lane
2. Camera placed at the side of the bridge
3. SMC 2586W-G wireless bridge set on the Bridge Slave mode.
4. A computer connected to the bridge.
5. Antenna placed at the location preset by a GPS device to connect with the Antenna at Flagler Weigh Station.

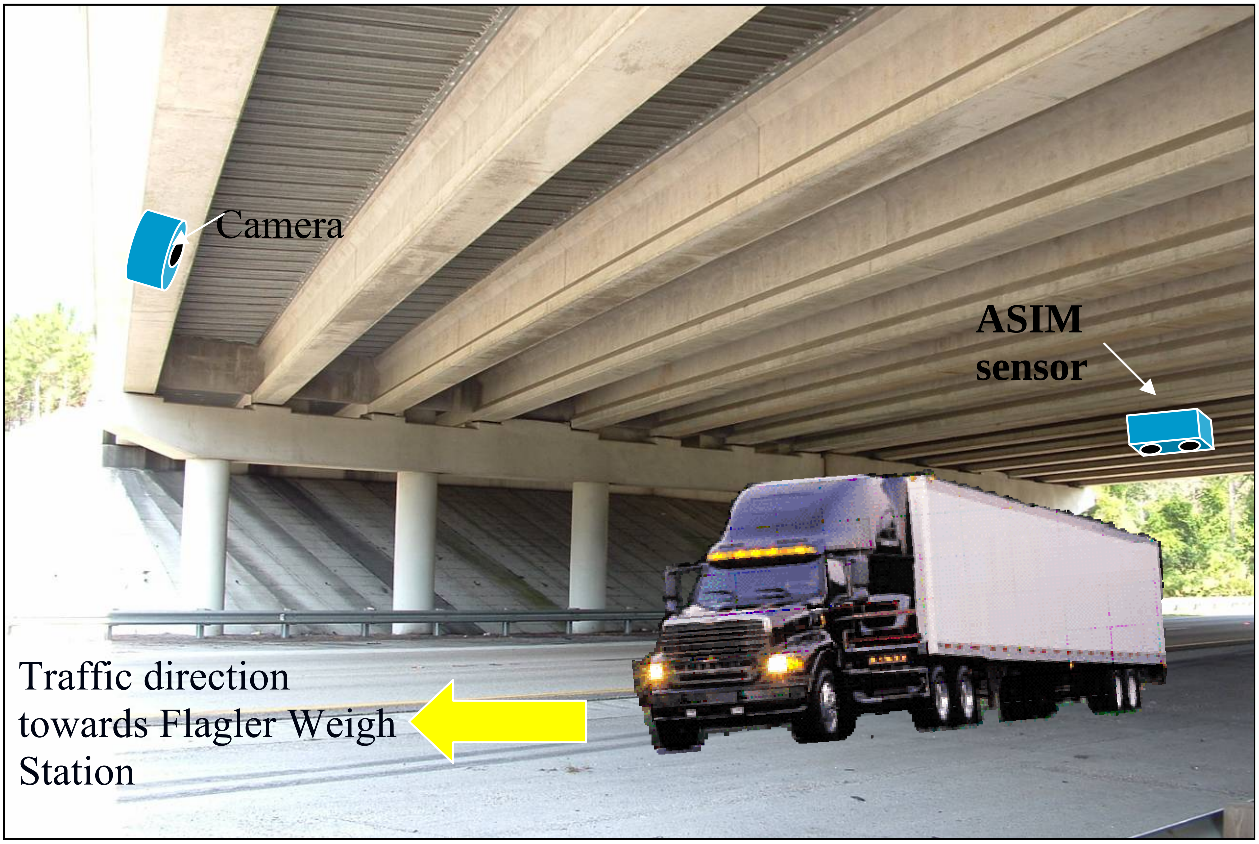



**Figure 35: Testing Equipment at Coast Palm Bridge**

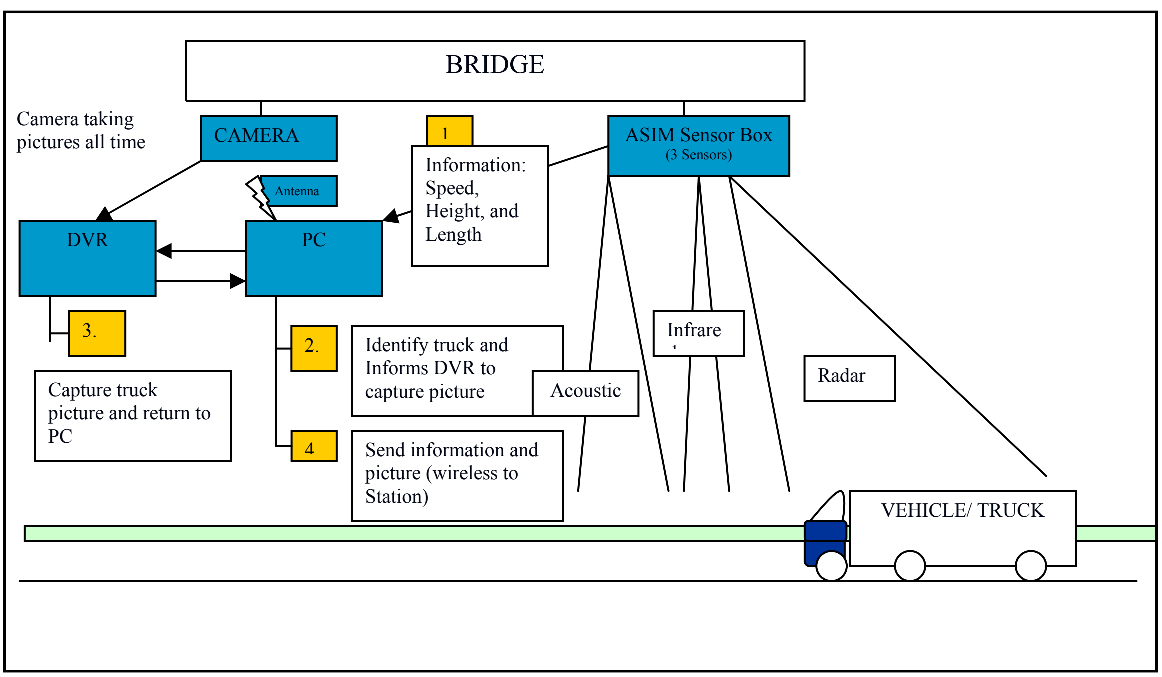



**Figure 36: Schematic Representing the WIM Experiment Setup**

## *Test Procedures*

A schematic drawing that summarizes the procedure is shown in Figure 36.

**At Location (B) Palm Coast Bridge**

1. The right lane was closed for equipment installation
2. ASIM Sensor was installed at the center of right-hand lane of the Palm Coast bridge parallel to the road as shown in Figure 37.
3. The distance from the roadway to bottom of sensor is measured manually to calibrate for any deviated reading from the sensor
4. The power box and the PC are connected.
5. ASIM sensor is connected to the PC to check the triggering.
6. Before opening traffic, the sensor was reset and triggering is checked
7. Camera bracket is connected on the other side of the bridge as shown in Figure 38
8. Camera is aimed and to confirm the desired view a small TV is used.
9. Both Antennas are installed at the top of the bridge.
10. Amplifier is installed together with the power box and the PC on the bridge as shown in Figure 39.

**At Location (A) Weigh in Motion station at Flagler.**

1. The computer is connected to the bridge with an Ethernet cable.
2. Antenna is installed on the communication mast beside the station as shown in Figure 40
3. Amplifier is installed on outside wall of the station
4. The bridge is then connected to the amplifier & PC

**Figure 37: ASIM Sensor on the Middle of the Bridge.**

**Figure 38: Camera Installation**

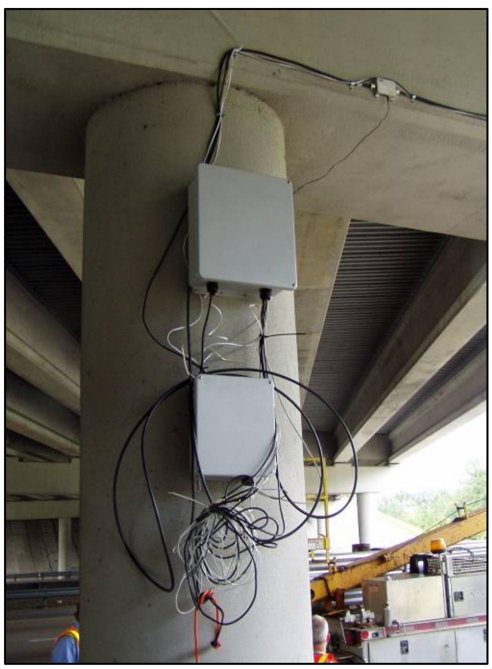


**Figure 39: Amplifier, Power Box and PC**

**Figure 40: Antenna Installation at Flagler Weigh Station**

## *Testing Results*

The sensor under the Palm Coast bridge is set to trigger trucks length, height, and speed, which are over the legal limits. Trucks trigger the sensor, then the camera takes 6 pictures and the PC sends them remotely to the WIM station at Flagler.

## *Conclusion*

The ASIM sensor is an inexpensive and easy to install sensor which enables dimensional and speed measurement for commercial vehicles.  While it does not measure width, its relative ease of installation makes it addition to existing configurations relatively easy.

# Commercial Vehicle Remotely Operated Compliance Station (CV-ROCS)

Weigh-In-Motion is considered a tool for weight enforcement and data collection. The adoption of modern Weigh-in-Motion systems has allowed trucks to avoid stopping at static scales in weigh stations leading to large benefits for interstate commerce and the reduction of pollution.

The Virtual and remotely operated weigh station is a technology that offers a more complete coverage of compliance issues as well as addressing new highway infrastructure demands. As discussed earlier, the locations of WIM stations are known to truck drivers, so some truck drivers take bypass roads to avoid being weighed and measured. This results in vast deterioration of pavements and reduced safety. This section discusses an approach aiming to put more stringent control on the bypass roads by installing weight, speed and dimension sensors at various locations. The test was performed at Palm Coast Bridge, an area close to Flagler WIM station.

## *System Software*

- CV-ROCS server (Figure 41), where the cars, trucks passing under Palm Coast are triggered by the sensor. The software is designed in a way where only trucks are captured, stored and sent to the station. The allowable dimensions and speed are identified in the software and the trucks in violation are framed in red. For each truck captured, six images are taken by the camera and sent to station.

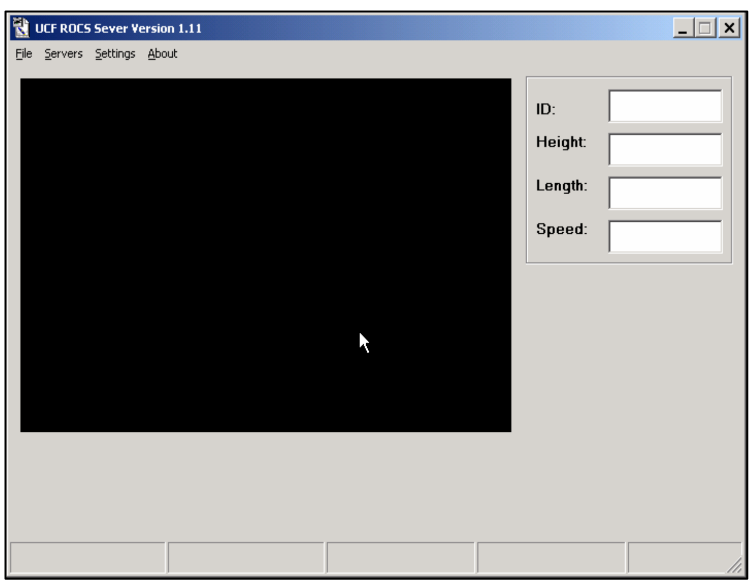



**Figure 41: CV-ROCS server**

- CV-ROCS viewer, where all the trucks captured under the bridge can be viewed. Six shots of the trucks are sent remotely to the station (Figure 42). This software is designed in a way where it can be viewed from any PC connected to the internet. It can be placed in enforcement vehicles and trucks can be identified and stopped. The figure below shows an example of a truck that was in violation. Date and time of capturing the picture is recorded as well.

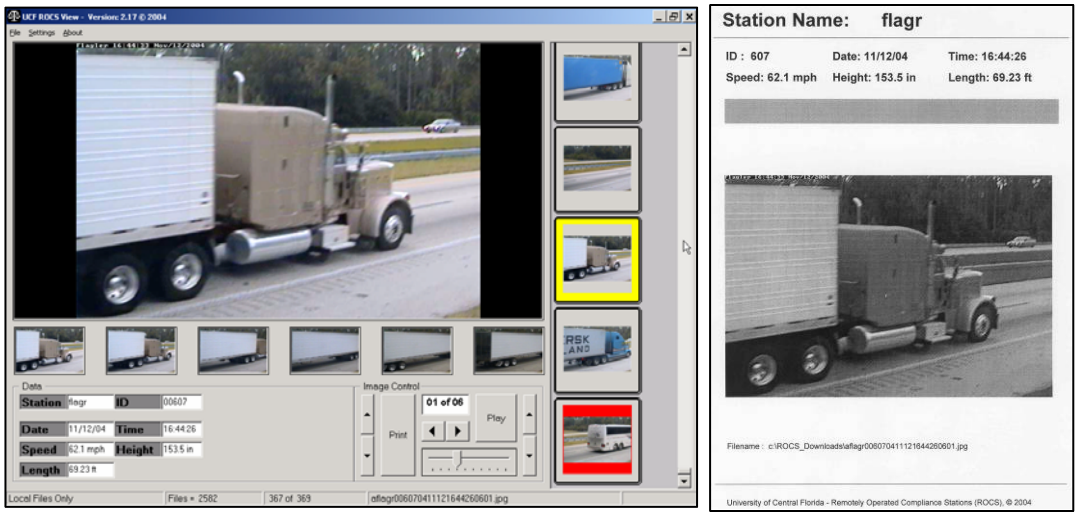



**Figure 42: CV-ROCS Viewer**

## CV-ROCS System Architecture

The figure below shows the system architecture. At Palm Coast Bridge, the sensor is triggered by trucks, and images are sent to the server. The software installed, CV-ROCS server, is programmed where it identifies truck length, width, height and speed. The data processing terminal (PC) then informs DVR to capture picture. The pictures are then sent remotely to the weigh station in seconds. The size of the pictures captured is relatively small (almost 28 kb) and such small size allows the picture to be sent by wireless means in a shorter time.

The size of the picture is of great importance as large size pictures might take more time to be sent which might give the truck a chance to travel away from the WIM station. At the weigh station, another software is installed, CV-ROCS viewer, that the pictures captured at the bridge are viewed.

## CV-ROCS System Network

The figure below summarizes the CV-ROCS network (Figure 43). As shown in the figure, the main goal is to wirelessly send the pictures from Palm Coast Bridge to the weigh station. A problem encountered in this test location was the line of sight between the two antennas, at Palm Coast Bridge and the weigh station. The presence of a water tank hinders the signal to move between them thus the use of a repeater was needed. The repeater is at a distance that can receive the signal from both locations and an antenna is installed at this location. Each bridge at each location, weigh station, Palm Coast Bridge, and the repeater site has a unique IP address as shown in the figure below. Amplifier was used in order to increase the strength of the signal going from and to both locations.

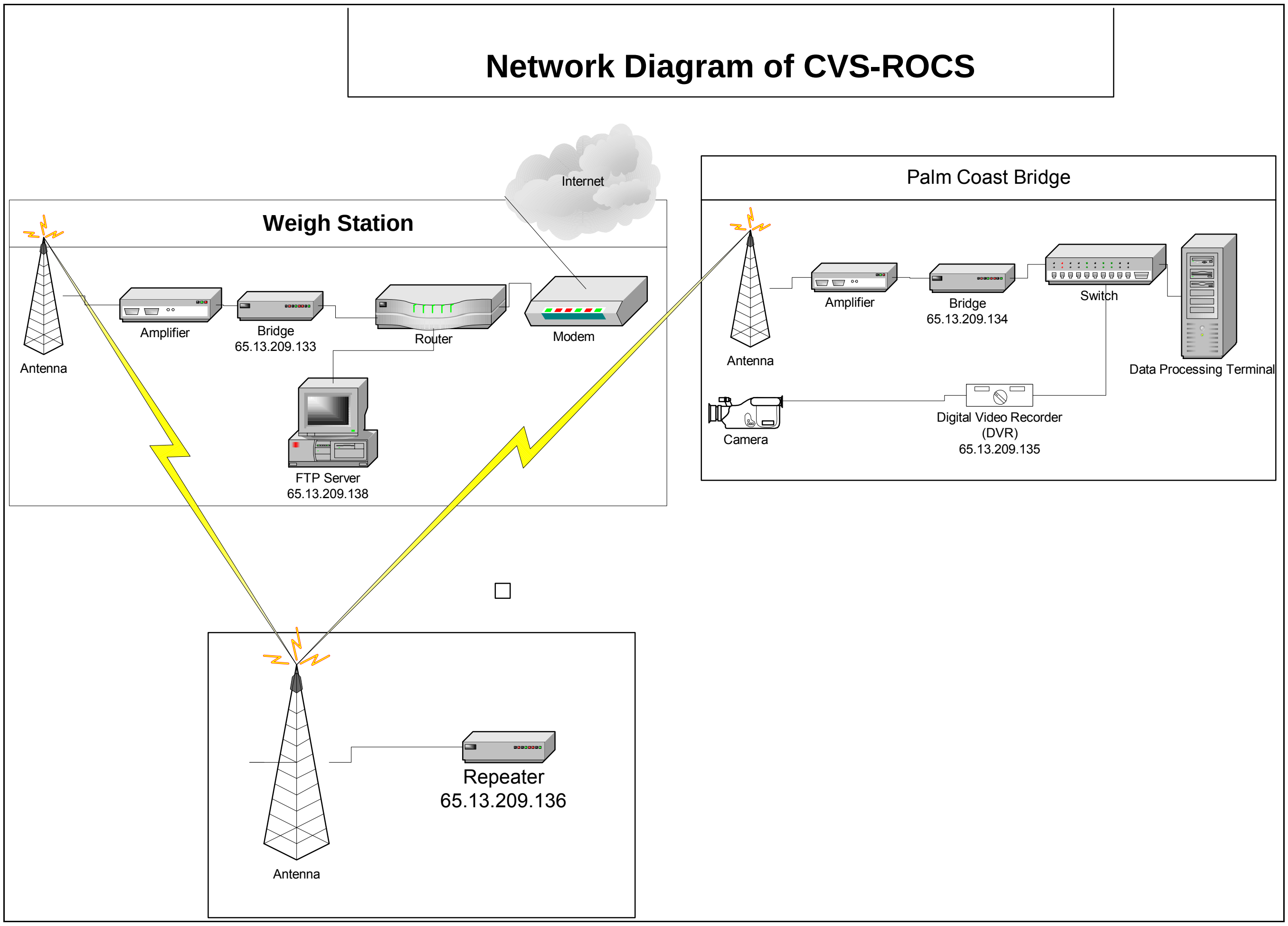



**Figure 43: CV-ROCS Network Diagram**

## *CV-ROCS Testing Results*

The system was installed at each location as described above. The sensor is triggered by trucks and the PC instructs camera to take 6 shots of the each truck (Figure 44). The shots are then sent remotely to the WIM station. If the truck is violating the legal allowed dimensions the photo will have a colored frame. In this way, the officers at the WIM will be able to identify the trucks easily and will stop it at the WIM station for further inspection. The pictures are saved where the exact time and date of capturing it is recorded.

**Figure 44: Six Shots of Truck Captured**

## The Virtual Weigh-in-Motion Database

With the introduction of new remotely operated technologies, weigh-in-motion stations are capable of assisting law enforcement in a variety of applications that go well beyond traditional weigh enforcement.

However, a major dilemma faces departments of transportation who are constantly struggling to select the most appropriate technologies for commercial vehicle enforcement. As an aid to similar organizations, this research project included the development of a web-based database to act as a “Reference Bible” to Products, Vendors, and the technologies employed in various products. It also provides a link to scientific tutorials for applications and technologies, as well as link to all previous research and literature reviews made in the area of WIM applications

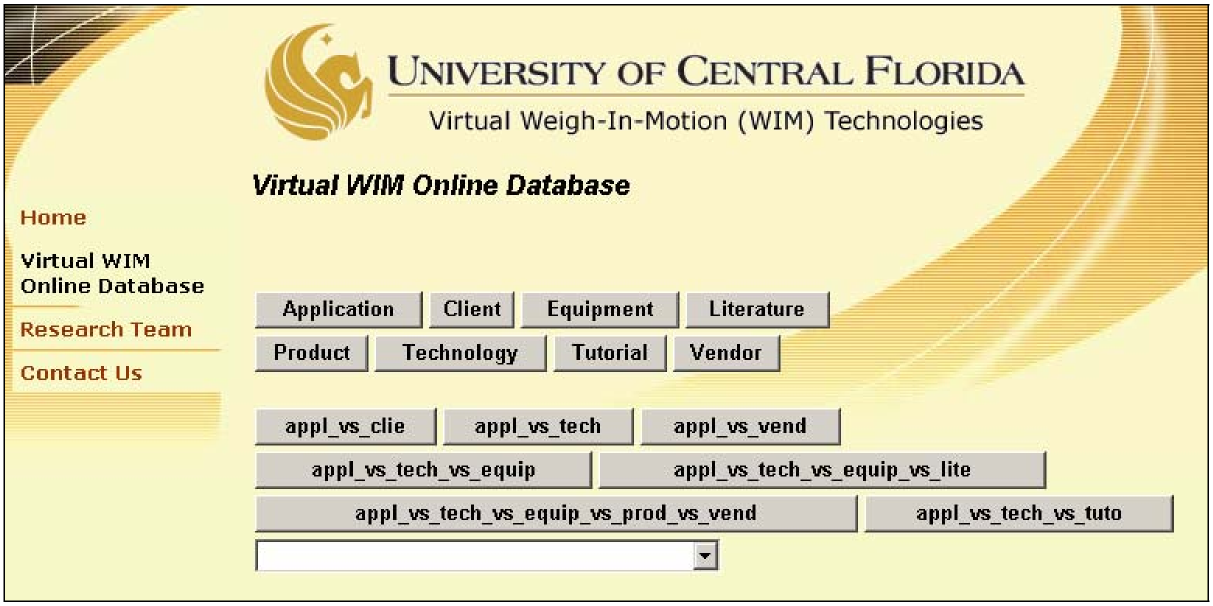



**Figure 45: The front web-page for the database**

## *The database location and Accessibility*

The database is hosted online at the University of Central Florida website. It is made available to the public and can be accessed directly from the following web link: http://virtualwim.cecs.ucf.edu/database.aspx

## *The Contents of the Database*

The database is designed and built with Microsoft SQL server. This web-based database is a structured collection of data about the types of equipment and technologies available for installation in commercial vehicle inspection stations.

The database output reports can be used to provide documented information that supports the decision maker criteria when selecting a certain product for installation compared to all similar products and techniques.

## *The Structure of the Database*

The database consists of eight tables listed below:

- **Applied Technology**: e.g. Laser, X-ray, Gamma ray, visual image processing, etc.
- **Application:** (what to measure) e.g.: weight verification, speed, dimensional check, etc.
- **Equipment:** e.g.: Visual Cameras, Truck Scales, Radars, etc.
- **Product:** Commercial products from a specific vendor, web links, and technical information.
- **Interested Entities:** e.g.: MCCO, ITS, Ag. Dept., etc.
- **Application/Entity:** Application required by every Interested Entity.
- **Vendors:** including mailing addresses, telephone numbers etc.

- **Research:** information regarding papers, conferences, current & past research regarding any equipment.

To illustrate a typical result of a query related to the tables above, Figure 45 shows a typical result:

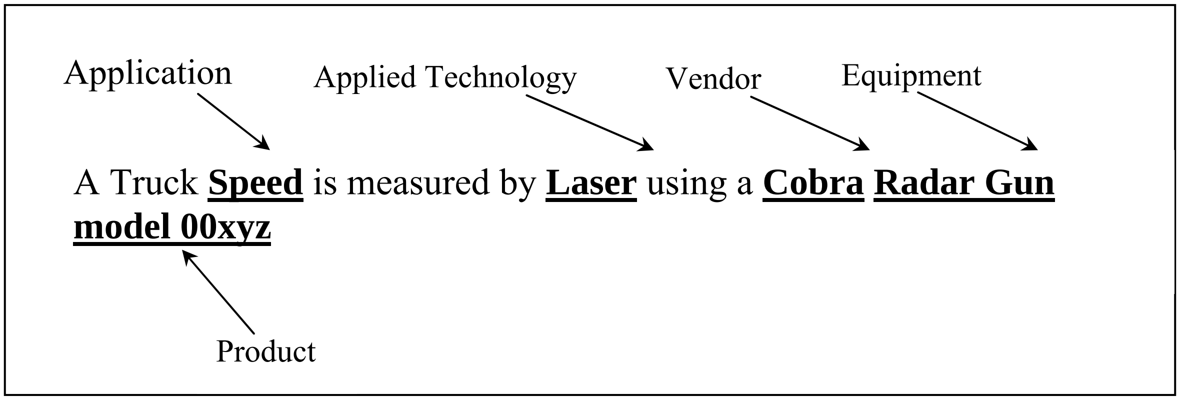



**Figure 46: Example of Database Structure**

In Figure 46, the user has to specify the application subject of his search (Figure 45). For example, if a user wants to check what technologies are available for measuring speed, he/she has to choose "speed" from the drop box. This search procedure was made possible by performing all the data queries required to link the tables as shown in the following database schema of Figure 47.

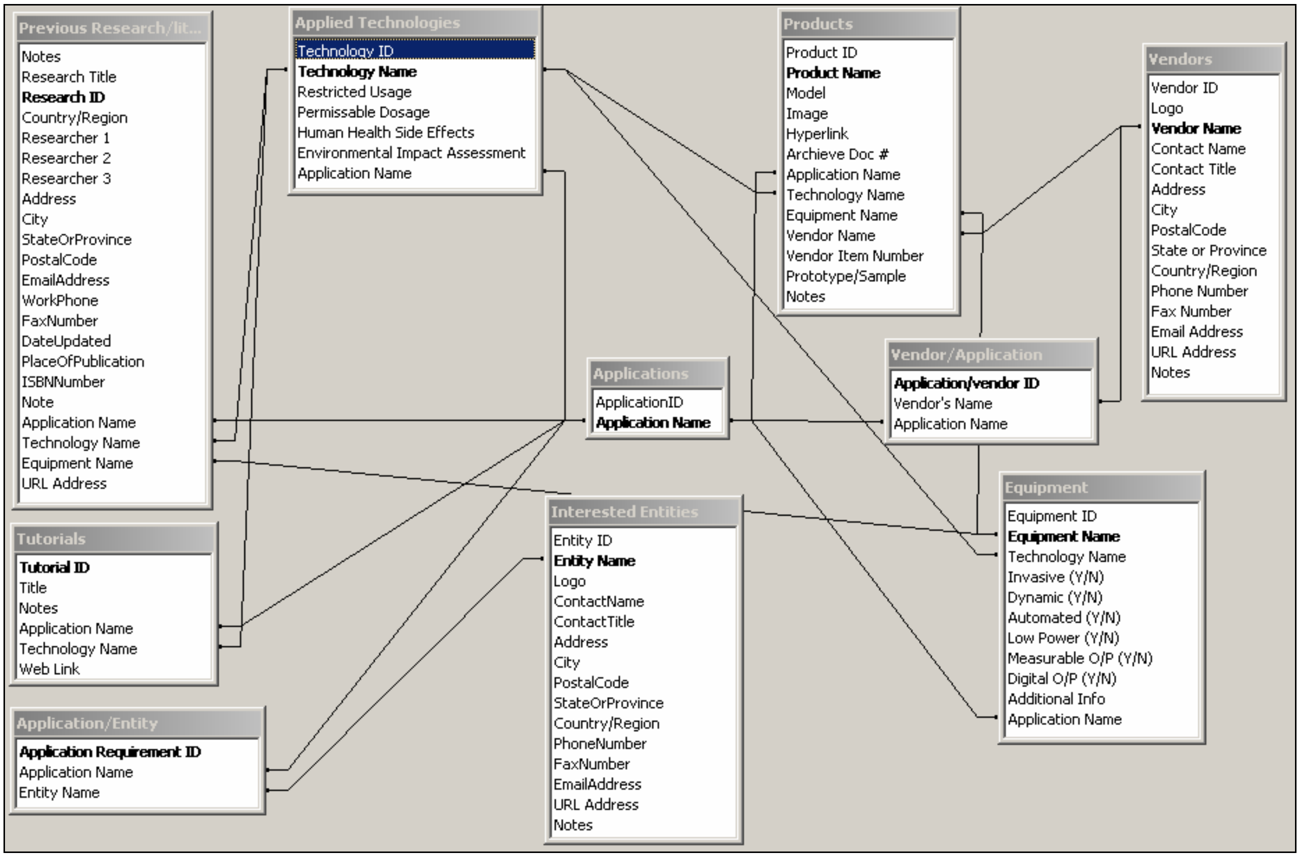



**Figure 47: Database Schema**

## Database Content

So far, the database contains information for fifty five different applications. The applications are shown in Table 1 below.

| ID | Application Name | ID | Application Name |
|---|---|---|---|
| 1 | Air Leaks | 29 | Location Tracking |
| 2 | Axle Alignment | 30 | Road Accidents and Fatalities |
| 3 | Brake Hub Temperature | 31 | Service Record on Truck & trailer |
| 4 | Brake Pad Condition | 32 | Shipment Tracking |
| 5 | Brake Tester | 33 | Spare Tyre Condition verification |
| 6 | Cargo Theft | 34 | Speed detection |
| 7 | Catch & Release | 35 | Suspension Play |
| 8 | Center of Gravity | 36 | Tail Gaiting |
| 9 | Dimensional Check | 37 | Tire Pressure |
| 10 | Driver Fatigue | 38 | Tire Temperature |
| 11 | Driver Identification | 39 | Tire Tread Condition |
| 12 | Driver's Safety | 40 | Trailer Identification |
| 13 | Drugs and Contraband | 41 | Truck Dimension |
| 14 | Earthing existance verification | 42 | Truck Fuel Consumption Rate |
| 15 | Electronic Logbook | 43 | Truck Identification |
| 16 | Electronic Tolls & Credentials | 44 | Truck lights and Signals |
| 17 | Emissions & Air Quality | 45 | Truck Load content |
| 18 | Engine Operation | 46 | Truck Load Radiation |
| 19 | Flammable Loads Identification | 47 | Truck Motor Emmisions |
| 20 | Fuel Decal, Dyed Fuels | 48 | Truck Radiation |
| 21 | Fuel Truck Conformance | 49 | Truck Safety |
| 22 | Hazardous Material Identification | 50 | Truck Security |
| 23 | Hazardous Material Load Permits | 51 | Warning Cells |
| 24 | head & Tail beam lights check | 52 | Weight |
| 25 | Horn level | 53 | Weigh -in-Motion |
| 26 | Image Scanning | 54 | Wheel Alignment |
| 27 | Leaking loads | 55 | Wheel Bearings |
| 28 | Load Tie Down & Unsecured loads | | |

**Table 1: Applications contained in the database**

## *Database Major Outcome*

- The database is considered the first nationwide reference for Weigh-In-Motion technologies & applications
- It will help in determining requirements and limitations for retrofitting of Weigh-In-Motion stations worldwide
- The database will provide a guideline for assessing and evaluating current products available for installation in Weigh-In-Motion Stations

- With its online tutorials, the data base is an educational resource available to interested parties.
- The database is envisioned to be a useful academic resource for all technical papers available up-to-date in the field of Weigh-In-Motion.

## Conclusion

The WIM is a great technology that aids in the future planning of the highways, and minimize the maintenance costs that will result from the deterioration caused by the overweighed trucks. Future research is always needed to enhance the functionality of the WIM stations. The remote operation of the WIM station allows for a better function of the traditional weigh enforcement system. More areas will be monitored and a more enforcement will be required. The remote operation assists highly in the allocation of the officers through placing sensors at areas where heavy traffic of trucks expected or at bypass roads. In addition, it will enhance the pavement deterioration resulted from over dimension or over weighed trucks, and thus the cost of maintenance will be reduced. CV-ROCS system proved to be a great tool in providing a remote operation of the weigh station. CV-ROCS viewer can be viewed at any location, for instance the police officer car, which assists in a more efficient and fast way of stopping the trucks.

In addition, the development of a web-based database serve as a resource for Departments of Transportation to aid in their efforts of product and technology selection for remotely operated compliance stations (a.k.a. virtual weigh stations).

## ROCS installation at Sneads Station

Phase II of the WIM project involves new hardware and software and the design and implementation of the Florida Virtual Weigh Station at I-10 close to Sneads WIM station.


**Figure 48: The site location with respect to Sneads weighs station**

The Sneads ROCS was installed in July 2006. The software and hardware for capture and display have been extensively updated. The Cardinal Model QWIM-1 In-Motion Vehicle Scale and associated instrumentation was installed. The sensors and equipment from Banner Engineering & Moxa were tested and the results have been analyzed. Also, Input received from MCCO and incorporated.

## The equipment

- <u>IN-MOTION SCALE</u>

  The QWIM-1 in-motion vehicle scale consists of two sets of two Kistler Lineas® quartz-piezo sensors each 0.75 m in length embedded in the pavement surface. The sensors are placed in a slot approximately 50 mm wide x 50 mm deep x 1.5 m cut in the pavement. The sensors are held in place using a special epoxy agent provided by Kistler. Included with the sensors is an inductive loop detector that is installed upstream of the sensors. When installed in pavement conforming to the requirements listed in ASTM E1318-02, the QWIM-1 in-motion scale will meet or exceed the performance requirements for a Type 3 in-motion scale as defined in ASTM E1318-02.

- <u>CONTROLLER</u>

  Included with the sensors and loop detector is a CVM series Cardinal in-motion scale controller. The controller is housed within a environmentally-protected roadside enclosure and includes a dual-channel charge amplifier, A/D converter, power supply, power outlet, and work light. The enclosure is constructed from aluminum and includes a locking door.

- <u>ROADSIDE DISPLAY</u>

  Included in this proposal is a hand held pocket PC with Bluetooth interface including software to display in real time the total weight of each passing vehicle. The pocket PC is a Dell Model AXIM X51 with a 416 Mhz Intel® X-Scale™ PXA270 processor. Cardinal will provide the source code for the application software used to display the total weight.

## The Scale Output

The CVM controller will be provided with two serial outputs. One serial output will be used to transmit a vehicle record for each passing vehicle including the following information:

- Time and Date
- Consecutive Number
- Vehicle Classification
- Axle Weights
- Axle Spacing
- Vehicle Length
- Total Vehicle Weight
- Status Messages including Off-Scale, Over Weight, Over Speed, Out of Balance Load

This information may be transmitted to other equipment using appropriate means provided by others.

The second output will be connected to a Parani10 Serial RS232 to Bluetooth adapter and will transmit the total weight of each passing vehicle to the Handheld PC where it will be displayed for the operator.

## *Installation details*

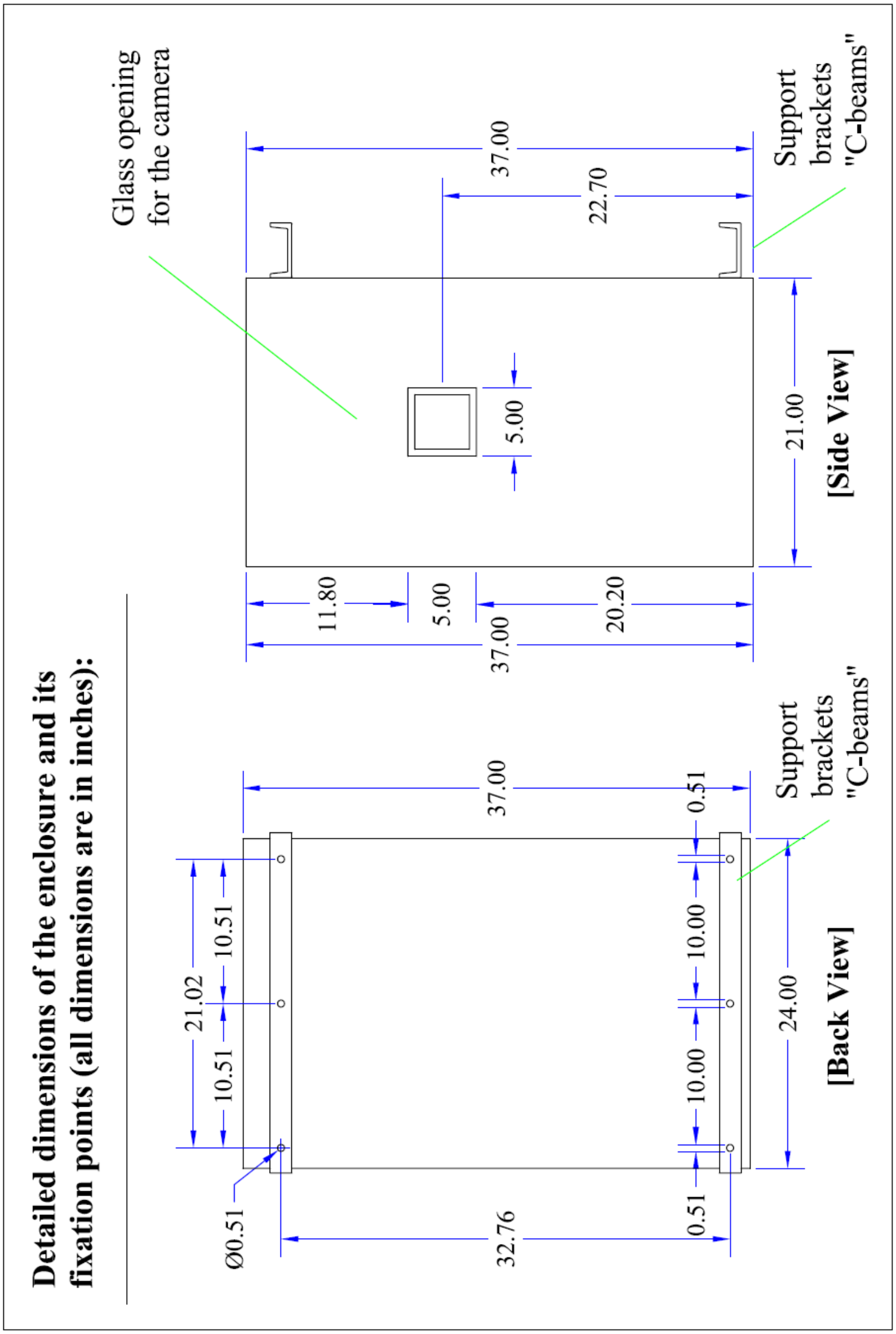



**Figure 49: UCF enclosure dimensions**

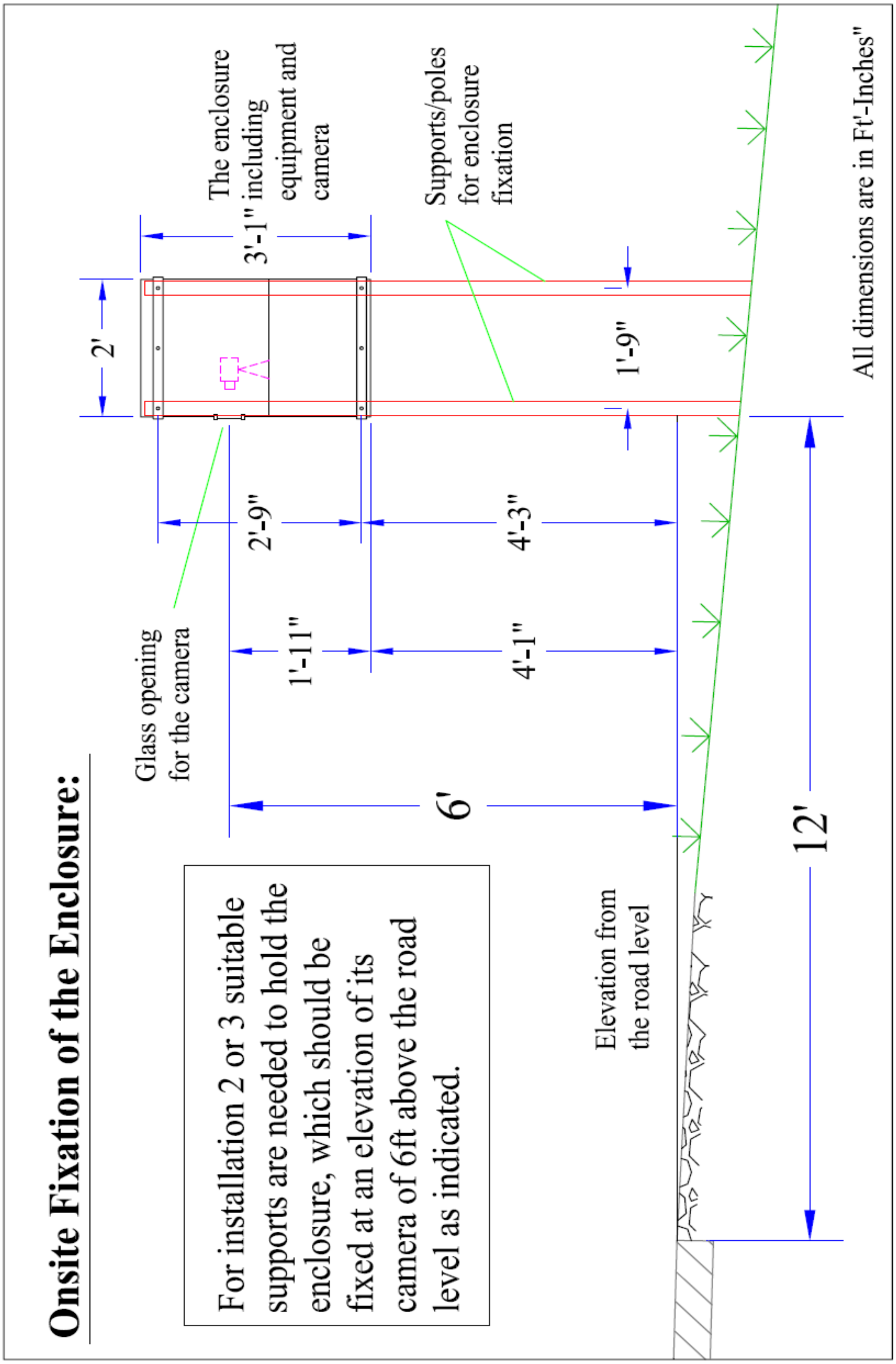



**Figure 50: fixation of the UCF enclosure**

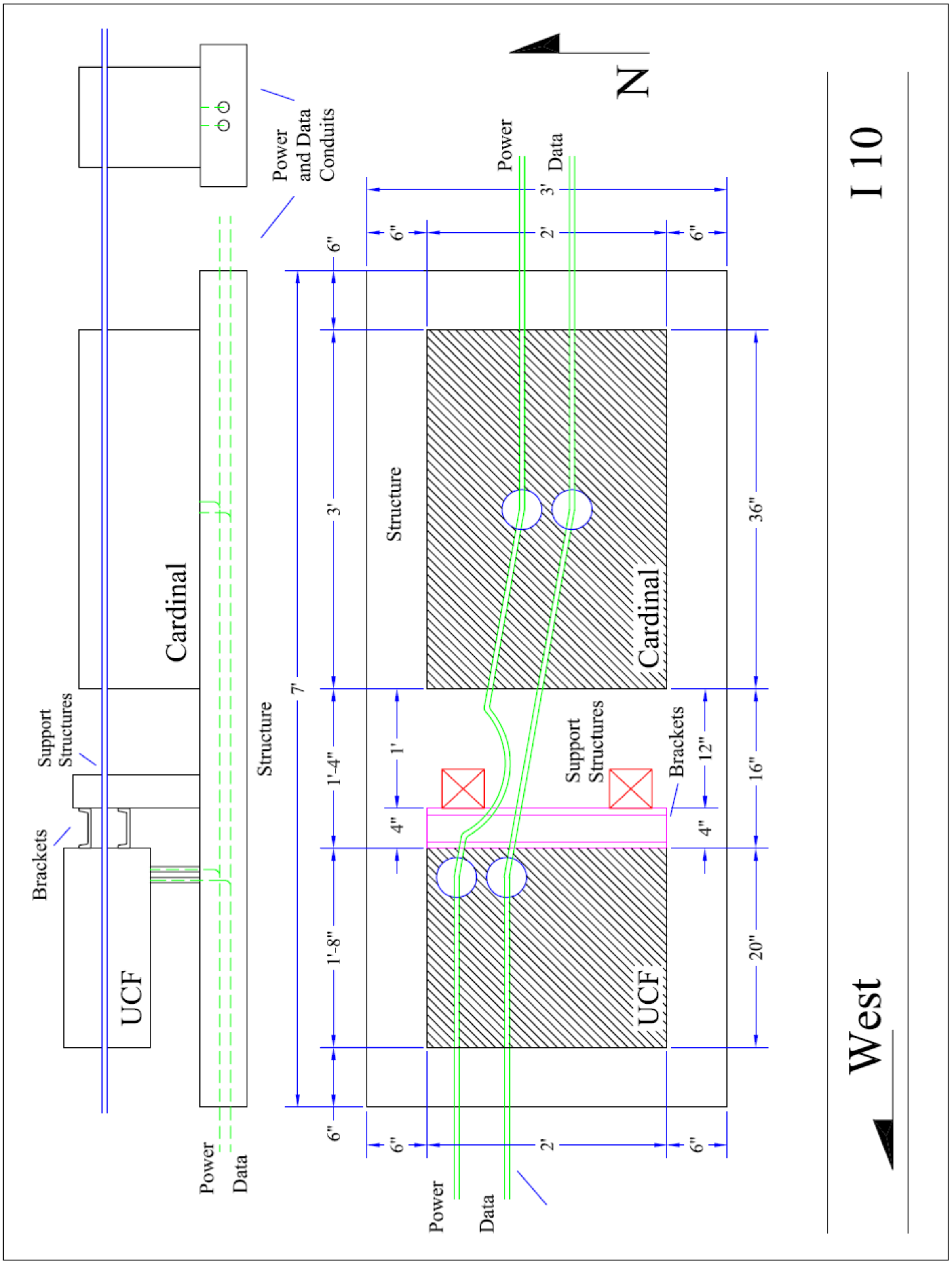



**Figure 51: installation of the enclosure and cardinal control box**

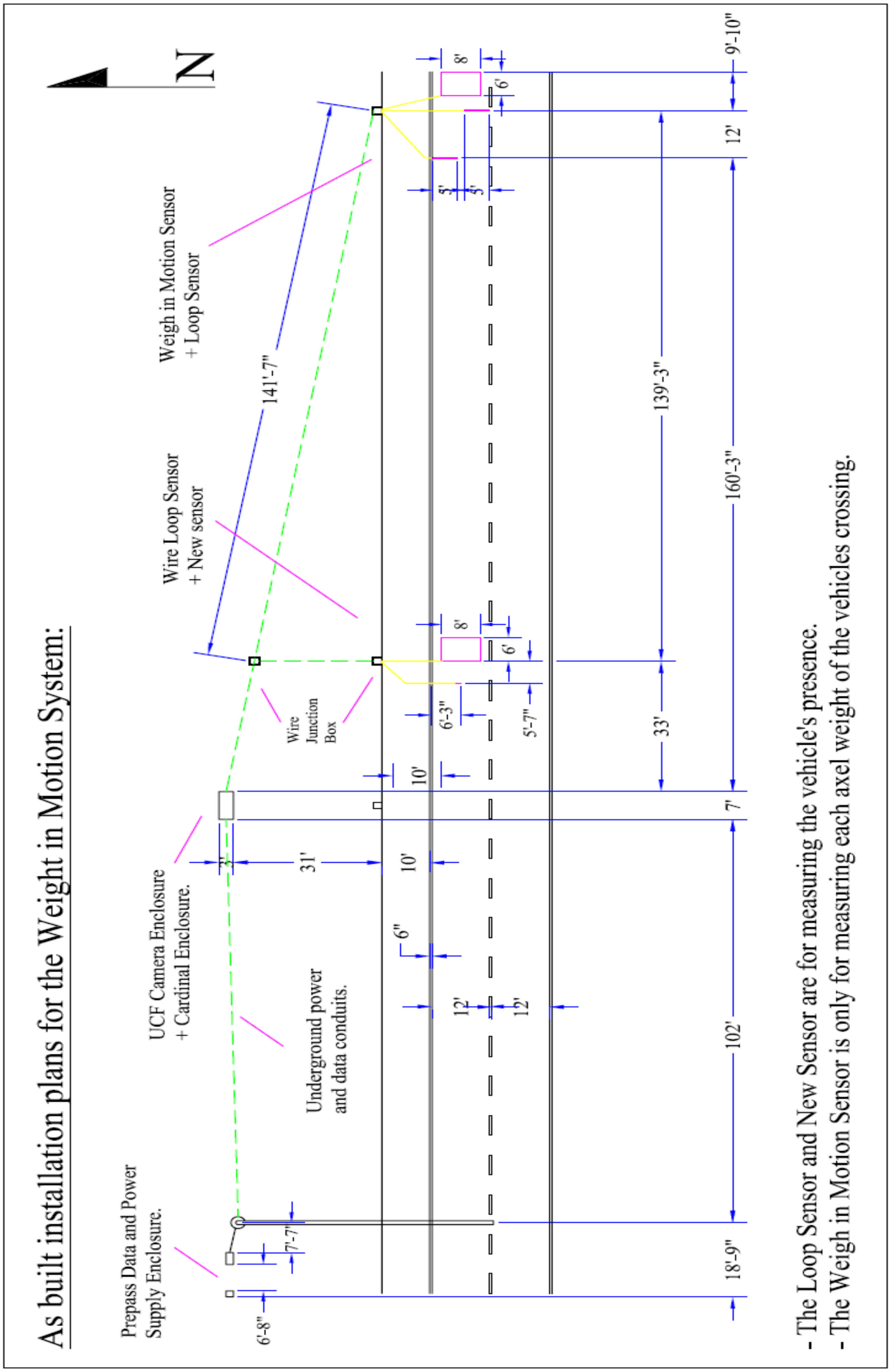



**Figure 52:As built installation plan for the WIM system at Sneads**

## *Onsite installation*

**Figure 53: During onsite installation**

**Figure 54: After installation completion**


**Figure 55: Installing Kistler strips on the road**

**Figure 56: The UCF enclosure with window for the camera**

**Figure 57: The site after equipment is installed**

## *Software operation at Sneads*

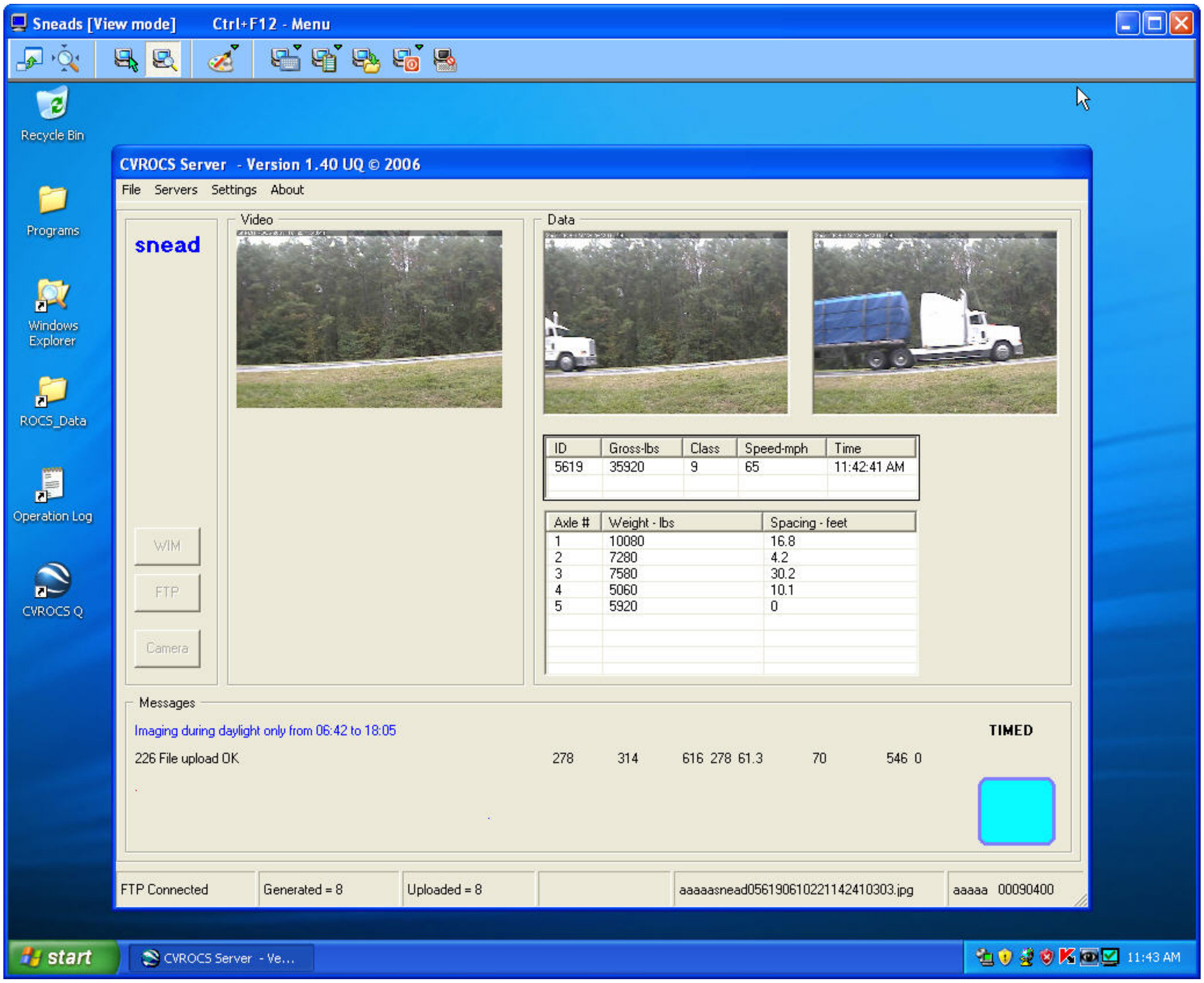



**Figure 58: Data Captures at Sneads**

As shown in Figure 58 the software shows the data captured for truck. The data includes pictures for the captured truck, time of capture, the total weight, the weights corresponding to each axle, the number of axles, the speed, and the truck class. This information is transmitted and stored at Sneads Inspection Station, via an already existing infrastructure of fiber optic extensions. The data can be only accessed by authorized parties. In case of a violation the window triggers a red signal and the software keeps track of the nature of violation, whether it is speed excessive weight or other.

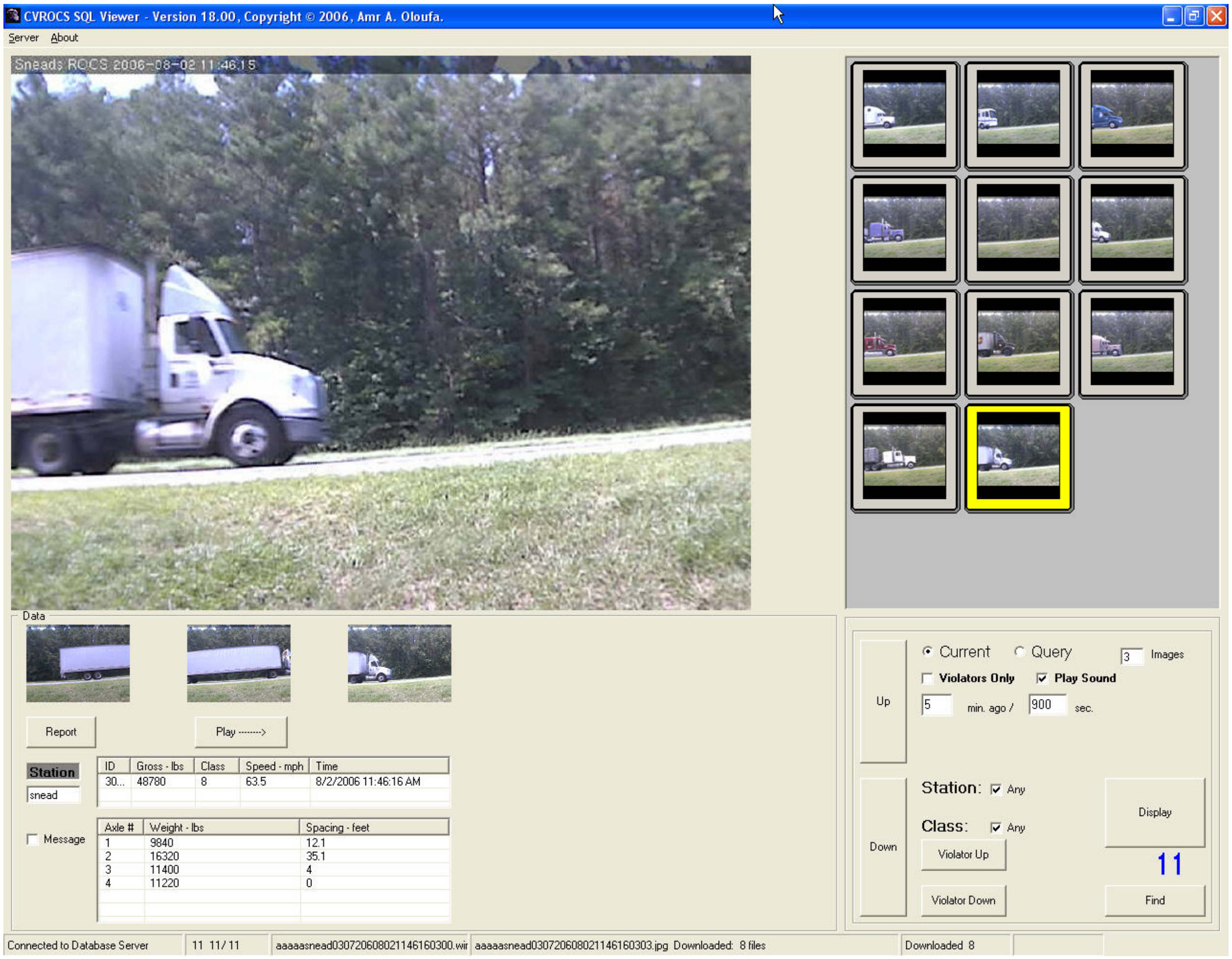



**Figure 59: Data viewer window for database query**

## *Preliminary data error analysis for system calibration*

### The Objective

The objective of this analysis is to verify that the error in weigh-in-motion (WIM) measurements is below 10%, and to recommend acceptance or rejection of the WIM equipment.

### Data Collection and classification

<u>The data collected consist of two sets of readings for a sampled truck:</u>

(1) Weight Station (WS) readings. In such case the truck is weighed while it stands on the scale. It is referred to in the analysis as **Static Weight**, and it is considered the correct weight of the truck. The Static weight measures three readings as follows:
   a. Weight-1 : (Axle-1)
   b. Weight-2 : (Axle-2) + (Axle-3)
   c. Weight-3 : (Axle-4) + (Axle-5)

   The total weight of the truck is the summation of the three readings

(2) Weigh In Motion (WIM) readings. In such case the truck is weighed while in motion at every axle. It is referred to in the analysis as **WIM Readings.** For a typical 5-axle truck, 5 readings are recorded.

The total weight of the truck is the summation of the axle readings.

<u>The data was classified into 5 sets:</u>

- Regular 5-axle Trucks
- 5-Axles Car/Boat Carrier:
- 5-Axles Liquid Carrier
- 5-Axles House Carrier
- 2,3,4 or 6-Axles Trucks

The error was calculated as (Static Reading - WIM Reading) for the following:

- Weight-1 : (Axle-1)
- Weight-2 : (Axle-2) + (Axle-3)
- Weight-3 : (Axle-4) + (Axle-5)
- Total Weight : (Axle-1) + (Axle-2) + (Axle-3) + (Axle-4) + (Axle-5)

*For each case the actual (+ve and –ve), and absolute error were calculated.*

The percentage error was computed as (Static Reading - WIM Reading) / Static Reading:

*For each case the actual and absolute error was calculated.*
*For each data classification the mean absolute error was computed.*

## Findings and Results

### Regular 5-Axle Trucks:

For a sample size of 25 observations

| | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
| Mean ...................... | 296.0 | 2,116.8 | 2,745.6 | 5,158.4 | 7,246.4 | 2.29% | 7.84% | 12.96% | 8.97% | 12.80% |
| Variance ................. | 1,037,267 | 26,088,356 | 30,108,751 | 109,947,264 | 82,966,824 | 0.007272 | 0.0781 | 0.0426 | 0.0268 | 0.0181 |
| Standard Deviation ... | 1,018.5 | 5,107.7 | 5,487.1 | 10,485.6 | 9,108.6 | 8.53% | 27.95% | 20.65% | 16.36% | 13.45% |

| | | |
|---|---|---|
| Total Weight Mean Absolute Error : | | 7,246.4 |
| Total Weight Percentage Mean Absolute Error : | | 12.80% |

**Table 2: Analysis for 5-axles regular trucks**

The regular 5-Axle trucks had a sample size of 25 observations. The absolute mean error was found to be 7,250 lb. However the actual mean error (not absolute) was found to be 5,160 lb which shows that the WIM readings tend to be lower than the WS (Static) readings. The percentage error was calculated per total static weight of the truck. It was found that the absolute mean percentage error was 12.8%. On the other hand, the actual mean error shows that the WIM readings tend to be lower than the WS readings by 9%. The above table also shows the associated variance and standard deviations.

The same computations were executed for Weights (1, 2 and 3); that is to better understand at which axles of the same truck typically results in higher/lower error. It was found that the readings generated from the front axles of the same truck were generally more accurate than rest of the axles.

An assumption was made that a few faulty data affected the overall average accuracy of the system. Therefore, 8 outliers were removed and the statistics were recalculated for a sample size of 17 readings.

| | | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
| Mean ...................... | | (61.2) | (789.4) | (194.1) | (1,044.7) | 2,025.9 | -0.78% | -5.73% | 1.33% | -1.36% | 4.27% |
| Variance ................. | | 257,424 | 4,944,556 | 4,066,138 | 4,892,976 | 1,691,888 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Standard Deviation ... | | 507.4 | 2,223.6 | 2,016.5 | 2,212.0 | 1,300.7 | 4.66% | 22.64% | 12.43% | 5.47% | 3.54% |

| | | |
|---|---|---|
| Total Weight Mean Absolute Error : | | 2,025.9 |
| Total Weight Percentage Mean Absolute Error : | | 4.27% |

**Table 3: Analysis for 5-axles regular trucks after removing outliers**

The results were by far better. The absolute mean error was found to be around 2,025 lb. However the actual mean error (not absolute) was found to be "negative" 1,044.7 lb which shows that the WIM readings tend to be higher than the WS readings after the outliers have been removed. The percentage error was calculated per total static weight of truck. It was found that the absolute mean percentage error was 4.3%. On the other hand, the actual mean percentage error for the modified sample shows that the WIM readings tend to be higher than the WS readings by only 1.3%. The above table also shows the associated variances and standard deviations.

The computations for Weights (1, 2 and 3) in this case showed that the (Axle-1), (Axle-4) and (Axle-5) showed slightly better results than the middle axles (Axle-2) and (Axle-3).

## 5-Axles Car/Boat Carrier:

| | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
| Mean .................... | 23.3 | 1,746.7 | 3,283.3 | 5,053.3 | 5,200.0 | 0.03% | 6.55% | 11.60% | 7.53% | 7.74% |
| Variance ............... | 265,827 | 8,939,467 | 12,718,307 | 36,560,107 | 34,755,520 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Standard Deviation | 515.6 | 2,989.9 | 3,566.3 | 6,046.5 | 5,895.4 | 8.55% | 11.59% | 10.87% | 8.69% | 9.00% |

| | |
|---|---|
| Total Weight Mean Absolute Error : | 5,200 |
| Total Weight Percentage Mean Absolute Error : | 7.74% |

**Table 4: Analysis for 5-axles Car/Boat Carrier trucks**

The 5-Axle car/boat carriers had a sample size of 6 observations. The absolute mean error was found to be around 5,200 lb. However the actual mean error (not absolute) was found to be 5,050 lb which shows that the WIM readings tend to be lower than the WS readings. The percentage error was calculated per total static weight of the truck. It was found that the absolute mean percentage error was around 7.8%. On the other hand, the actual mean error shows that the WIM readings tend to be lower than the WS readings by 7.5%. The above table also shows the associated variances and standards deviations.

An assumption was made that a few faulty data affected the overall average accuracy of the system. Therefore, 2 outliers were removed and the statistics were recalculated for a sample size of 4 readings.

| | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
| Mean .................... | 105.0 | (110.0) | 1,240.0 | 1,235.0 | 1,455.0 | 0.73% | -0.03% | 3.96% | 1.66% | 1.99% |
| Variance ............... | 394,767 | 1,103,600 | 4,384,267 | 2,454,767 | 1,665,700 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Standard Deviation | 628.3 | 1,050.5 | 2,093.9 | 1,566.8 | 1,290.6 | 4.40% | 5.37% | 4.60% | 1.70% | 1.59% |

| | |
|---|---|
| Total Weight Mean Absolute Error : | 1,455 |
| Total Weight Percentage Mean Absolute Error : | 1.99% |

**Table 5: Analysis for 5-axles Car/Boat Carrier trucks after removing outliers**

The results were by far better. The absolute mean error was found to be around 1,455 lb. However the actual mean error (not absolute) was found to be 1,235 lb which shows that the WIM readings tend to be lower than the WS readings after the outliers have been removed. The percentage error was calculated per total static weight of the truck. It was found that the absolute mean percentage error was only 2%. On the other hand, the actual mean percentage error for the modified sample shows that the WIM readings tend to be lower than the WS readings by only 1.7%. The above table also shows the associated variances and standard deviations.

The computations for Weights (1, 2 and 3) in this case showed that the (Axle-1), (Axle-2) and (Axle-3) showed slightly better results than the rear axles (Axle-4) and (Axle-5).

The overall results for the 5-axle car/boat carriers were significantly better than the regular 5-axle trucks.

**5-Axles Liquid Carrier:**

| | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Error Weight (1) | ErrorWeight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % ErrorTotal Weight | % Absolute Error Total Weight |
| Mean ........................ | 116.0 | 2,196.0 | 3,590.0 | 5,902.0 | 6,646.0 | 1.10% | 12.92% | 24.30% | 12.77% | 13.94% |
| Variance .................... | 369,493 | 13,577,227 | 19,203,844 | 62,658,529 | 52,285,516 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Standard Deviation ...... | 607.9 | 3,684.7 | 4,382.2 | 7,915.7 | 7,230.9 | 5.66% | 19.04% | 25.38% | 15.91% | 14.77% |

| | |
|---|---|
| Total Weight Mean Absolute Error : | 6,646 |
| Total Weight Percentage Mean Absolute Error : | 13.94% |

**Table 6: Analysis for 5-axles liquid trucks**

The 5-Axle liquid carriers had a sample size of 10 observations. The absolute mean error was found to be around 6,650 lb. However the actual mean error (not absolute) was found to be 5,900 lb which shows that the WIM readings tend to be lower than the WS readings. The percentage error was calculated per total static weight of the truck. It was found that the absolute mean percentage error was around 14%. On the other hand, the actual mean error shows that the WIM readings tend to be lower than the WS readings by 12.8%. The above table also shows the associated variances and standard deviations.

In the case of 5-axle liquid trucks the overall error was high throughout the readings. There were no few outliers that really influenced the sample results.

The computations for Weights (1, 2 and 3) showed that the readings generated from the front axles of the same truck were generally more accurate than rest of the axles.

**5-Axles House Carrier:**

| | | Error = Weight Station Reading - WIM Reading | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
| | | -280 | -1000 | 12100 | 10820 | 10820 | -2.75% | -6.23% | 100.00% | 28.21% | 28.21% |
| | | -440 | -420 | 14340 | 13480 | 13480 | -4.59% | -3.43% | 100.00% | 37.28% | 37.28% |
| Mean .................... | | (360) | (710) | 13,220 | 12,150 | 12,150 | -3.67% | -4.83% | 100.00% | 32.74% | 32.74% |
| Variance .............. | | 12,800 | 168,200 | 2,508,800 | 3,537,800 | 3,537,800 | 0.0 | 0.0 | - | 0.0 | 0.0 |
| Standard Deviation | | 113.1 | 410.1 | 1,583.9 | 1,880.9 | 1,880.9 | 1.31% | 1.98% | 0.00% | 6.42% | 6.42% |

| | | |
|---|---|---|
| Total Weight Mean Absolute Error : | | 12,150 |
| Total Weight Percentage Mean Absolute Error : | | 32.74% |

**Table 7: Analysis for House Cariers**

There were only two data points that were collected for House carriers. They both appear to be erroneous, because out of the 5 or 6 axles only 2 or 3 axles were captured. It seems that there is partial missing data in the case of House Carriers.

It was also noticed that the front axle showed better results than the other axles.

## 2,3,4 or 6-Axles Trucks:

| Number of Axles | | | Error Weight (1) | Error Weight (2) | Error Weight (3) | Error Total Weight | Absolute Error Total Weight | % Error Weight (1) | % Error Weight (2) | %Error Weight (3) | % Error Total Weight | % Absolute Error Total Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4- Axles | | | 200 | -4640 | 20 | 40 | 40 | 2.72% | -50.33% | 0.23% | 0.16% | 0.16% |
| 2- Axles | | | 440 | 960 | 0 | 1400 | 1400 | 4.69% | 6.45% | 0.00% | 5.77% | 5.77% |
| 3- Axles | | | -180 | -1820 | 480 | 1960 | 1960 | -2.22% | -17.70% | 12.12% | 8.77% | 8.77% |
| 4- Axles | | | 520 | -1420 | 21940 | 30900 | 30900 | 5.11% | -9.58% | 56.72% | 48.52% | 48.52% |
| 4- Axles | | | 120 | -5740 | 5820 | 200 | 200 | 2.94% | -92.28% | 43.50% | 0.84% | 0.84% |
| | Mean | | 220.0 | (2,532.0) | 5,652.0 | 6,900.0 | 6,900.0 | 2.65% | -32.69% | 22.51% | 12.81% | 12.81% |
| | Variance | | 77,200 | 7,168,120 | 88,935,320 | 180,650,800 | 180,650,800 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 |
| | Standard Deviation | | 277.8 | 2,677.3 | 9,430.6 | 13,440.6 | 13,440.6 | 2.91% | 39.22% | 26.09% | 20.28% | 20.28% |
| | | | | Total Weight Mean Absolute Error : | | | | | 6,900 | | | |
| | | | | Total Weight Percentage Mean Absolute Error : | | | | | 12.81% | | | |

**Table 8: Analysis for 2,3,4 or 6-axles trucks**

The results were reasonable for 2 and 3- Axles Trucks. However it was not necessarily the case for 4 or 6-axles trucks.

It was also noticed that the front axle showed far better results than the other axles.

### ***Results Summary***

| Truck Type | Sample size | Total Weight Mean Absolute Error | Total Weight Percentage Mean Absolute Error |
|---|---|---|---|
| 5-Axle Regular | 25 | 7246 lbs. | 12.9% |
| 5-Axles Car/Boat Carrier | 6 | 5200 lbs. | 7.74% |
| 5-Axles Liquid Carrier | 10 | 6466 lbs. | 13.94% |
| 5-Axles House Carrier | 2 | 12150 lbs. | 32.74% |
| 2,3,4 or 6-Axles Trucks: | 5 | 6900 lbs. | 12.81% |

The total percentage Mean Absolute error exceeded the equipment manufacturer claim of <= 10%.

However, an attempt was made to isolate the source of error by truck type, but the percentage MAE was almost high in all of the readings despite the truck type with the exception of 5-axles car/boat carrier type.

***Conclusions:***

Based on the findings of this experiment, the manufacturer's claim of <= 10% error was not accepted. Therefore, the system has been recalibrated and a larger number of data were analyzed to validate the observation.

After the system has been calibrated, the data for a time span of approximately 6 months was retrieved and used for statistical analysis of the trucks. The results of the data analysis are discussed in the next section.

## Truck Statistics at Sneads over a Span of Six Months

An overall statistical at Sneads station was performed over a span of 6 months starting at the beginning of August 2006 until the end of January 2007. The data included a total number of 358,139 trucks that were captured.

The following are the trigger point for the software:

| **Trigger values:** | |
|---|---|
| Speed ≥ 80mph | (violation) |
| Trigger Weight ≥ 20,000lb | (not considered a truck) |
| Total Weight ≥ 82,000lb | (violation) |
| Tandem Weight ≥ 44000lb | (violation) |
| Axle weight ≥ 22,000 lb | (violation) |

**Table 9: Software triggers points**

## *Truck Class Statistics*

| Time | | Classes | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From | To | Others | Cl-2 | Cl-3 | Cl-4 | Cl-5 | Cl-6 | Cl-8 | Cl-9 | Cl-10 | Cl-11 | Cl-12 | Cl-15 | Total Records |
| 8/1/2006 11:01 | 12/13/2006 3:54 | 6 | 1 | 470 | 343 | 678 | 212 | 888 | 25204 | 184 | 858 | 334 | 61 | 29,239 |
| 8/2/2006 7:01 | 12/14/2006 11:44 | 4 | 0 | 595 | 420 | 751 | 230 | 919 | 25637 | 204 | 832 | 306 | 103 | 30,001 |
| 8/3/2006 14:48 | 12/17/2006 2:10 | 2 | 2 | 659 | 459 | 766 | 224 | 911 | 25598 | 201 | 772 | 307 | 99 | 30,000 |
| 8/8/2006 7:43 | 12/21/2006 19:24 | 3 | 2 | 538 | 296 | 672 | 220 | 907 | 25910 | 213 | 837 | 316 | 87 | 30,001 |
| 8/11/2006 8:43 | 12/29/2006 3:42 | 3 | 0 | 669 | 485 | 751 | 222 | 895 | 25654 | 176 | 758 | 303 | 85 | 30,001 |
| 8/16/2006 15:29 | 1/4/2007 10:16 | 3 | 3 | 780 | 468 | 762 | 290 | 888 | 25457 | 168 | 771 | 282 | 129 | 30,001 |
| 8/21/2006 23:49 | 1/9/2007 13:24 | 3 | 4 | 655 | 371 | 693 | 220 | 889 | 25748 | 197 | 814 | 325 | 82 | 30,001 |
| 8/26/2006 12:12 | 1/13/2007 14:20 | 3 | 1 | 658 | 439 | 818 | 278 | 937 | 25491 | 180 | 800 | 306 | 90 | 30,001 |
| 9/1/2006 8:34 | 1/16/2007 1:40 | 2 | 3 | 745 | 493 | 798 | 235 | 865 | 25567 | 172 | 730 | 276 | 115 | 30,001 |
| 9/8/2006 15:10 | 12/7/2006 10:50 | 3 | 2 | 503 | 462 | 652 | 205 | 855 | 25965 | 185 | 793 | 291 | 85 | 30,001 |
| 7/30/2006 10:39 | 1/16/2007 2:29 | 10 | 15 | 507 | 570 | 618 | 196 | 749 | 22169 | 762 | 660 | 269 | 215 | 26,740 |
| 1/17/2007 0:00 | 1/31/07 11:58 PM | 5 | 0 | 773 | 445 | 748 | 248 | 935 | 27448 | 296 | 781 | 318 | 155 | 32,152 |
| **8/1/2006 11:01** | **1/31/2007 23:58** | **42** | **33** | **6779** | **4806** | **7959** | **2532** | **9703** | **278400** | **2642** | **8625** | **3315** | **1151** | **358,139** |
| | **Percentage** | **0.01%** | **0.01%** | **1.89%** | **1.34%** | **2.22%** | **0.71%** | **2.71%** | **77.74%** | **0.74%** | **2.41%** | **0.93%** | **0.32%** | **91.02%** |

**Table 10: Number and Percentage of Trucks for each Class**

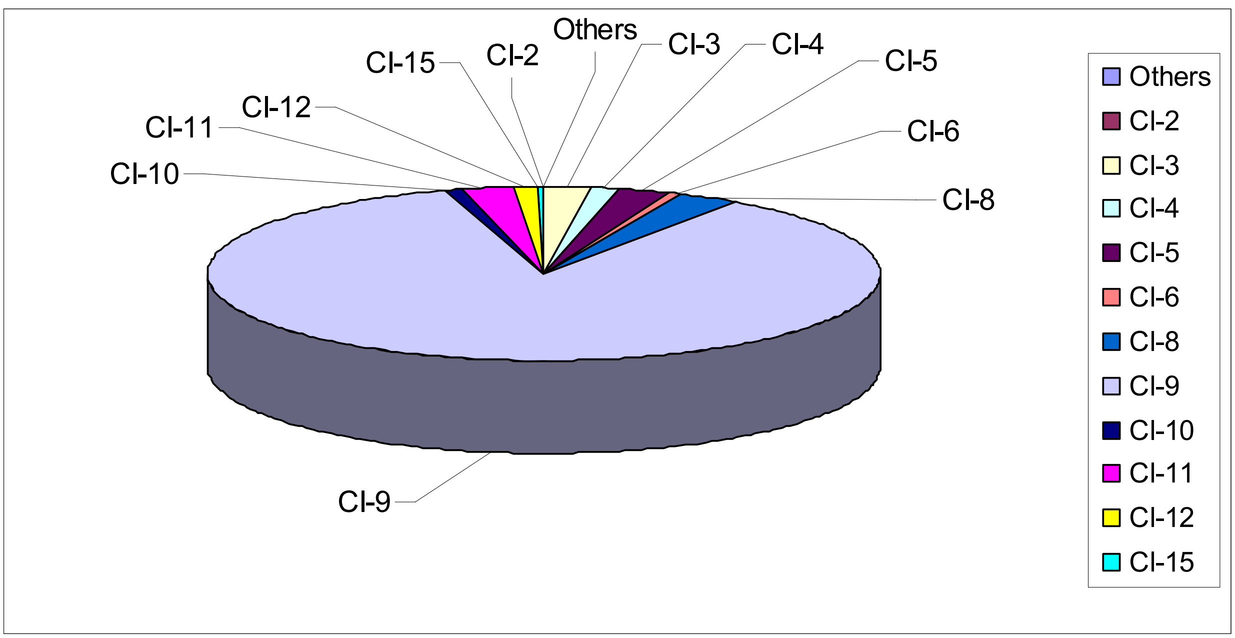



**Figure 60: Percentage of Trucks for each Class**

The statistics show that the overwhelming majority of trucks crossing are “Class-9”, which holds (77%) of all other classes. Other significant classes are Class-3, Class-5 and Class-11 and they hold on average 2.5% of all other classes each.

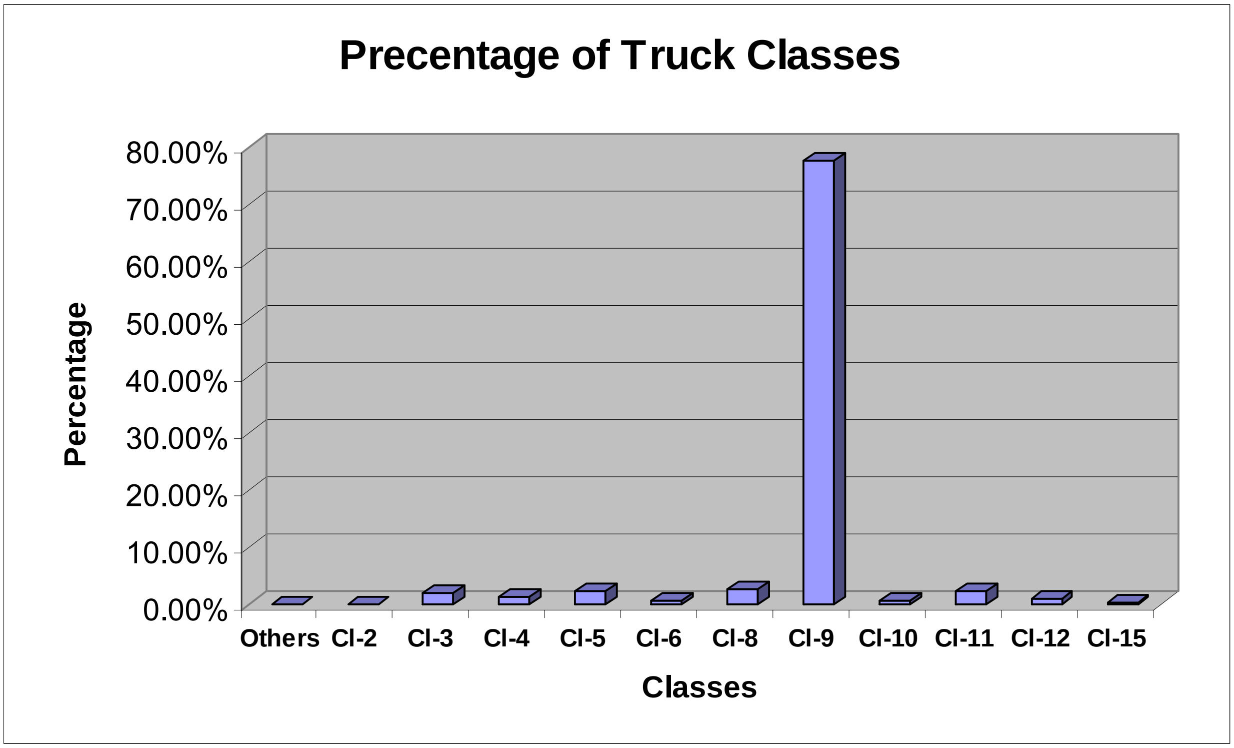



**Figure 61: Number of Trucks Crossing per each Class**

## *Average Weight and Speed Statistics*

| Month | # of Enteries | Average Weight | Average Speed |
|---|---|---|---|
| Aug-06 | 55050 | 51611.322 | 66.82 |
| Sep-06 | 59634 | 51986.27 | 67.61 |
| Oct-06 | 60634 | 51717.387 | 67.05 |
| Nov-06 | 61312 | 51526.717 | 67.75 |
| Dec-06 | 59741 | 52390.921 | 67.82 |
| Jan-07 | 61768 | 52410.118 | 67.71 |
| Average | 358139 | 51940.456 | 67.47 |

**Table 11: Average Weight and Speed per each Month**

The average speed and weight of trucks appears to be almost constant throughout the months.

- The overall average Speed is (67.5mph)
- The overall average Weight is (51,940.5 lb)

However a slight peak appears During the Month of December for both the average weights and speeds. An educated guess for this peak would be that by the end of the fiscal year, most of businesses try to wrap up their work. So trucks might tend to carry more load then regular or speed a little more then usual.

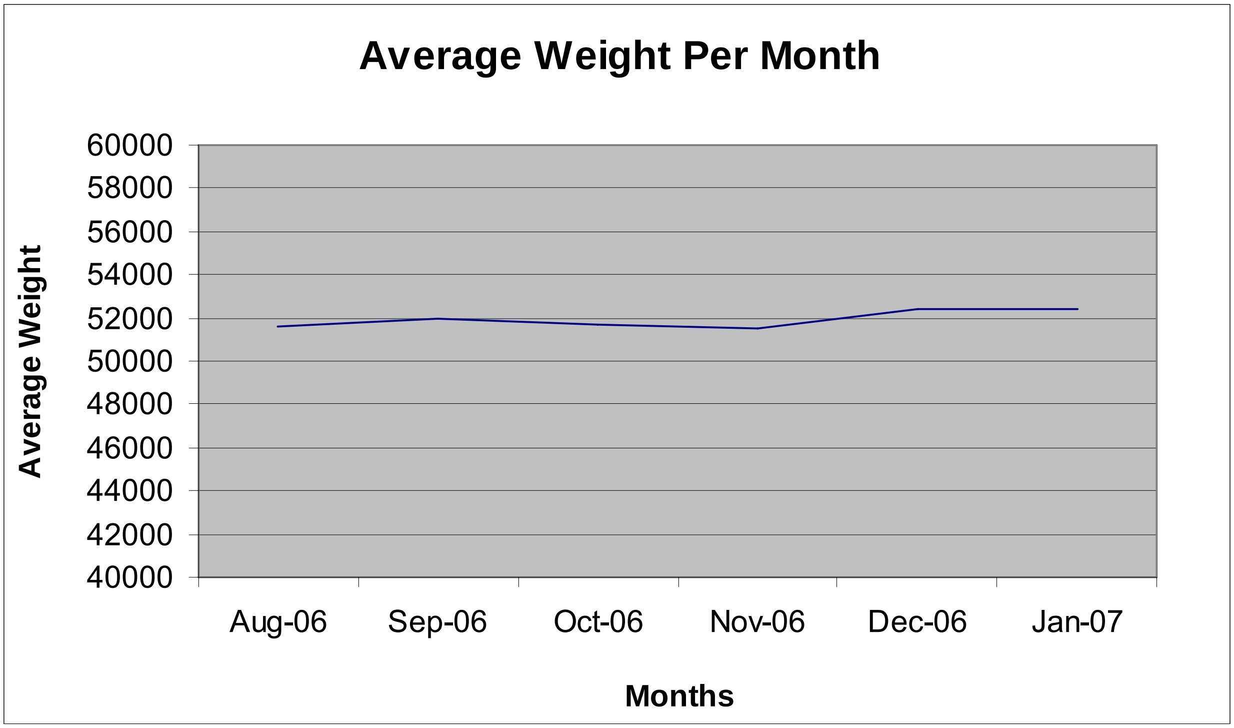



**Figure 62: Average Weight per each Month**

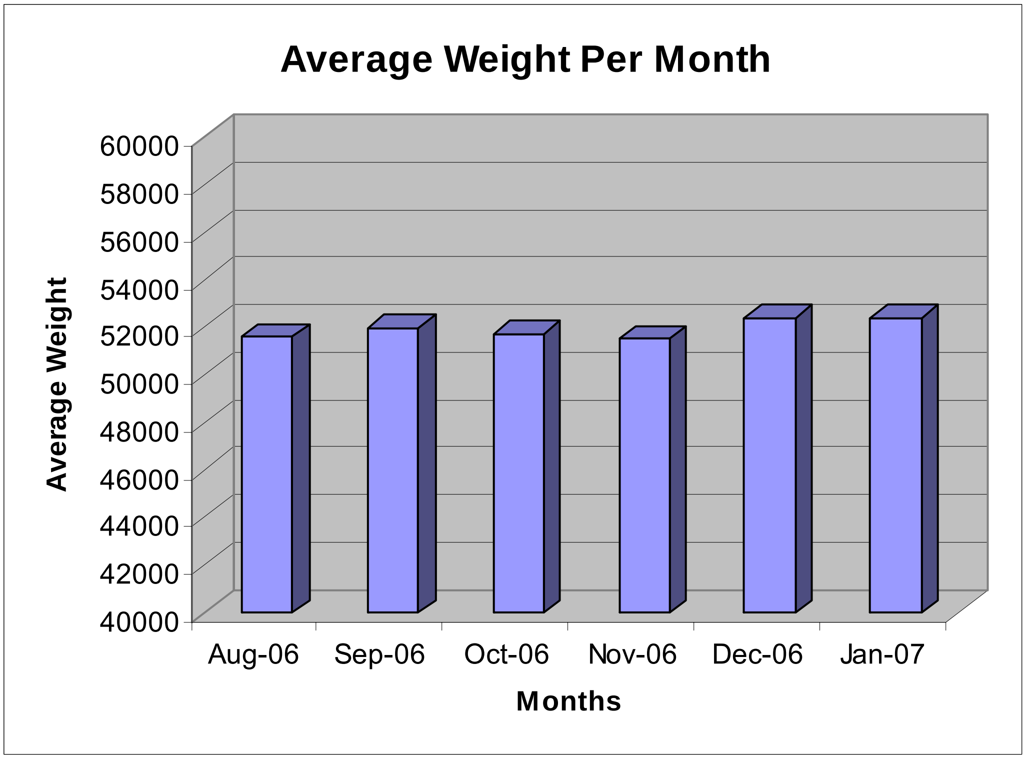



**Figure 63: Average Weight per each Month (Bar Chart)**

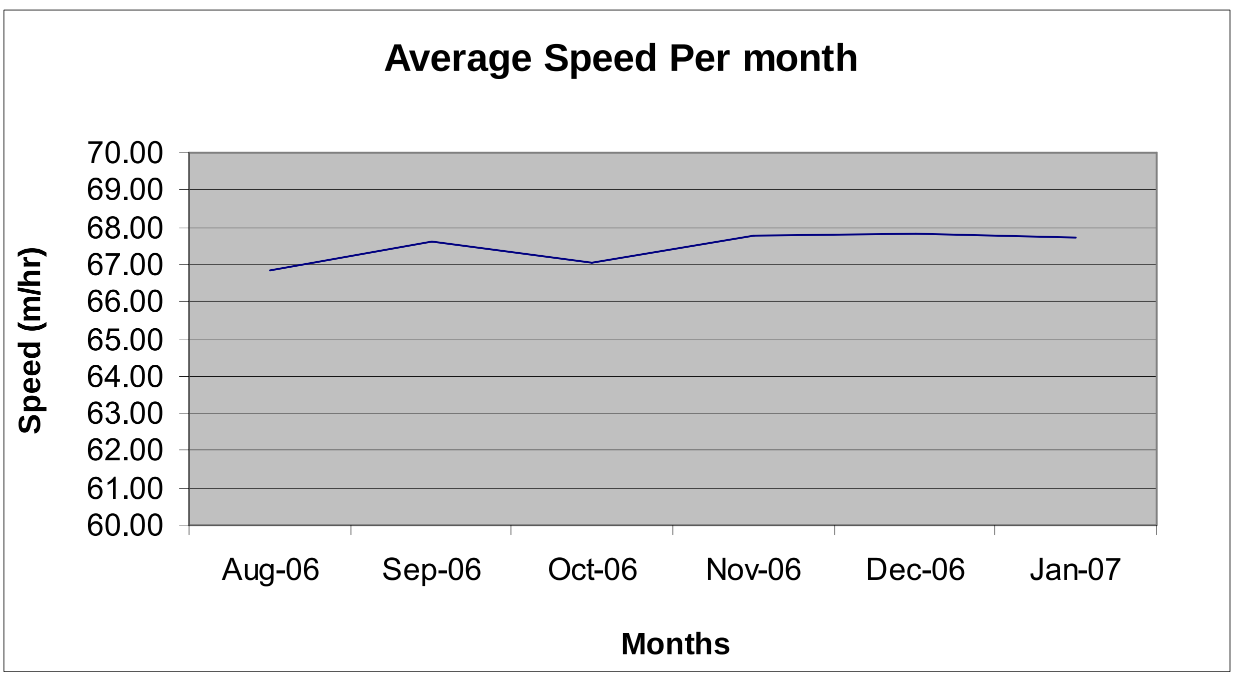



**Figure 64: Average Speed per each Month**

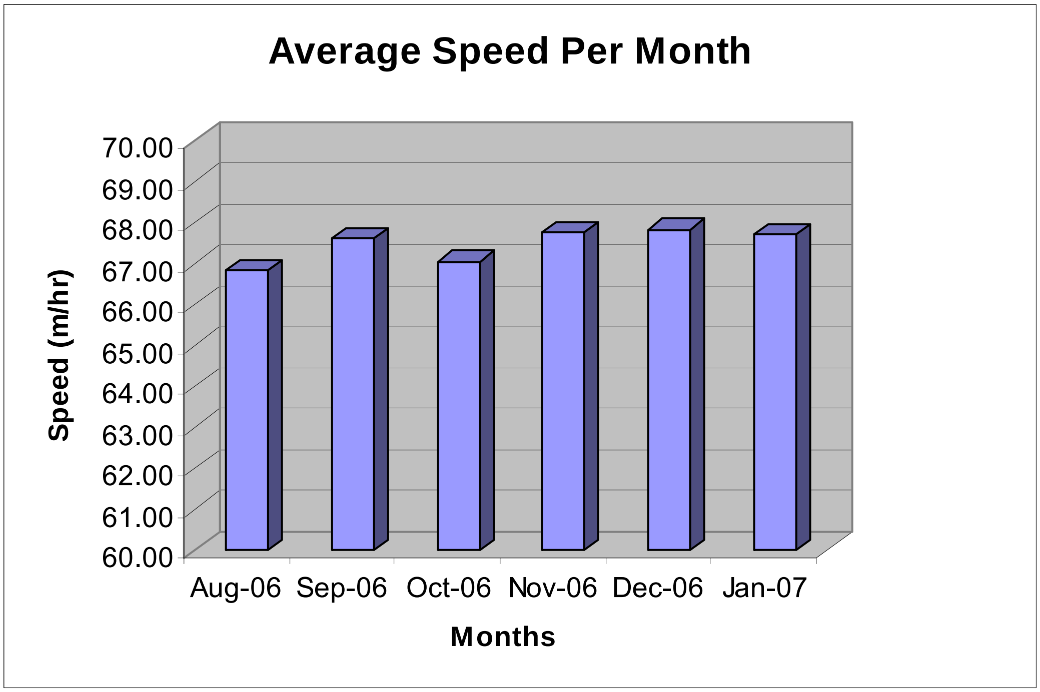



**Figure 65: Average Speed per each Month (Bar Chart)**

## *Statistics for Total and Percentage Number of Trucks Per Each Hour of the Day for all Days*

| | Time | | Number of Trucks | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | hr-0 | hr-1 | hr-2 | hr-3 | hr-4 | hr-5 | hr-6 | hr-7 | hr-8 | hr-9 | hr-10 | hr-11 | hr-12 |
| 1 | 8/1/2006 11:01 | 12/13/2006 3:54 | 796 | 786 | 753 | 856 | 896 | 816 | 1070 | 1223 | 1398 | 1584 | 1420 | 1522 | 1599 |
| 2 | 8/2/2006 7:01 | 12/14/2006 11:44 | 616 | 615 | 543 | 579 | 830 | 965 | 1113 | 1498 | 1518 | 1411 | 1477 | 1430 | 1322 |
| 3 | 8/3/2006 14:48 | 12/17/2006 2:10 | 648 | 662 | 623 | 724 | 783 | 855 | 951 | 1149 | 1397 | 1770 | 1574 | 1660 | 1771 |
| 4 | 8/8/2006 7:43 | 12/21/2006 19:24 | 546 | 518 | 543 | 675 | 827 | 872 | 1167 | 1443 | 1566 | 1560 | 1557 | 1539 | 1635 |
| 5 | 8/11/2006 8:43 | 12/29/2006 3:42 | 683 | 669 | 699 | 672 | 721 | 830 | 1100 | 1265 | 1400 | 1603 | 1611 | 1586 | 1583 |
| 6 | 8/16/2006 15:29 | 1/4/2007 10:16 | 687 | 647 | 633 | 690 | 876 | 923 | 1075 | 1357 | 1480 | 1591 | 1531 | 1435 | 1441 |
| 7 | 8/21/2006 23:49 | 1/9/2007 13:24 | 655 | 640 | 614 | 681 | 857 | 1016 | 1254 | 1389 | 1608 | 1655 | 1620 | 1764 | 1706 |
| 8 | 8/26/2006 12:12 | 1/13/2007 14:20 | 713 | 730 | 718 | 700 | 834 | 956 | 1187 | 1373 | 1344 | 1436 | 1423 | 1396 | 1454 |
| 9 | 9/1/2006 8:34 | 1/16/2007 1:40 | 706 | 674 | 634 | 711 | 759 | 872 | 1086 | 1254 | 1494 | 1673 | 1565 | 1533 | 1620 |
| 10 | 9/8/2006 15:10 | 12/7/2006 10:50 | 681 | 667 | 682 | 667 | 804 | 895 | 1108 | 1321 | 1499 | 1611 | 1461 | 1365 | 1397 |
| 11 | 7/30/2006 10:39 | 1/16/2007 2:29 | 621 | 615 | 529 | 652 | 700 | 756 | 924 | 1106 | 1197 | 1278 | 1433 | 1414 | 1453 |
| 12 | 1/17/2007 0:00 | 1/31/07 11:58 PM | 747 | 732 | 673 | 795 | 838 | 969 | 1195 | 1469 | 1592 | 1655 | 1580 | 1606 | 1687 |
| | **8/1/2006 11:01** | **1/31/2007 23:58** | **8099** | **7955** | **7644** | **8402** | **9725** | **10725** | **13230** | **15847** | **17493** | **18827** | **18252** | **18250** | **18668** |
| | | **Percentage** | **2.26%** | **2.22%** | **2.13%** | **2.35%** | **2.72%** | **2.99%** | **3.69%** | **4.42%** | **4.88%** | **5.26%** | **5.10%** | **5.10%** | **5.21%** |

| | Time | | Number of Trucks | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | hr-13 | hr-14 | hr-15 | hr-16 | hr-17 | hr-18 | hr-19 | hr-20 | hr-21 | hr-22 | hr-23 | Total Records |
| 1 | 8/1/2006 11:01 | 12/13/2006 3:54 | 1526 | 1579 | 1564 | 1491 | 1460 | 1405 | 1249 | 1071 | 1145 | 1106 | 924 | 29,239 |
| 2 | 8/2/2006 7:01 | 12/14/2006 11:44 | 1474 | 1493 | 1661 | 1762 | 1884 | 1891 | 1645 | 1355 | 1188 | 989 | 742 | 30,001 |
| 3 | 8/3/2006 14:48 | 12/17/2006 2:10 | 2037 | 1776 | 1674 | 1615 | 1605 | 1500 | 1401 | 1204 | 952 | 881 | 788 | 30,000 |
| 4 | 8/8/2006 7:43 | 12/21/2006 19:24 | 1613 | 1871 | 1860 | 1770 | 1793 | 1720 | 1471 | 1115 | 990 | 702 | 648 | 30,001 |
| 5 | 8/11/2006 8:43 | 12/29/2006 3:42 | 1638 | 1676 | 1670 | 1525 | 1516 | 1650 | 1518 | 1383 | 1189 | 1028 | 786 | 30,001 |
| 6 | 8/16/2006 15:29 | 1/4/2007 10:16 | 1597 | 1606 | 1704 | 1701 | 1721 | 1659 | 1410 | 1292 | 1120 | 933 | 892 | 30,001 |
| 7 | 8/21/2006 23:49 | 1/9/2007 13:24 | 1651 | 1652 | 1570 | 1583 | 1571 | 1377 | 1398 | 1149 | 1070 | 864 | 657 | 30,001 |
| 8 | 8/26/2006 12:12 | 1/13/2007 14:20 | 1617 | 1759 | 1733 | 1604 | 1719 | 1557 | 1477 | 1299 | 1077 | 1014 | 881 | 30,001 |
| 9 | 9/1/2006 8:34 | 1/16/2007 1:40 | 1794 | 1880 | 1718 | 1580 | 1611 | 1522 | 1352 | 1162 | 1073 | 955 | 773 | 30,001 |
| 10 | 9/8/2006 15:10 | 12/7/2006 10:50 | 1532 | 1609 | 1762 | 1710 | 1776 | 1734 | 1505 | 1278 | 1099 | 1003 | 835 | 30,001 |
| 11 | 7/30/2006 10:39 | 1/16/2007 2:29 | 1575 | 1581 | 1549 | 1529 | 1414 | 1432 | 1285 | 1100 | 992 | 868 | 737 | 26,740 |
| 12 | 1/17/2007 0:00 | 1/31/07 11:58 PM | 1798 | 1876 | 1857 | 1851 | 1627 | 1634 | 1605 | 1366 | 1156 | 980 | 864 | 32,152 |
| | **8/1/2006 11:01** | **1/31/2007 23:58** | **19852** | **20358** | **20322** | **19721** | **19697** | **19081** | **17316** | **14774** | **13051** | **11323** | **9527** | **358,139** |
| | | **Percentage** | **5.54%** | **5.68%** | **5.67%** | **5.51%** | **5.50%** | **5.33%** | **4.83%** | **4.13%** | **3.64%** | **3.16%** | **2.66%** | **100.00%** |

**Table 12: Statistics for Number and Percentage of Trucks per each Hour of the Day**

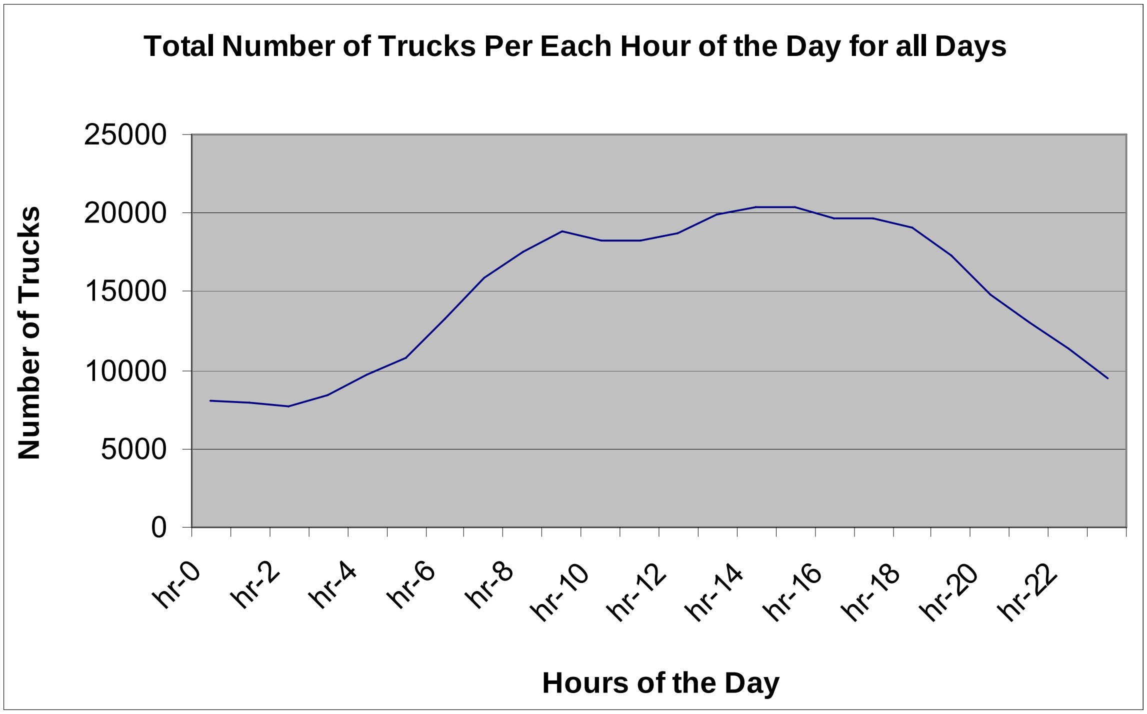



**Figure 66: Total Number of Trucks per Each Hour of the Day**

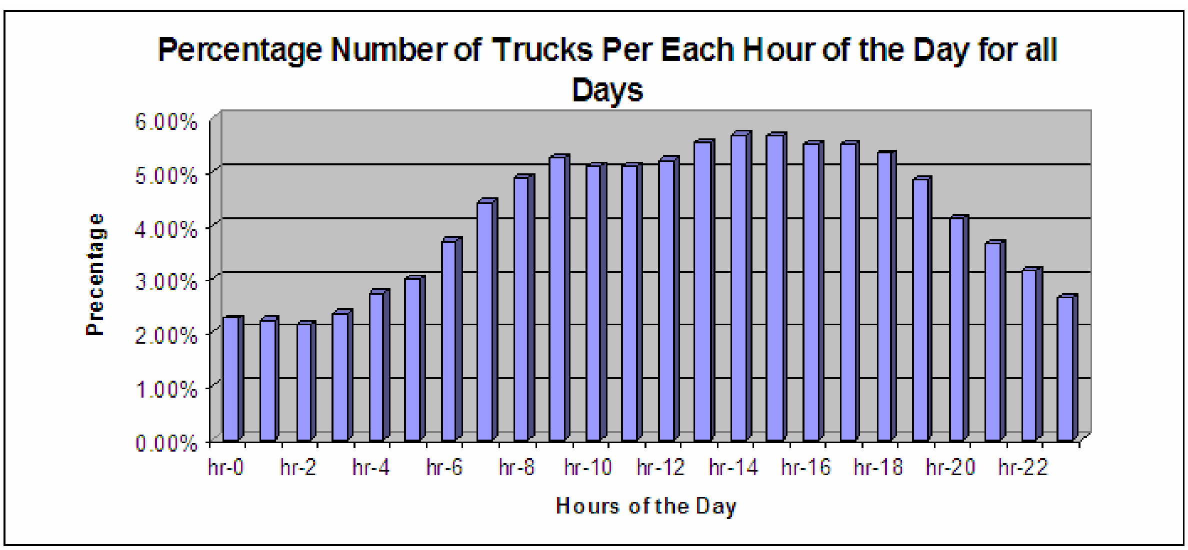



**Figure 67: Total Number of Trucks per Each Hour of the Day (Bar Chart)**

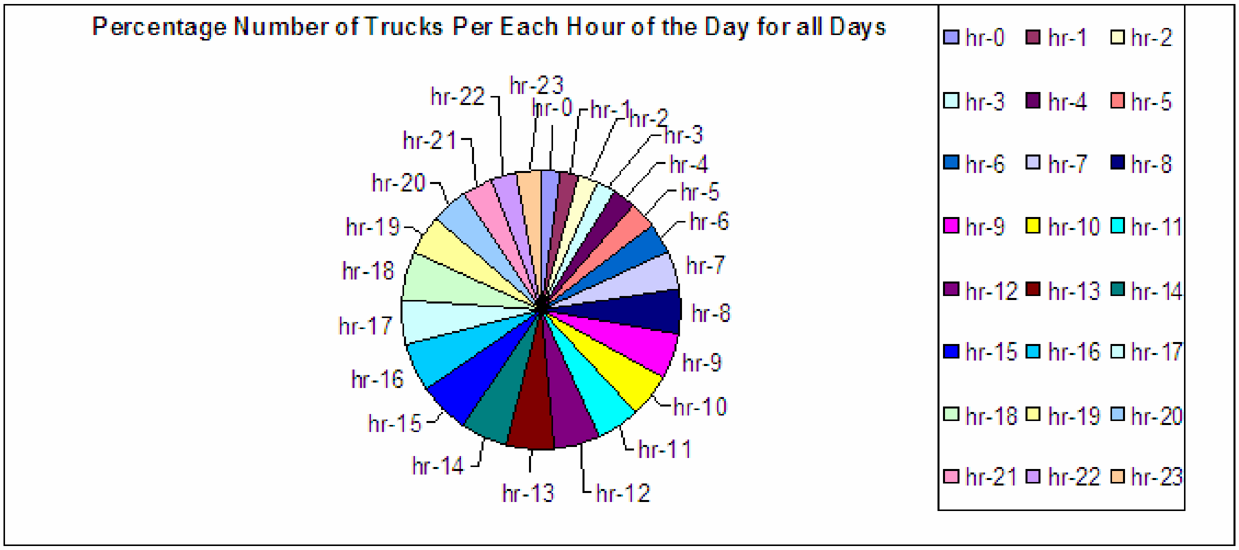



**Figure 68: Percentage of Trucks per Each Hour of the Day (Bar Chart)**

## *Violator's Statistics per Month*

| Number | Aug-06 | Sept-06 | Oct-06 | Nov-06 | Dec-06 | Jan-07 | Total |
|---|---|---|---|---|---|---|---|
| Number of Trucks per Month | 55050 | 59634 | 60634 | 61312 | 59741 | 61768 | 358139 |
| Violators Per Month | 726 | 740 | 622 | 613 | 565 | 566 | 3832 |
| Percentage Monthly Violators per Total Violators | 18.95% | 19.31% | 16.23% | 16.00% | 14.74% | 14.77% | 100.00% |
| Percentage Monthly Violators per Total Trucks | 1.32% | 1.24% | 1.03% | 1.00% | 0.95% | 0.92% | 1.07% |

**Table 13: Violator Statistics per Month**

From the statistics, the percentage of violators seems to account for 1.07% of all trucks. However, the violations appear to reach its peak during August and September. Perhaps during the summer season violations tend to be more excessive. This peak definitely requires further investigation.

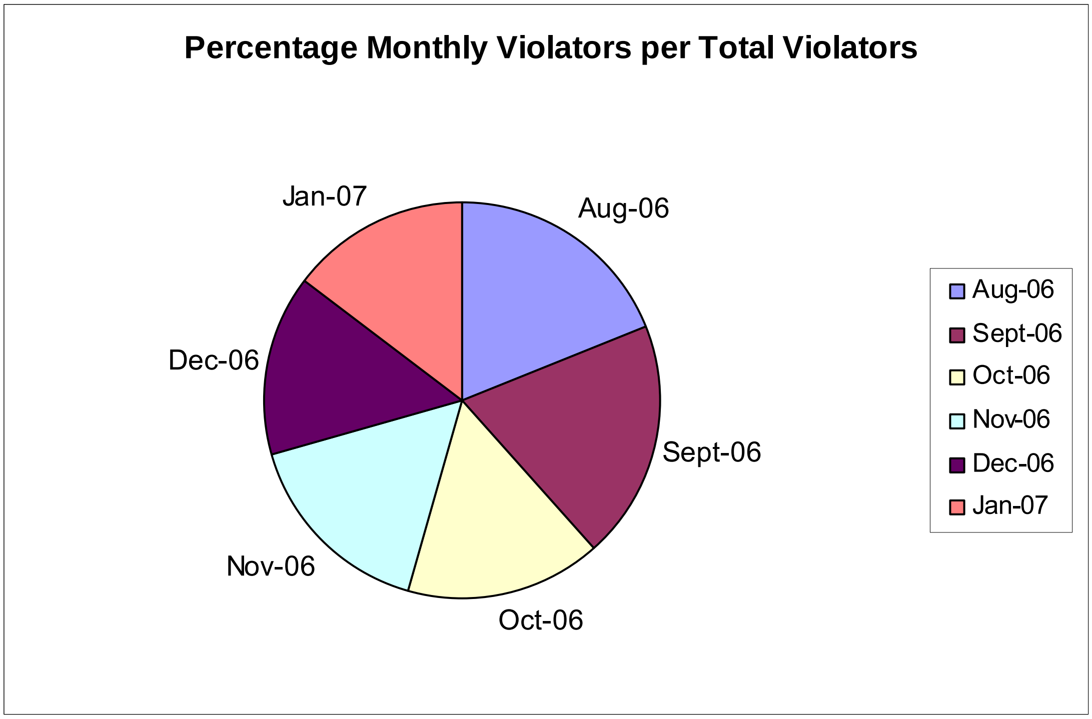



**Figure 69: Percentage of Violators per Month**

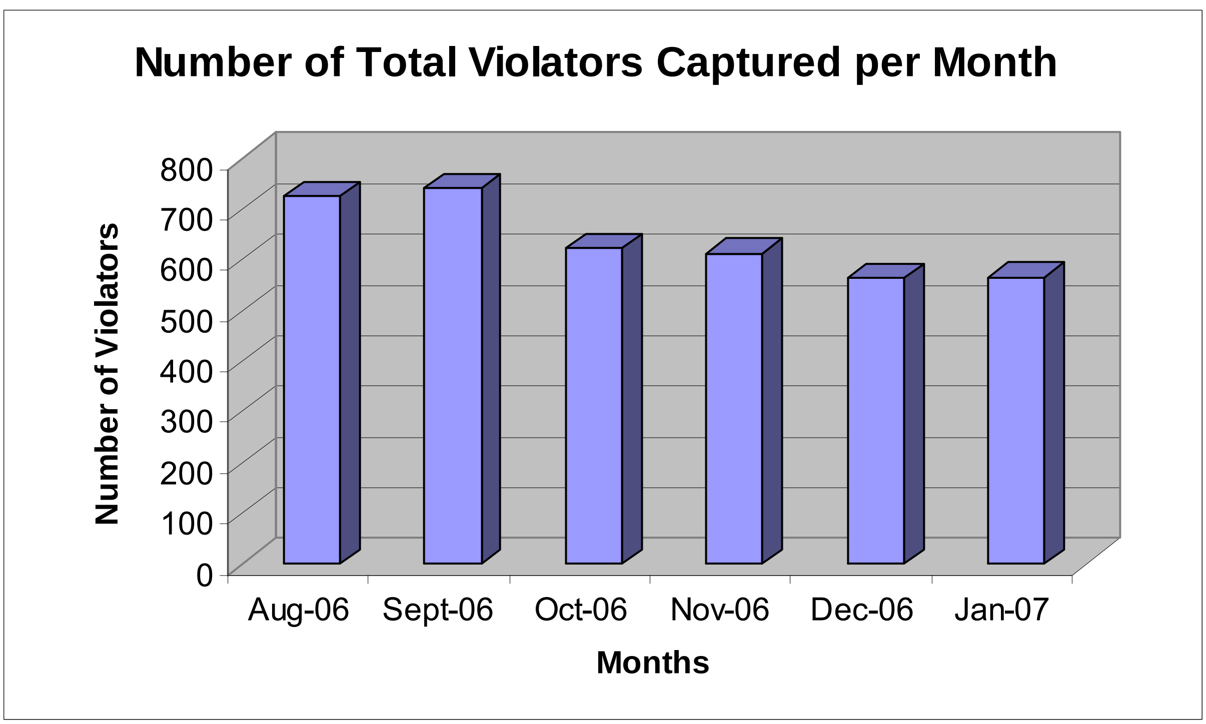



**Figure 70: Number of Violators per Month**

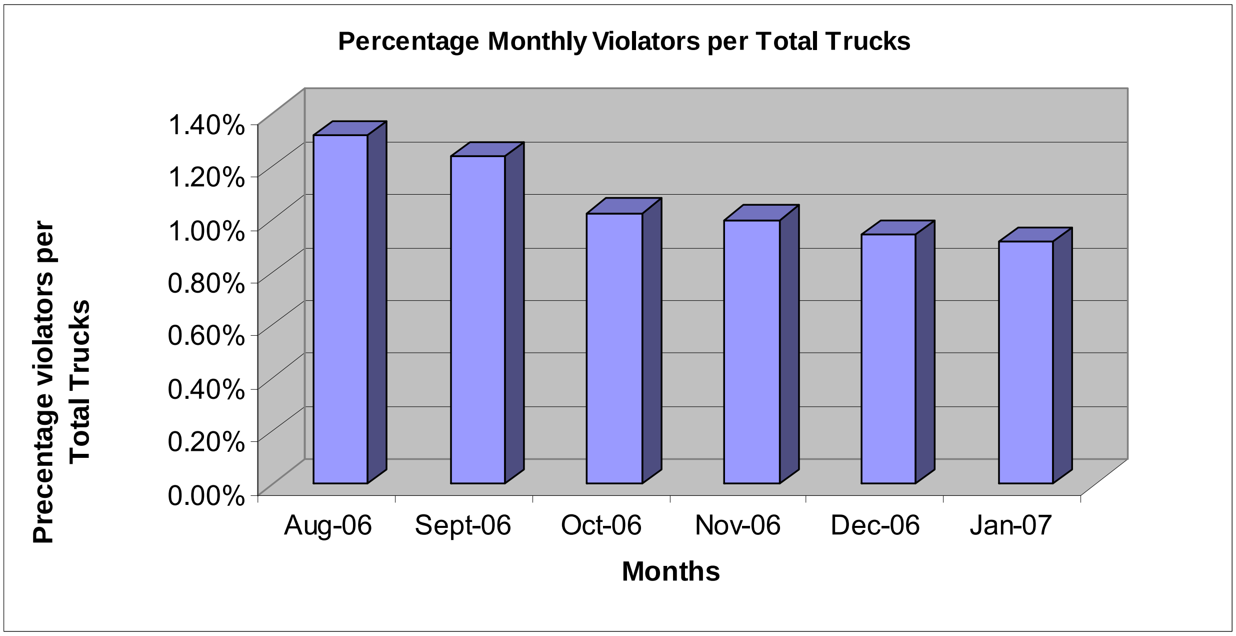



**Figure 71: Percentage Monthly Violators per Total Trucks**

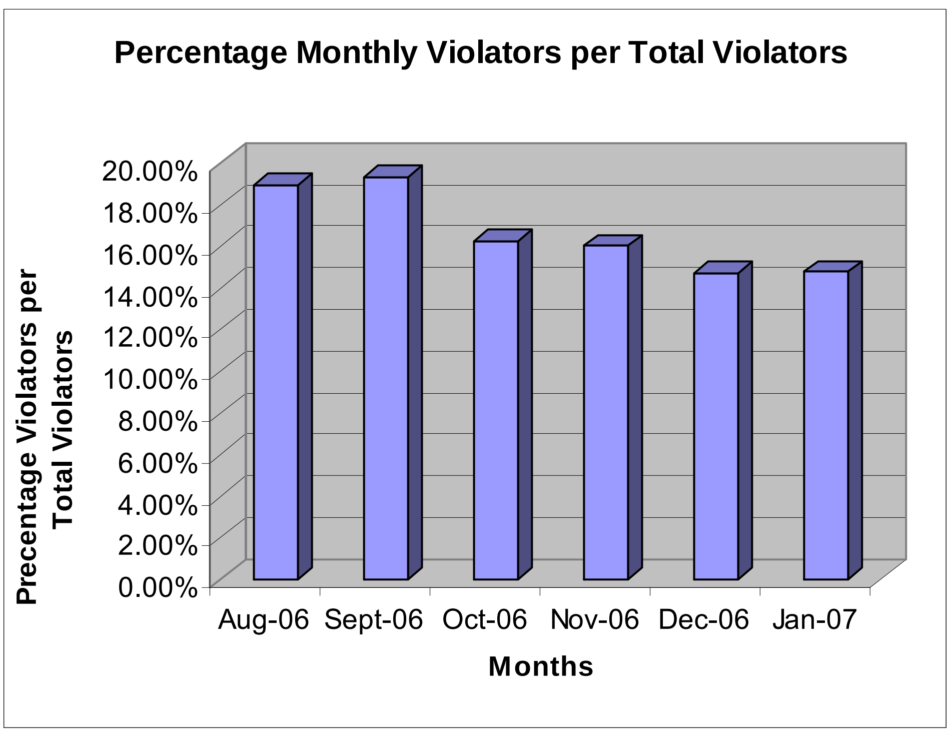



**Figure 72: Percentage Monthly Violators per Total Violators**

## *Non-Speed Violator's Statistics per Month*

| Number | Aug-06 | Sept-06 | Oct-06 | Nov-06 | Dec-06 | Jan-07 | Total |
|---|---|---|---|---|---|---|---|
| Number of Trucks per Month | 55050 | 59634 | 60634 | 61312 | 59741 | 61768 | **358139** |
| **Non-Speed** Violators Per Month | 636 | 660 | 516 | 511 | 463 | 455 | **3241** |
| Violators per month | 726 | 740 | 622 | 613 | 565 | 566 | **3832** |
| Percentage Monthly **Non-Speed** Violators per Total Violators | 19.62% | 20.36% | 15.92% | 15.77% | 14.29% | 14.04% | **100.00%** |
| Percentage Monthly **Non-Speed** Violators per Total Trucks | 1.16% | 1.11% | 0.85% | 0.83% | 0.78% | 0.74% | **0.90%** |
| Percentage Monthly **Non-Speed** Violators per Total Violators | 87.60% | 89.19% | 82.96% | 83.36% | 81.95% | 80.39% | **84.58%** |

**Table 14: Non-Speed Violator Statistics per Month**

From the data analysis the speed violations appear to account for approximately 15.4% of all violations. Therefore, further violation analysis was performed by excluding speed violations and comparing it to the rest of the violations.

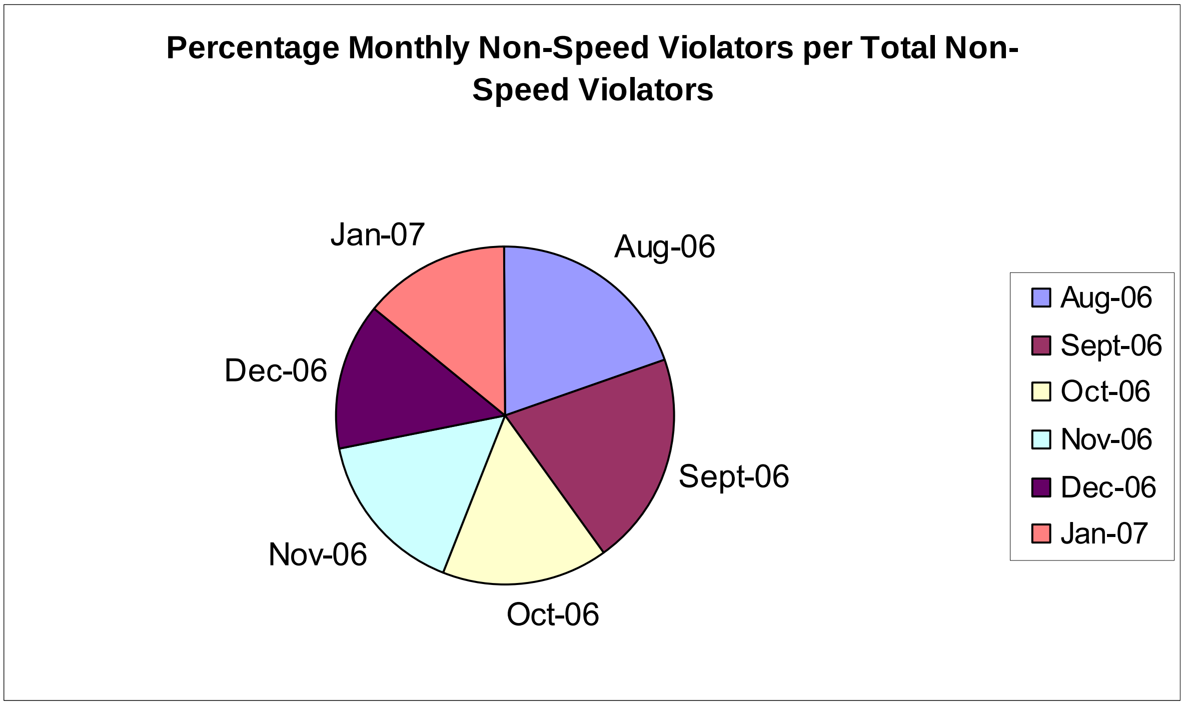



**Figure 73: Percentage Non-Speed Violators per Month**

The analyses show that the non-speed violations still tend to be a little higher during the months of August and September.

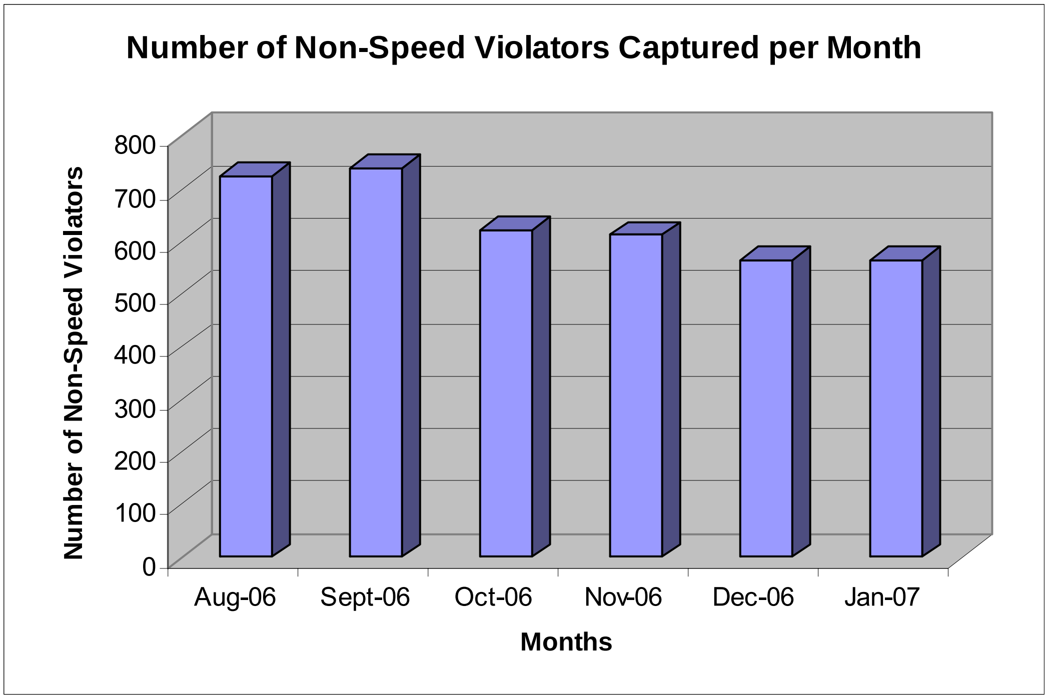



**Figure 74: Number of Non-Speed Violators per Month**

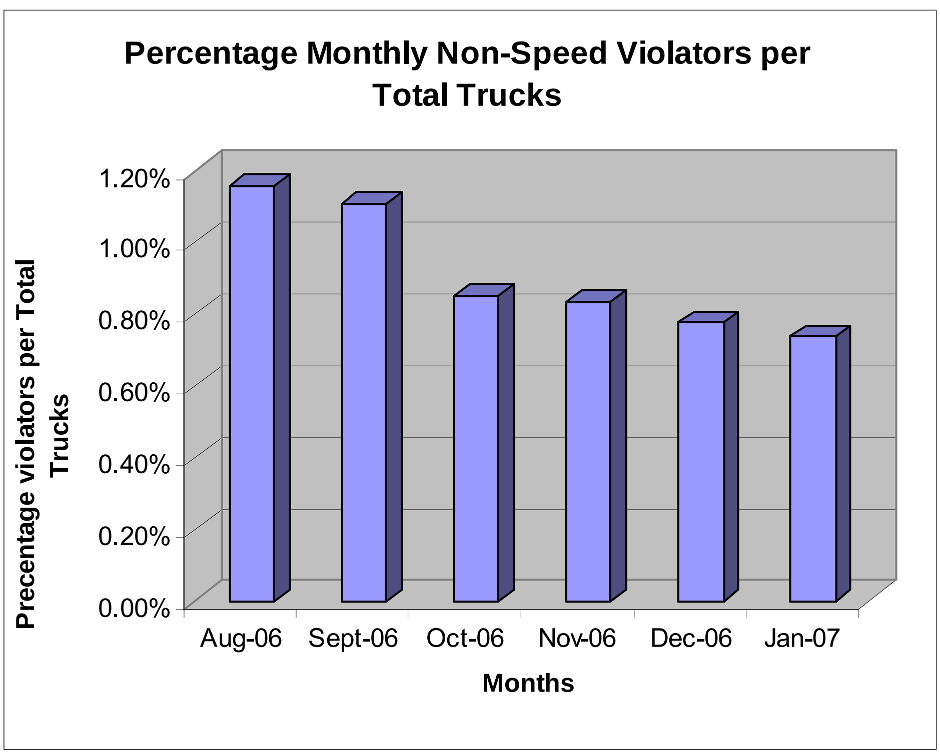



**Figure 75: Percentage Monthly Non-Speed Violators per Total Trucks**

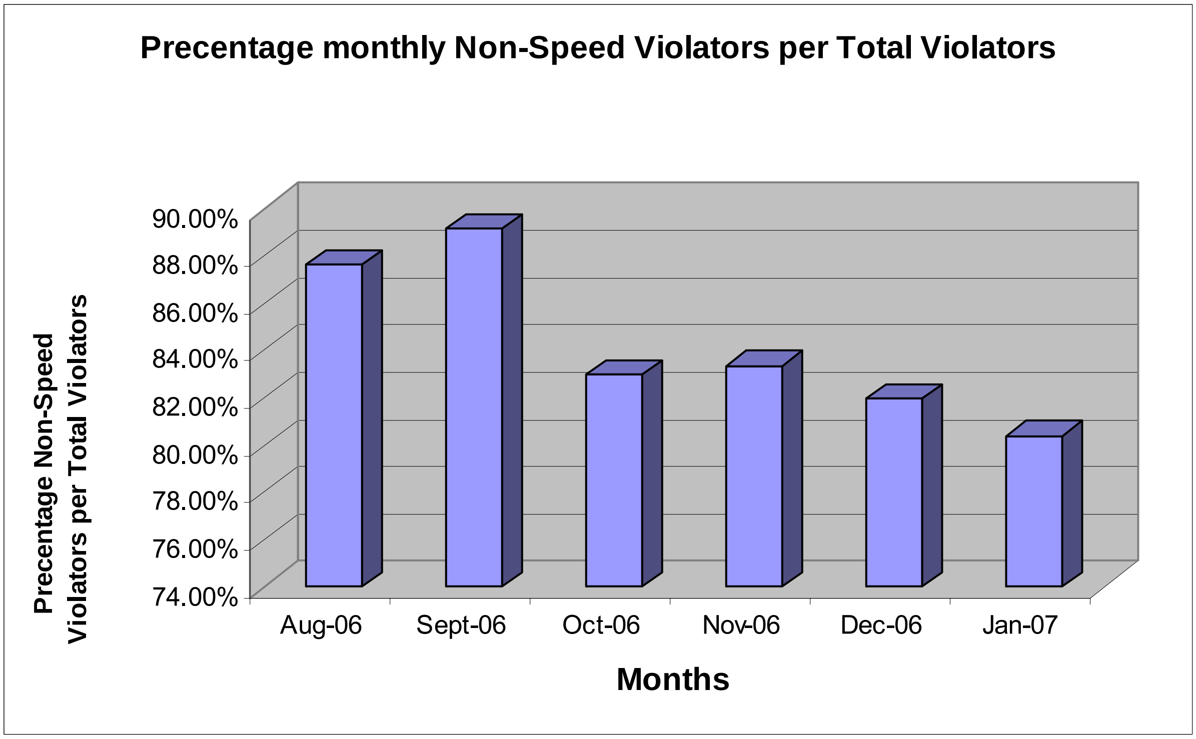



**Figure 76: Percentage Monthly Non-Speed Violators per Total Violators**

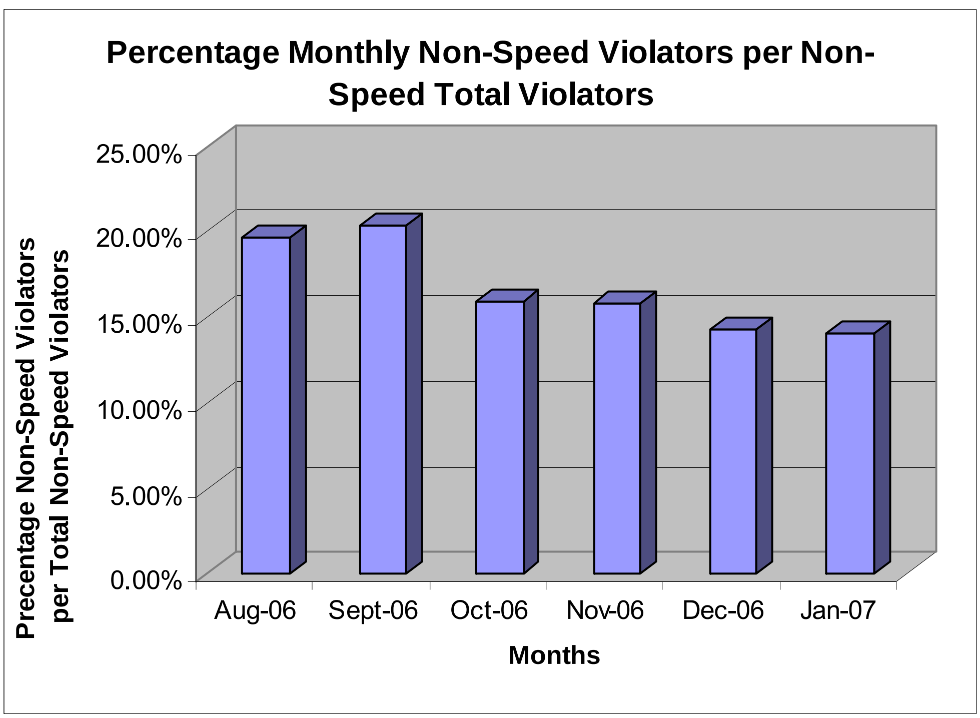



**Figure 77: Percentage Monthly Non-Speed Violators per Total Non-Speed Violators**

The violator's analysis shows that the percentage of speed violations tends to increase as we move from the month of August to December. An explanation for that could be that during the summer time traffic in Florida maybe relatively denser due to tourism then during the winter months. Further analysis is required to investigate the causes behind this observation.

### *Statistics of the Average Speed of Trucks per Each Hour of the Day for all Days*

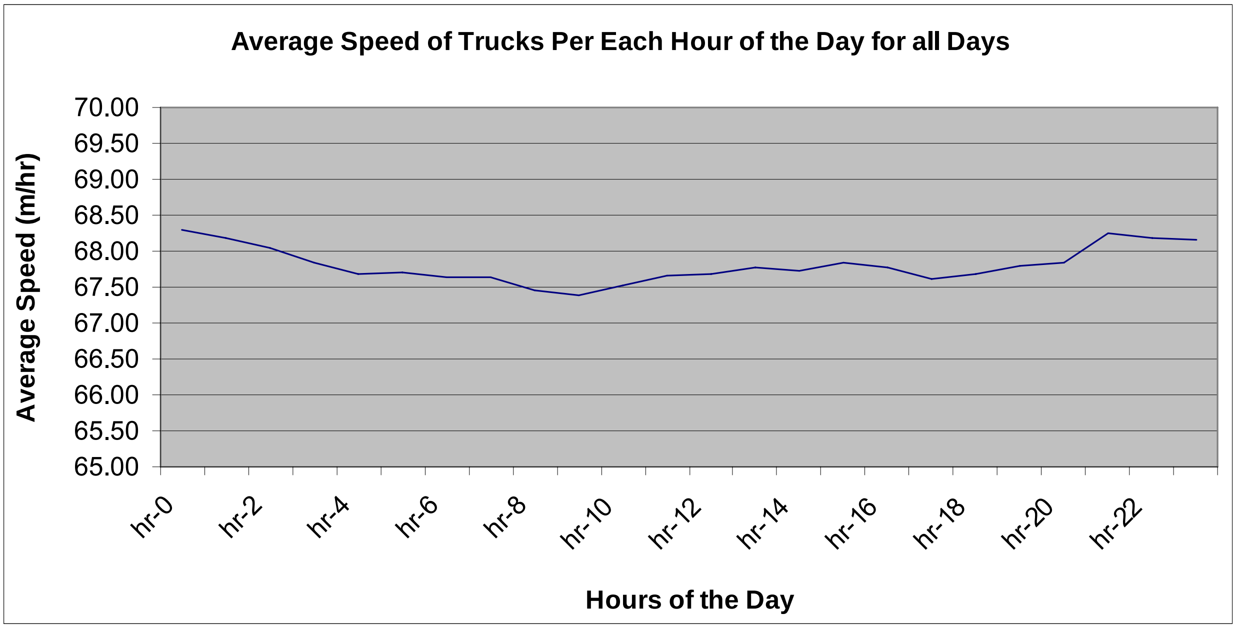



**Figure 78: Average Speed of Trucks per Hour of the Day**

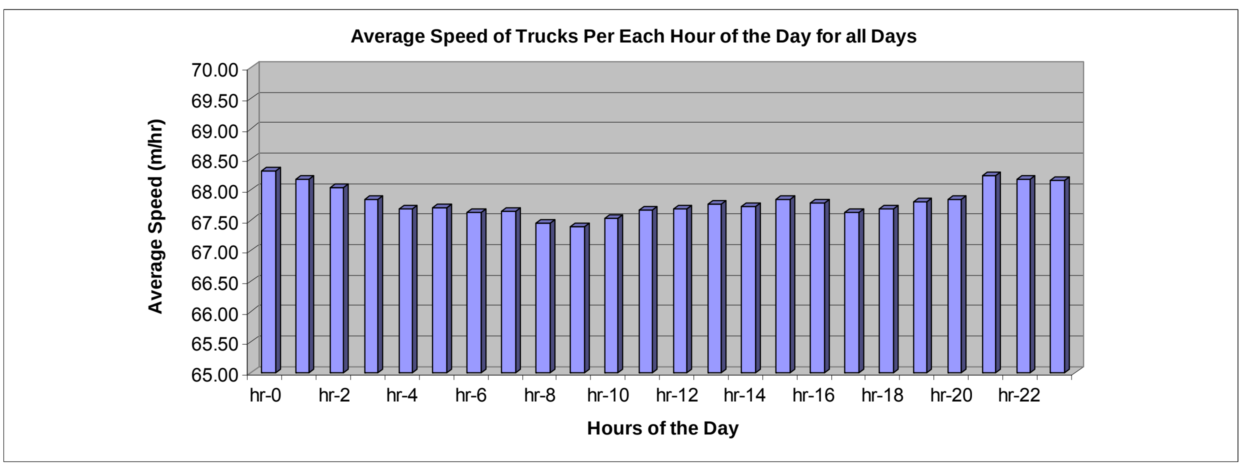



**Figure 79: Average Speed of Trucks per Hour of the Day (Bar Chart)**

The highest average speeds were recorded during the late hours of the night. The roads are typically empty and trucks may be tempted to speed. There are two recesses: (one is around 8am and the other is around (6pm). They both correspond to the daily rush hours where the overall flow tends to be slower.

## Summary and Recommendations:

This research demonstrated three essential issues:

1. The need for an outdoor “living” lab for the evaluation of promising commercial vehicle technologies.
2. The utility of an on-line database for the technologies above.
3. The economic and operational benefits or remotely-operated compliance stations.

Nationally, departments of transportation, after multiple negative experiences with false assertions of technology vendors, are looking for neutral-party evaluations of those technologies. Evaluations that are done, as much as is practically possible, in the same operational environments the equipment will be subjected to. Results of these tests would be stored in an online database resource available to the public.

The primary objective of this research project, namely the design and deployment of the first remotely-operated compliance station in Florida (aka virtual weigh station) was extremely successful. The station met all its design parameters and demonstrated, for a relatively small investment, the feasibility and power of such technologies.

In closing, it cannot be stressed enough, that the ultimate success of such technologies will depend to a large extent on the maintenance and management of these facilities for both hardware and software.

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