# Effect on Speed Distribution due to Intrusive and Non-Intrusive Portable Speed Measurement Devices

**by**

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Version of the following thesis:

# Effect on Speed Distribution due to Intrusive and Non-Intrusive Portable Speed Measurement Devices

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# ABSTRACT

Accurate traffic data are essential for supporting a multitude of transportation related decisions which affect transportation system operations, management, and planning. Advanced technology offers us various alternatives for accurately collecting traffic data. But accuracy of data is not just about the mechanical accuracy of the device, but it also about how people react when they see these devices installed either on roads or off roads. It is very important that the drivers should not get affected by the presence of these devices as these devices are not always to control the speeds but they are also installed to measure the true speed of the drivers. Such studies are the basis for important decisions, such as setting speed limits, timing traffic signals, placing traffic signs, and determining the effectiveness of the countermeasures.

To evaluate the effectiveness on speed distribution due to the presence of various intrusive and non-intrusive portable speed measurement devices, automated traffic counters with pneumatic tubes, Smartsensor, Autoscope with camera trailer and Lidar gun were compared. Results showed that drivers did not react to pneumatic tubes and continued driving at the same speed; there was no significant difference in speeds at different locations while pneumatic tubes were installed. Drivers tend to react most by reducing their speeds when a Lidar gun was used, the Autoscope with camera trailer also effected driver behavior to a considerable amount. There was slight increase in speeds when the Smartsensor was installed.

Similar driver behavior was observed when effect on the speeds of faster drivers was evaluated. For this analysis drivers driving above 85th percentile speeds were picked and tracked throughout the test site. Drivers reacted most to Lidar guns and then to the Autoscope with camera trailer. There was no significant difference in speeds when pneumatic tubes were installed.

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# CHAPTER 1- INTRODUCTION

"The more precisely the position is determined, the less precisely the momentum is known, and vice-versa" (1), according to Werner Heisenberg's uncertainty principle. This is not a statement about the inaccuracy of measurement instruments, or a reflection on the quality of experimental methods; it arises from the wave properties inherent in the quantum mechanical description of nature. Even with perfect instruments and technique, uncertainty is inherent in the nature of things. Similarly, no matter how precisely the speeds are measured at a fixed location, it is very likely that the true speed of a driver is not recorded as every driver may respond differently on seeing the device installed on-pavement or off-pavement causing discrepancies in the data.

Accurate traffic data are essential for supporting a multitude of transportation related decisions which affect transportation system operations, management, and planning (2). Any study can only be as accurate as the data on which it is based. For this reason it is extremely important that the traffic data collected from the devices should be accurate and the data should not be influenced by the presence of the data collection devices, themselves. The measurement of vehicular speeds is a common and important task performed by practitioners of many traffic-related disciplines, including engineers, managers, researchers, and law enforcements individuals. Transportation agencies often use results of speed studies as the basis for important decisions, such as setting speed limits, timing traffic signals, placing traffic signs, and determining the effectiveness of countermeasures(3).

There are several commercial portable speed measurement devices (traffic speed detectors) available for measuring the speeds. Some of them are intrusive devices, some are non-intrusive and some are off-roadway. The following are a few examples of each technology.

**Intrusive devices**

- Inductive Loops
- Pneumatic tubes
- Piezoelectric tubes
- Bending Plates
- Magnetic Detector

**Non-Intrusive devices**

- Sonic and Ultrasonic Doppler
- Passive Infrared - Active Infrared
- Microwave Detector
- Video

**Off-Roadway**

- Probe Vehicle
- Lidar Gun
- Radar Gun

All of these technologies have certain advantages and disadvantages. As these devices used for speed measurement are either placed on the roadbed or on the road sides on trailers, posts or even handheld, therefore, they are likely to be seen by drivers and could affect driver behavior. This affect can lead to discrepancies in the speed data and the speeds collected might not be the speeds that would have been in the absence of the devices.

## 1.1 Research Overview

As the drivers may respond differently to each of these portable speed measurement devices, there can be some discrepancy in these data. This thesis will quantify the difference in speed distribution due to the presence of various portable speed measurement devices and also, suggest which device influences the speed distribution in comparable ways. The thesis will also aid researchers in understanding if different speed measurement devices are interchangeable or not. The study will also look at the ease in installation of the devices in terms of labor hours and time required for calibration and will also consider the cost effectiveness of the devices.

To perform the data collection, three very similar sites are selected and four devices are tested, where each device is tested for three days in a week. The first location is on U.S. 59, between 62nd and 70th Street, KS, the second location is on U.S. 24 between west of the U.S.

24/59 junction and mile post 385, KS and the third location is on U.S. 24/40, between E 1500 W road to E 1500 W road, KS. The speeds of vehicles will be recorded for the study.

## 1.2 Contribution to the State of the Art

The research will demonstrate the effect on speeds due to each portable speed measurement device. The results will aid researchers in understanding if different speed measurement devices are interchangeable or not.

This research will focus on the speed distribution of the vehicles, installation time and cost effectiveness on two lane rural highway. Future research is needed to determine the effect on multi lane roads, with different speed limits.

## 1.3 The Organization

This thesis is divided into seven chapters. Chapter 1, Introduction, discusses the importance of speed data in transportation and various available portable speed measurement devices to collect data and the possible effects on data due to the presence of these devices and starts to explain the scope of the research. Chapter 2, Literature Review, briefly reviews the scenario of speed measurement in today's world. The chapter also looks at the application of devices and comparison of these devices for their accuracies, installation methods and costs. Chapter 3, Methodology, presents the various devices used for study, site selection and the criteria for site selection. Chapter 4, Data Collection, presents how the data were collected from three sites. Chapter 5, Analysis, presents the results of the data collected and comparison of devices with each other. Finally, Chapter 6, Findings and Recommendations, summarizes the research effort, presents the recommended actions based on the research findings, and proposes the future research.

# CHAPTER 2-LITERATURE REVIEW

As the need for automatic traffic monitoring increases with the evolution of Intelligent Transportation Systems (ITS), market opportunity and application needs urge manufacturers and researchers to develop new technologies and improve existing ones. A variety of detector technologies and methods are currently are available.

Martin, et al. (4) in his study has defined and explained three categories of detector technologies that exist: intrusive detectors (in-roadway), non-intrusive detectors (above roadway or sidefire), and off-roadway technologies. Intrusive detectors are installed within or across the pavement on roads and bridges. Non-intrusive detectors can be installed above or on the sides of roads and bridges with minimum disruption to traffic flow. He also mentioned that issues of reliability, safety, traffic disruption, complex road geometry and cost lead to the advancement of non-intrusive detector technology. Until the 1960s only two type of non-intrusive detectors - ultrasonic and microwaves - were available on the market. Traffic operators took more interest in non-intrusive detector as these devices could be installed overhead or sidefire, they minimized traffic disruption during installation and maintenance. He also expressed that "However, in the early stage of non-intrusive technologies, immaturity kept them from being widely used. Most non-intrusive detector technologies are still in small-range applications." Over time there have been huge improvements due to the development of computer, information, communication, electronics and control technologies. These devices use aerial/satellite images to obtain traffic information (4).

## 2.1 Intrusive Detector Technologies

A study performed by Mimbela, et al.( 5) summarized various vehicle detection and surveillance technologies. The study discussed intrusive and non-intrusive devices, along with their advantages, disadvantages, principles of operation, their application and uses. The next section draws heavily from the study performed by them.

**Inductive Loop:** Mimbela, et al. claimed that "inductive loop detector (ILD) is the most common sensor used in traffic management applications. Its size and shape vary, including the 5-ft by 5-ft or 6-ft by 6-ft square loops, 6-ft diameter round loops, and rectangular configurations having a 6-ft width and variable length. Figure 1 shows inductive loop detector system. The wire loop is excited with signals whose frequencies range from 10 KHz to 50 KHz and functions as an inductive element in conjunction with the electronics unit. When a vehicle stops on or passes over the loop, the inductance of the loop is decreased. The decreased inductance increases the oscillation frequency and causes the electronics unit to send a pulse to the controller, indicating the presence or passage of a vehicle" (5).

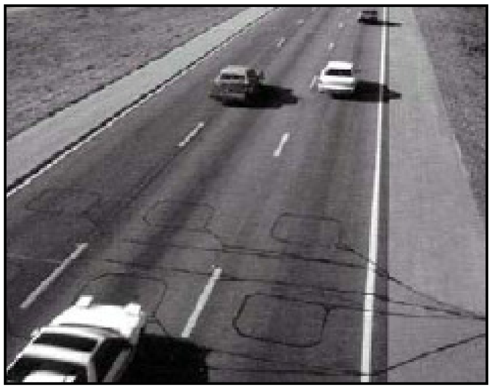


**Figure 1 Inductive Loop Detector System (7)**

***Stated Capabilities:*** Inductive loops and be used to derive basic traffic parameters like volume, presence, occupancy, speed, headway, and gap and represents a mature technology. The equipment cost of inductive loop sensors is low when compared to non-intrusive sensor technologies (5).

***Limitations:*** The major drawback of inductive loop sensors is that they cause disruption of traffic for installation and repair. In many instances multiple detectors are usually required to instrument a location. In addition, resurfacing of roadways and utility repair can also create the need to reinstall these types of sensors. Also, wire loops are exposed to stresses of traffic and temperature (5).

**Pneumatic road tubes:** These are rubber tubes that are placed across the road lanes to detect vehicles from pressure changes that are produced when a vehicle tire passes over the tube. The pulse of air that is created is recorded and processed by a counter located on the side of the road (6). Figure 2 below shows pneumatic tube and automatic traffic counter setup.

***Stated Capabilities:*** Advantages of road tube sensors are that they are quick and easy to install for permanent and temporary recording of data and use low power. Road tube sensors are usually low cost and easy to maintain (5).

***Limitations:*** Disadvantages include inaccurate axle counting when truck and bus volumes are high, temperature sensitivity of the air switch, and cut tubes resulting from vandalism and wear produced by truck tires (5).

**Figure 2 Pneumatic Tubes with Automated Vehicle Classifier (8)**

**Piezo-electric sensor:** These sensors are placed in a groove along the roadway surface of the lane(s) monitored. Figure 3 shows an example of a piezoelectric sensor grooved along the roadway. The principle behind their operation is to convert kinetic energy into electrical energy. Mechanical deformation of the piezoelectric material modifies the surface charge density of the material so that a potential difference appears between the electrodes. The amplitude and frequency of the signal is directly proportional to the degree of deformation (6).

***Stated Capabilities:*** The unique ability of piezoelectric sensors to detect the passing of tire over them allows them to differentiate individual vehicles with extreme precision. If only installation cost is considered, they are only marginally more expensive than an inductive loop, but they provide lot more significant information like more accurate speeds, vehicle classification, and weights of Weigh-in-Motion (WIM) systems.

***Limitations:*** The drawbacks to the use of piezoelectric sensors are similar to those of inductive loop sensors (5).

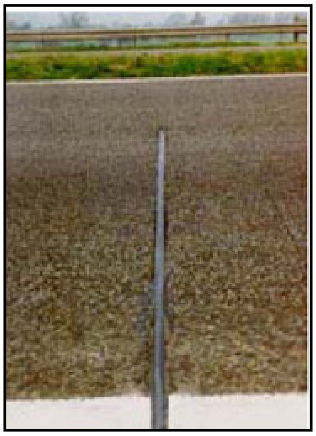


**Figure 3 Piezoelectric Sensor (8)**

**Bending plate:** The bending plate scale consists of two steel platforms for each wheel path of the traffic lane, installed with two inductive loops. The loop's inductance changes and produces a readable signal when a vehicle passes over it (8). A weight pad is attached to a metal plate embedded in the road to measure axle weight and speed. It is an expensive device and requires alteration to the road bed (10). Figure 4 is an example of bending plate sensor.

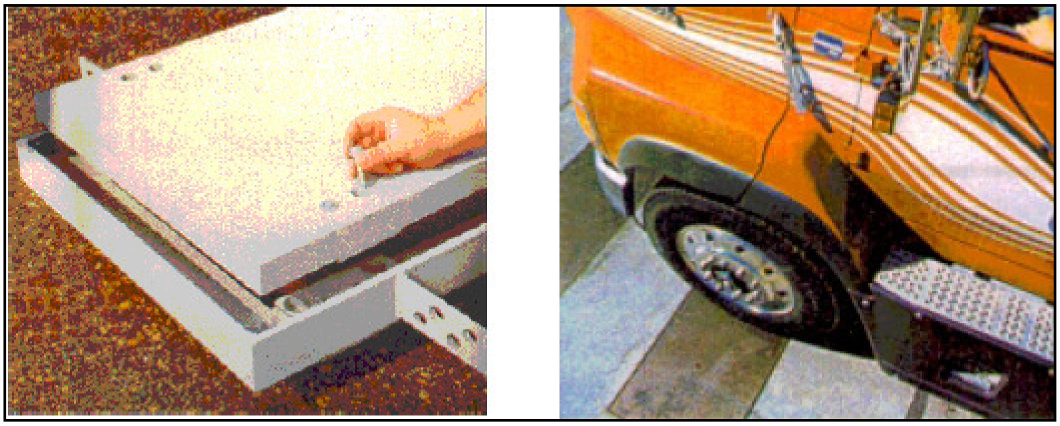


**Figure 4 Bending Plate Sensor (5)**

***Stated Capabilities:*** Bending plate WIM systems can be used for traffic data collection as well as for weight enforcement purposes. The accuracy of these systems is higher than piezoelectric systems and their cost is lower than load cell systems.

***Limitations:*** Bending plate WIM systems are considerably more expensive than piezoelectric systems (5).

**Magnetic Detector:** Martin, et al. in his study Detector Technology Evolution has explained magnetic detectors, stating that “the two primary types of magnetic detectors are the induction magnetometer and the dual-axis fluxgate magnetometer. Induction magnetometers are also referred to as search coil magnetometers, commonly contain a single coil winding around a permeable, magnetic rod. The detector generates a voltage by measuring distortion in the magnetic flux lines. The detectors require a minimum speed, usually three to five mph. The dual-axis fluxgate magnetometers typically are composed of a primary winding, two secondary sense windings and a high permeability, soft magnetic core. The detectors measure changes in horizontal and vertical components of the Earth's magnetic field. When voltage exceeds the predetermined threshold, a vehicle signature is determined" (4). Figure 5 shows both microloop sensor and vehicle detector used for magnetic detector system.

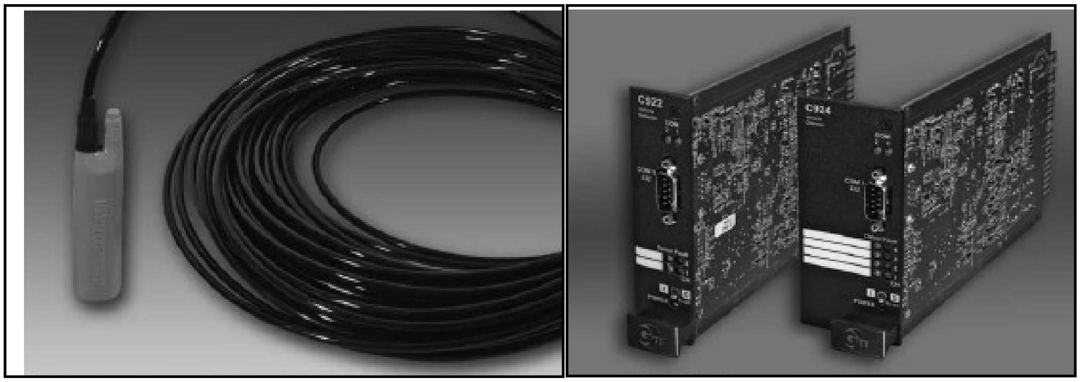


**Figure 5 Microloop Sensor and Vehicle Detector (11)**

***Stated Capabilities:*** The two-axis fluxgate magnetometer is less vulnerable than loops to stresses of traffic. Also some models of the two-axis fluxgate magnetometer transmit data over wireless link (5).

***Limitations:*** Installation of magnetic sensors requires pavement cuts or tunneling under the roadway and thus requires lane closure during installation. Magnetic detectors cannot generally detect stopped vehicles (5).

## 2.2 Non-Intrusive Detector Technologies

In the study performed by Quoc, et al. "Guidelines for maintenance of traffic signal actuation at signalized intersections with non-intrusive technologies", various nonintrusive detector technologies have been discussed (12). Most of the information in the next section has been drawn directly from their study.

**Sonic (Passive Acoustic) and Ultrasonic (Pulse and Doppler):** Quoc, et al. state, "Passive acoustic devices consist of an array of microphones aimed at the traffic stream. The devices are passive in that they are listening for the sound energy of passing vehicles. Pulse devices emit pulses of ultrasonic sound energy and measure the time for the signal to return to the device.

Doppler devices emit a continuous ultrasonic signal and utilize the Doppler principle to measure the shift in the reflected signal" (12). Figure 6 shows pictures of ultrasonic pulse detector and ultrasonic passive detector.

***Stated Capabilities:*** Passive acoustic sensors can detect volume, speed and occupancy. Doppler ultrasonic sensors can detect volume, presence and speed. Pulsed ultrasonic sensors can detect volume, presence, classification and occupancy (12).

***Limitations:*** Sonic or passive acoustic sensors are limited by environmental conditions that inhibit the propagation of sound waves. Such conditions include strong winds and heavy snowfall or precipitation. Loud vehicles, such as trucks traveling in adjacent lanes, can give false readings. The nature of sound propagation limits the detector to short-range uses. Finally, some pulse ultrasonic sensors have difficulty measuring the lane occupancy of fast-moving vehicles (12).

**Figure 6 Ultrasonic Pulse Detector and Ultrasonic Passive Detector (4)**

**Passive Infrared - Active Infrared:** Quoc, et al. discussed types of infrared devices used for vehicle detection. "The first type, passive infrared sensors, detect the change in infrared energy emitted and reflected from detection zones. Passive infrared devices detect the presence of vehicles by comparing the infrared energy naturally emanating from the road surface with the change in energy caused by the presence of a vehicle. Since the roadway may generate either more or less radiation than a vehicle depending on the season, the contrast in heat energy is what is detected. The second type, active infrared sensors, emit low-energy laser beams to the target area on the pavement and measure the reflecting signal back to the sensors. Active infrared devices detect the presence of vehicles by emitting a low-energy laser beam(s) at the road surface and measuring the time for the reflected signal to return to the device. The presence of a vehicle is measured by the corresponding reduction in time for the signal return" (12). Figure 7 shows two examples of active infrared traffic detectors.

***Stated Capabilities:*** Passive infrared sensors can detect volume, presence, occupancy and speed in sensors with multiple detection zones. Active infrared sensors can detect volume, presence, density, classification and speed (12).

***Limitations:*** Active near-infrared laser sensors are generally limited to the same range in inclement weather as can be seen with the human eye (12).

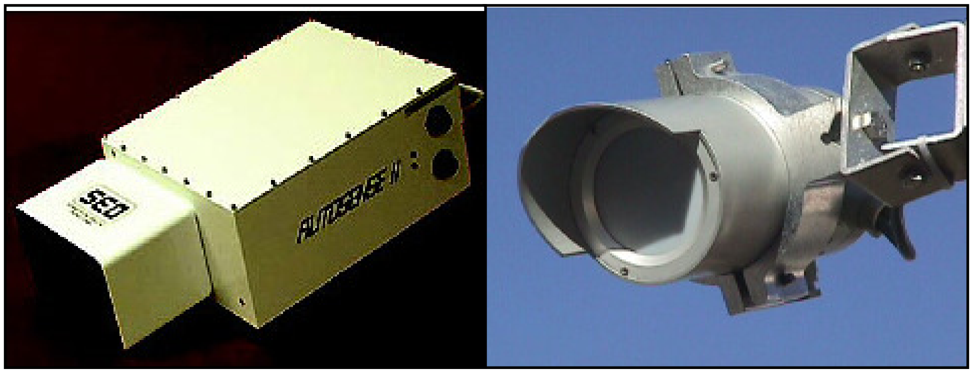


**Figure 7 Active Infrared Traffic Detectors (4)**

**Microwave**: Quoc, et al. also discussed microwave technology and stated that:

"Doppler microwave devices transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed. Radar devices use a pulsed, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar devices have the additional ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability. A third type of microwave detector, passive millimeter, operates at a shorter wavelength than other microwave devices. It detects the electromagnetic energy in the millimeter radiation frequencies from all objects in the target area" (12). Figure 8 shows two types of microwave technologies available in the market.

***Stated Capabilities:*** Doppler microwave sensors can detect volume and speed. Radar microwave sensors can detect volume, presence and speed (12).

***Limitations:*** Doppler microwave sensors can only detect vehicles moving faster than a certain minimum speed. Minimum speeds vary from sensor to sensor (12).

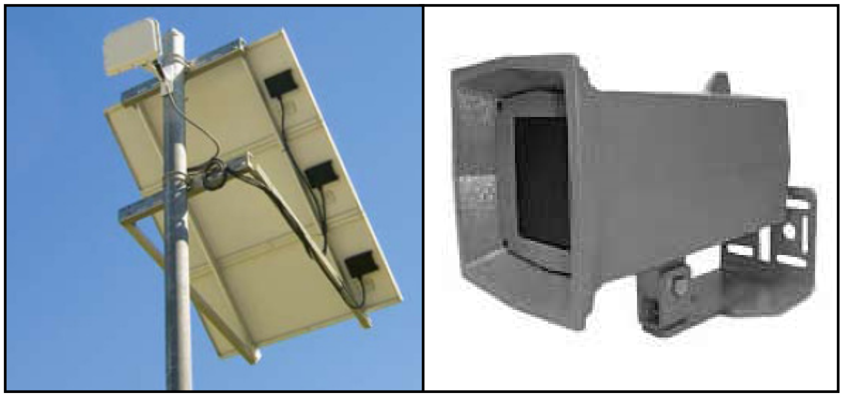


**Figure 8 Microwave Radar Detector (27) and Microwave Doppler Traffic Detector (4)**

**Video Image Detection:** Quoc, et al. also mentioned video image detection technology and stated:

“Video devices use a microprocessor to analyze the video image input from a video camera. Two basic analysis techniques are used: tripline and tracking. Tripline techniques monitor specific zones on the video image to detect the presence of a vehicle. Video tracking techniques employ algorithms to identify and track vehicles as they pass through the field of view. The video devices use one or both of these techniques” (12). Figure 9 shows the devices required for video image detection.

***Stated Capabilities:*** Video sensors can be used to collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, lane changes and classification (12).

***Limitations:*** Environmental conditions such as fog, rain, dust or snow in the air; frost, condensation or dirt on the camera lens; and adverse lighting conditions, such as headlight glare on wet pavement, low-angle sunlight, poor vehicle-road contrast and headlight reflection on curved roadways affect the video image quality which can reduce system performance. Proper setup and calibration is critical to achieving satisfactory performance in poor lighting conditions (12).

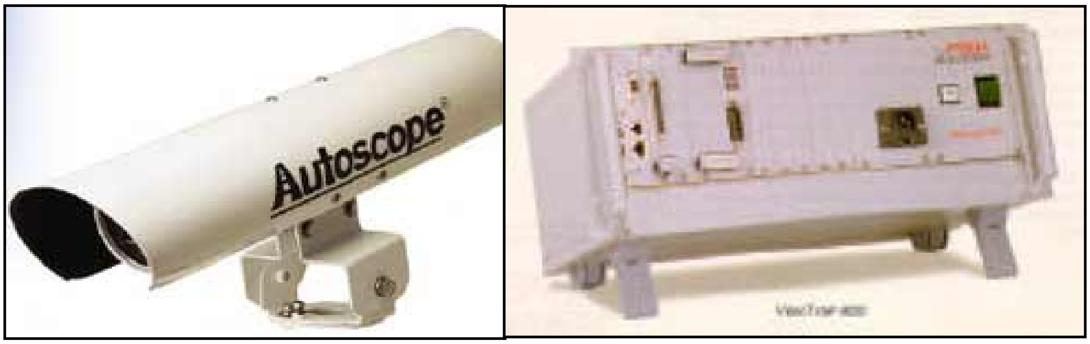


**Figure 9 Autoscope and Peek VideoTrak – 900 (4)**

**Combined Technologies**: Quoc, et al. encouraged combined technology and said that, by combining two or more technologies in a single detector, a wide range of optimized detectors for a large variety of applications becomes possible. The outcome of this technology is particularly useful in traffic data acquisition applications. Sensors that combine passive infrared detection with ultrasound or Doppler radar have been developed and are available in the market. The study mentioned that:

"The passive infrared-ultrasonic combination provides enhanced accuracy for presence and queue detection, vehicle counting, and height and distance discrimination. They detect all kinds of vehicles moving into or through their field of view. The passive infrared-Doppler radar sensor in designed for presence and queue detection, vehicle counting, speed measurement and length classification. The dual-passive infrared Doppler radar sensor relies on the radar to measure high to medium speeds and the passive infrared to measure vehicle count and presence. At medium speeds, the multiple detection zone passive infrared automatically calibrates its speed measurements against the radars. Their microprocessor controlled signal analysis combines the signals from both detector parts and gives accurate information on the presence of vehicles, objects and persons. This calibration permits the infrared to measure slow vehicle speeds and detect stopped vehicles" (12). Figure 10 shows examples of combined technology in the field of traffic detectors.

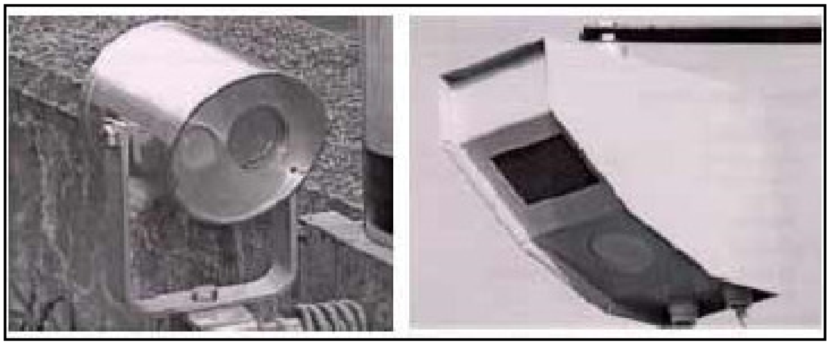


**Figure 10 Infrared Ultrasonic Sensor and Infrared- Doppler Radar Sensor (4)**

## 2.3 Off-Roadway Technologies

Martin, et al. in their study discussed off-roadway technology. The following section gives an overview on various off roadway technologies.

**Probe Vehicle:** Probe vehicle technologies meet particular ITS purposes, such as real-time operation monitoring, and incident detection and route guidance. They also collect real-time traffic data. Although probe vehicle systems require high implementation cost and fixed infrastructure, they offer advantages including low cost per unit of data, continuous data collection, automated data collection, and no disruption to traffic (4). Figure 11 shows a typical configuration for satellite-based probe vehicle system.

**Global Positioning System (GPS):** Probe vehicles are equipped with GPS receivers to pick up signals from earth-orbiting satellites. The positional information determined from the GPS signals is transmitted to a control center to display real-time position of probe vehicles (4).

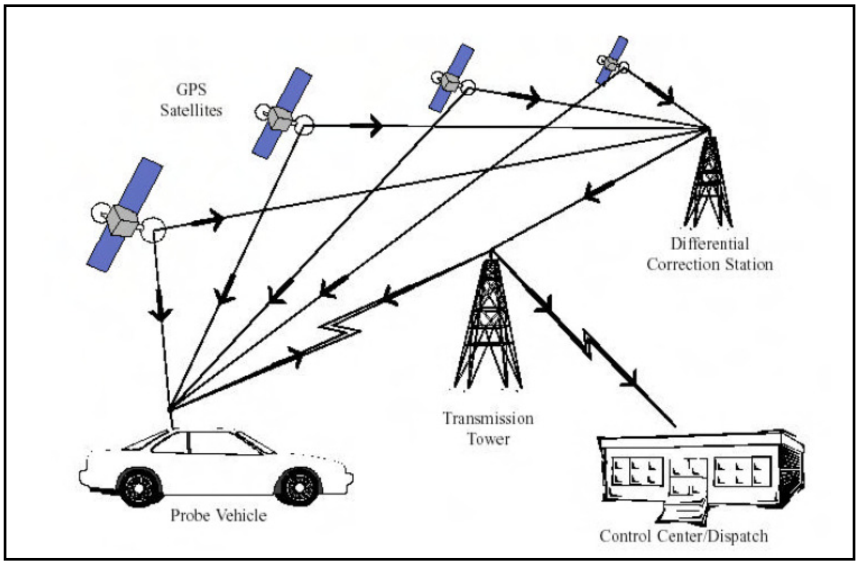


**Figure 11 Typical Configuration for Satellite-Based Probe Vehicle System (4)**

**Cellular Phone (e.g. CDMA, GSM, UMTS and GPRS networks):** The mobile phone positioning is regularly transmitted to the network usually by means of triangulation or by other techniques (e.g. handover) and then travel times and other data can be estimated over a series of road segments before being converted into useful information by traffic centers. Mobile phones need to be turned on, but not necessarily in use (4). Figure 12 shows communication using cellular geolocation.

**Automatic Vehicle Identification (AVI):** This technology requires probe vehicles equipped with electronic transponders, roadside antennae for detecting transponder presence, and roadside readers to bundle data. The vehicle equipment communicates with roadside transceivers to identify vehicles and collect travel times between transceivers. The antennae emit radio frequency signals within a capture range across one or more freeway lanes. The radio frequency capture range may be emitted constantly, or may be triggered by an upstream loop detector (i.e., toll plazas). When the probe vehicle enters the capture range, the radio signal is reflected off the electronic transponder. The coverage area of the AVI infrastructure restricts data collection capability (4). Figure 13 represents AVI Vehicle-to-Roadside communication process.

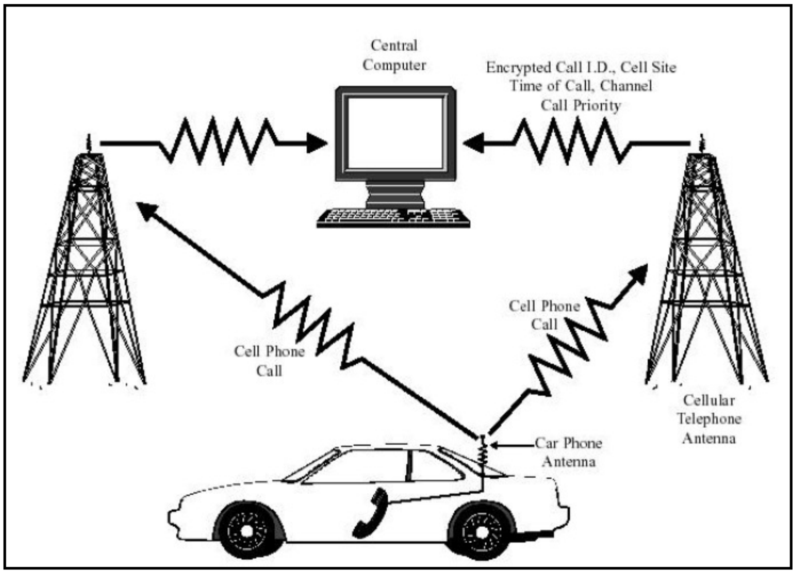


**Figure 12 Cellular Geolocation Communications (4)**

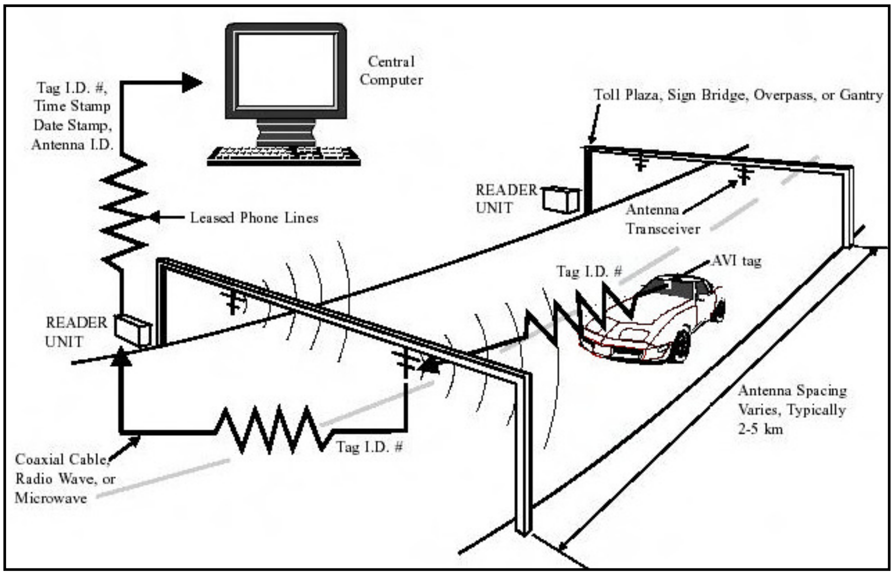


Figure 13 AVI Vehicle-to-Roadside Communication Process (4)

**Automatic Vehicle Location (AVL):** AVL primarily is used by transit agencies. The transit vehicles communicate with transmitters mounted on existing signpost structures and the system monitors the positions and status of transit vehicles.

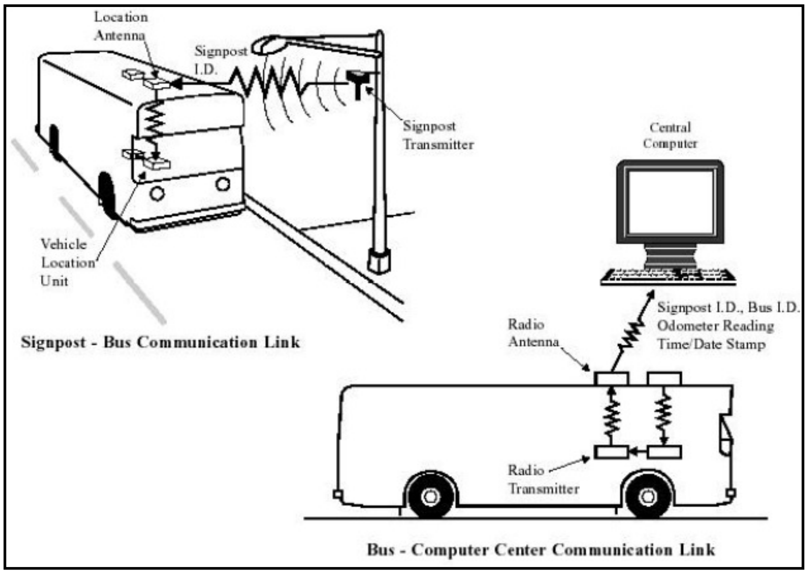


Figure 14 Signpost-Based AVL Communication Processes (4)

Vehicle probe technologies depend on consumer acceptance. The primary data collected by vehicle probe technologies is travel time. Other data include speed, crash, and origination destination flow (4). Figure 14 illustrates signpost-based AVL communication processes.

**Remote Sensing:** Researchers currently are studying the possibility of collecting traffic data by remote sensing technology. Remote sensing collects data about objects or landscape without direct physical contract. It is performed from aircraft or satellites. The high-resolution imagery is used to estimate annual average daily traffic (AADT) (4).

**Manual Counting Equipment:** Manual counting still is widely used for temporary data collection. However, it is limited due to safety, cost, and inclement weather. A counter board counts vehicles, radar gun and Lidar guns measures speed (1). The Lidar gun measures the time taken by a burst of infrared light to get to a vehicle, to get reflected and return back to the starting point. The Lidar system determines the distance from the object, by multiplying the speed of light by this time (13). Figure 15 shows both Lidar and Radar gun.

**Figure 15 Lidar Gun and Radar Gun (15)**

## 2.4 Comparison of Speed Measurement Devices

Several studies have compared various types of portable speed measurement devices for their data collection type, performance in variable traffic conditions, accuracies, ease in installation methods, cost effectiveness, data acquisition, portability and many other features.

In 2004, Gates, Schrock and Bonneson, performed a controlled field evaluation to determine the accuracy and precision of pneumatic tubes, piezoelectric tubes, tape switches, radar gun and Lidar gun at 35 and 55 mph. The speeds measured with each of these devices were compared with the speed of a test vehicle instrumented with a distance measuring instrument (DMI). They reported that a small yet statistically significant difference was found between these devices. However, the mean paired difference in speed did not exceed 0.6 mph. As a result none of the devices were considered inaccurate in a practical sense. The study reported that with the exception of Lidar and Radar, all devices became slightly less accurate and less precise at higher speeds. They also reported that inaccuracies observed in on-pavement equipment were likely caused by slight measurement errors made during placement of the sensors and movement of the sensors resulting from repeated tire hits (16).

A study conducted by the Minnesota Department of Transportation (Mn/DOT), Office of Traffic, Security & Operations and SRF consulting group in 2004, collected traffic data using a Portable Non-Intrusive Traffic Detection System (PNITDS). They tested three sensors, RTMS, SAS-1 and the Smartsensor. The goal of the study was to develop safe, accurate, simple and cost effective methods of collecting traffic data. They assessed performance in volume, speed and length-based vehicle classification data collection, various traffic levels, various mounting configurations and various weather conditions. Loop detectors configured in a speed trap configuration were used as a baseline for vehicle speed evaluation. The results indicated the Smartsensor provided accurate volume and speed results. The results showed that a sensor can accurately detect traffic in both free flow and heavy traffic levels. The overall volume detection error was between 1.0 percent to 5.0 percent, and the speed detection error was between 3.0 percent and 9.0 percent. For the RTMS sensor the overall volume error was between 2.4 percent and 8.6percent and the speed detection error was between 4.4percent to 9.0 percent. The volume error for the SAS-1 sensor was between 9.9 percent and 11.8 percent and speed error was between 5.6 percent to 6.8 percent (17).

Another study by the Mn/DOT and SRF Consulting conducted a two-year test of non-intrusive traffic detection technologies. This test, initiated by the Federal Highway Administration (FHWA), had a goal of evaluating non-intrusive detection technologies under a variety of conditions. The researchers tested 17 devices representing eight technologies. The test site was an urban freeway interchange in Minnesota that provided signalized intersection and freeway main lane test conditions. Inductive loops were used for baseline calibration. The test consisted of two phases, with Phase 1 running from November 1995 to January 1996 and Phase 2 running from February 1996 to January 1997 (18) - 20). A critical finding of this research was that mounting video detection devices is a more complex procedure than that required for other types of devices. Camera placement is crucial to the success and optimal performance of this detection device. Lighting variations were the most significant weather-related condition that impacted the video devices. Shadows from vehicles and other sources and transitions between day and night also impacted count accuracy (20).

Gerken and Guy conducted accuracy comparison of non-intrusive, automated traffic volume counting equipment. They compared the Automatic Traffic Data Recorder (ATDR) with an pneumatic road tubes, Smartsensor and Video Collection Unit (VCU). Tube data gave the baseline traffic counts. The study revealed that both tube data and Smartsensor performed with overall error of less than 4.0 percent. Given the reduced risk exposure to personnel, the flexible installation options and the high degree of accuracy, Smartsensor units provided a viable alternative to road tube installations. Also, Video Collection Units offer red an accurate alternative to traditional manual turning movement count technologies (21).

Middleton and Parker performed research in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation and FHWA, from February 1999 to August 2002 in which they evaluated vehicle detection systems. They reported that most vehicle detection today relies on inductive loop detectors. However, problems with installation and maintenance of these detectors have necessitated evaluation of alternative detection systems. The research included examination of the performance characteristics, reliability, and cost of video image detection, radar, Doppler microwave, passive acoustic, and a system based on inductive loops. Research results clearly indicated promising nonintrusive alternatives to loops, but they do have limitations. The research solicited information from a variety of agencies pertaining to installation and use of non-intrusive technologies and conducted field tests on a high volume freeway to determine their suitability for implementation. Count accuracies of 95 percent and speed accuracies within 5 mph of true values were common during free-flow conditions. During slower congested flow traffic, all non-intrusive device count accuracies degraded to the range of 70 to 90 percent, and most speed accuracies worsened as well – differing by 10 to 30 mph from the baseline system (22).

## 2.5 "State-of-the-Art" Non-Traditional Traffic Counting Methods

In 2001, the Arizona Department of Transportation (AZDOT) Traffic Counting Survey was conducted to ascertain the practices of State Departments of Transportation. All fifty states returned survey results. The question asked agencies to rate their level of satisfaction with each method for collecting traffic data. Responses were only to be given if the agency was actually using the equipment listed. The number and percent of states using each technology and the average level of satisfaction with each device is listed in Table 1.

**Table 1 Usage and Average Level of Satisfaction (23)**

| | **Inductive loop** | **Pneumatic rubber tube** | **Piezoelectric sensor** | **Manual observation** | **Bending plate** | **Radar** | **Video Image detection** | **Passive Acoustic** | **Passive Magnetic** |
|---|---|---|---|---|---|---|---|---|---|
| **No. of States Using Devices** | 50 | 49 | 47 | 41 | 25 | 17 | 5 | 4 | 4 |
| **Percent Usage** | 100 | 98 | 94 | 82 | 50 | 34 | 10 | 8 | 8 |
| **Level of Satisfaction** | 4.4 | 3.8 | 3.5 | 4 | 3.4 | 3.4 | 3.0 | 2.8 | 3.2 |

Participants were also asked to indicate what type of data they gather using each of the thirteen sensor technologies and approximate percent of results reported using each method. Forty-nine states reported results.

The study concluded that less than half of all State DOTs (24 out of 50) were using non-intrusive methods for gathering traffic data. This may be due to the lack of comparative data showing the accuracy of these new technologies as compared to standard road tubes, inductive loops, and piezo-electric sensors. Other factors contributing to the reluctance to convert to nonintrusive technology may be cost and the level of technical expertise required to operate the devices at the time of the study (23). Table 2 shows the method of data collection used by all the states.

**Table 2 Method of Data Collection (23)**

| | Number of States Responding | | | |
|---|---|---|---|---|
| **Sensor Technology** | **Count** | **Speed** | **Weight** | **Classification** |
| **Manual Observation** | 26 | 5 | 6 | 29 |
| **Bending Plate** | 15 | 11 | 23 | 20 |
| **Pneumatic Rubber Tube** | 47 | 20 | 4 | 43 |
| **Piezo-electric Sensor** | 28 | 23 | 29 | 40 |
| **Inductive Loop** | 47 | 32 | 14 | 24 |
| **Passive Magnetic** | 3 | 1 | 0 | 1 |
| **Radar** | 15 | 3 | 0 | 0 |
| **Passive Acoustic** | 4 | 1 | 0 | 0 |
| **Video Image Detection** | 2 | 1 | 1 | 4 |

## 2.6 Application of Various Traffic Detectors

There are several studies where these traffic detectors have been evaluated. The following are a few examples of studies where these devices have been used successfully.

**Pneumatic Tubes:** The FHWA conducted a study which evaluated the effectiveness on low cost traffic calming treatments in main rural highways passing through small, rural communities in Iowa. Speed and volume data were collected by a roadside traffic recorder using pneumatic road tubes placed across the road. Data were collected immediately downstream of each treatment or in the case of road narrowing near the midpoint of the section (24).

Nation Highway Traffic Safety Administration (NHTSA) conducted a study on Automated Speed Enforcement (ASE) in school zones in Portland, Oregon. The main aim of the study was to test the effectiveness of ASE in reducing speeds. In order to compare the speed distribution changes, traffic volume and speed data were used. Traffic volume and speeds were measured by means of pneumatic road tube traffic counters for at least 24 hours prior to, during, and following the ASE deployment program (22).

Another study conducted in Minnesota on "Long-Term Effectiveness of Dynamic Speed Monitoring Displays (DSMD) for Speed Management at Speed Limit Transitions" used pneumatic tubes for the baseline speed data to evaluate the effectiveness of DSMD (23).

**Lidar Guns:** The North Carolina Department of Transportation (NCDOT) conducted a study on evaluating the use of portable changeable message signs (PCMS) to regulate speed limit in an Interstate 95 work zone in Northampton County. A Lidar gun was used to collect the speed data in this study (27).

**Video Image Detection:** The Georgia Department of Transportation (GDOT) operates the Advanced Traffic Management System (ATMS) in the Atlanta area. The Atlanta system utilizes Video Image Detection System (VIDS) technology and provides GDOT with the ability to manage traffic along more than 60 miles of freeway. Flow of traffic is monitored along Interstates 75 and 85 through the middle of the Atlanta central business district and out to the surrounding suburbs. Small monochrome or color electronic cameras mounted on poles or bridges record traffic conditions for each section of the highway. More than 300 cameras feed real-time video images of traffic data to the traffic management center (TMC) via fiber optic cable (23).

**Microwave Radar:** The Utah Department of Transportation (UDOT) is deploying Smartsensor units at intersections throughout the state. More than 70 sensors have been purchased by UDOT as part of the agency's ongoing efforts to improve intersection safety and efficiency (24).

## 2.7 Speed Distribution Changes Due to Various Speed Monitoring and Control Devices

Teed and Lund (1991) studied the relative effectiveness of police radar and Lidar speed monitoring equipment in a brief field trial; the researchers used the same four locations, alternating use of Radar and Lidar speed guns over a two-week study period. They found that Lidar guns were significantly more effective in identifying speeding motorists (41 citations per 1,000 vehicles, compared to 33 per 1,000 for radar). Perhaps more important, it was found that speeders identified under the Lidar enforcement condition were four times more likely to have a radar detector in their vehicles than those ticketed under the radar condition. In fact, most of the additional speeders caught by the Lidar guns were using radar detectors, and those vehicles tended to be traveling at the most extreme speeds (30).

There are similar studies like the Teed and Lund study that have evaluated the effects of various speed control devices like speed cameras, photo radar, speed feedback trailers, rumble strips, police presence, changeable message signs, speed display boards, etc. For example, a few studies conducted at University of Illinois at Urbana Champaign, evaluated the effect of speed photo-radar enforcement in work zones (31); in another study they compared the effect on speed distribution due to the presence of automated speed enforcement and police (32). The effectiveness of portable changeable message signs in work zones was studied at University of Kansas (33). All these studies report that installations of these devices have significantly reduced mean speeds and percent exceeding the speed limit in the locations they have been implemented. However, no study was found that has compared the speed distribution changes due to the presence of intrusive or non-intrusive traffic detectors. Thus, in this study changes in speed distribution due to the presence of video image detection, microwave radar and a Lidar gun will be studied with pneumatic tubes proving baseline readings.

# CHAPTER 3 – METHODOLOGY

The next step in this research was to develop a method of studying various speed measurement devices and determine the ease of installation, the cost effectiveness and most importantly the variation in speed distribution due to their presence.

The chapter is broken into three sections. The first section will discuss test site selection and criteria on which they are selected. The second section will discuss test conditions required and the third section will discuss the devices that were tested.

## 3.1 Test Site Selection and Criteria

The location of a study should be chosen carefully so that recorded speeds reflect how vehicles typically travel along unimpeded sections of the road under free flow conditions. Three similar sites were required for data collection. Also, to get free flowing traffic and avoid any change in lanes by the drivers, two-lane rural highways were used for this study.

Test sites were selected which met the following criteria:

- All sites were two-lane rural highways
- Speed limits at all three sites were 65 mph
- Volumes in all sites were similar
- All three sites were away from
    - Traffic signals and other intersections
    - Work zones
    - Curves
    - Parking zones
    - Active crosswalks
- All three sites were reasonably flat (0 percent slope)

- All three sites had shoulders
- All sites had reasonably flat side slopes

The three test sites selected were:

A. U.S. 59, south of Oskaloosa, between 62nd and 70th Street

B. U.S. 24 between west of the U.S. 24 and U.S. 59 intersection and mile post 385

C. U.S. 24/40, near the Lawrence airport, between E 1500 W Road to E 1500 W Road

Figure 16, 17, 18 and 19 show locations of three test sites used for the data collection.

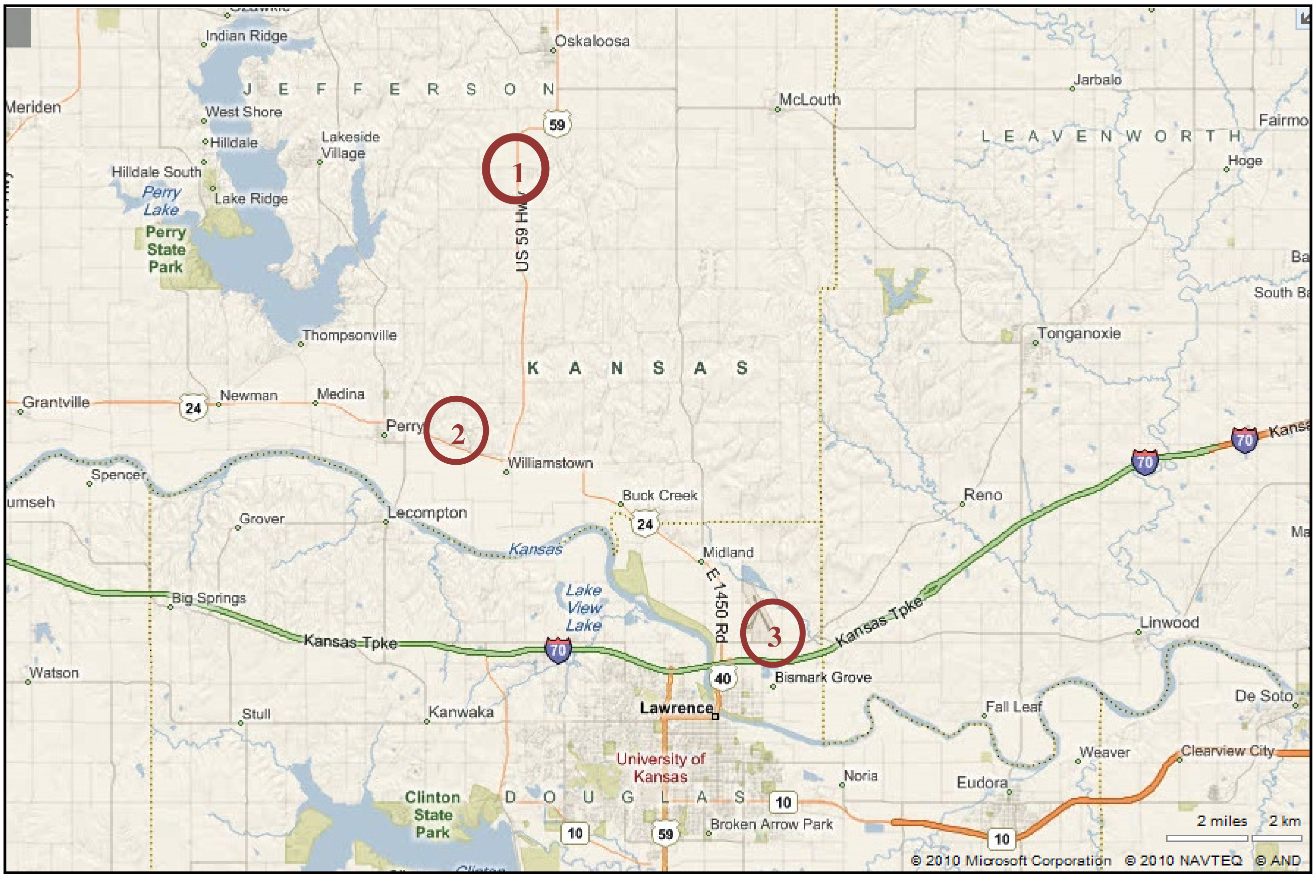


**Figure 16 Three Test Sites**

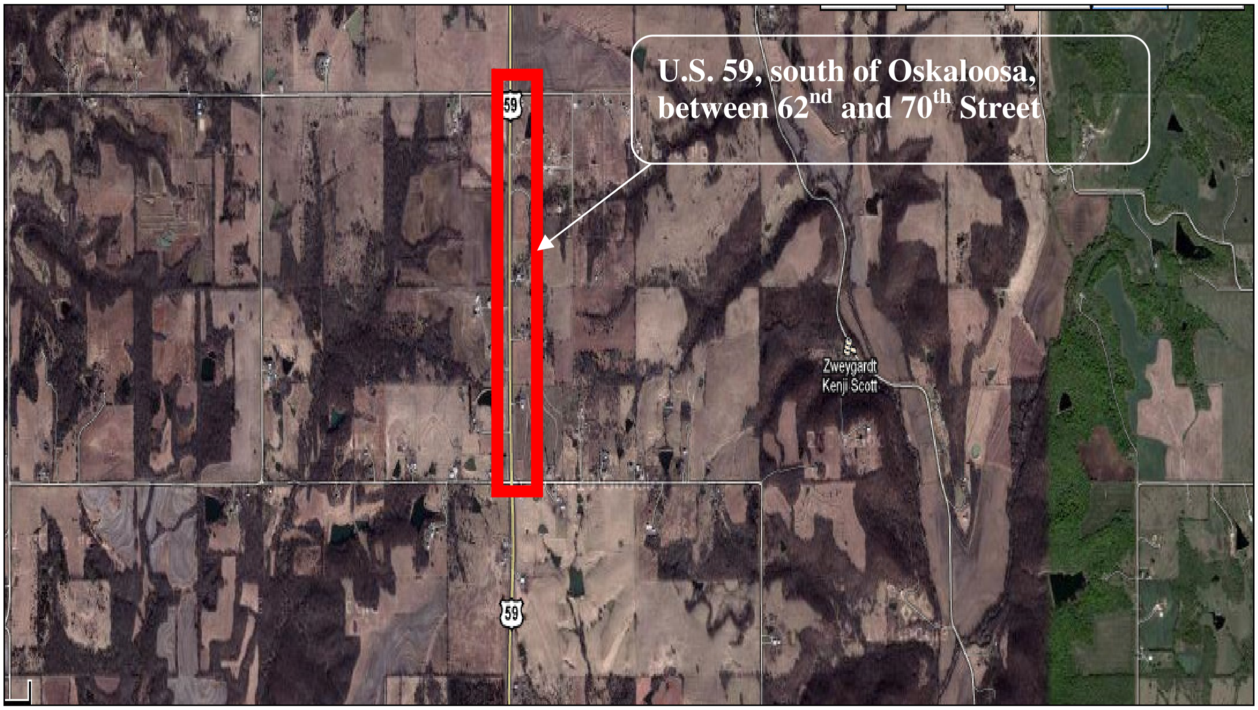


Figure 17 U.S. 59, South of Oskaloosa Between 62nd and 70th Street

Figure 18 U.S. 24 Between West of U.S. 24 and U.S.59 Intersection and Mile Post 385

U.S. 24/40, near the Lawrence airport, between E 1500 W Road to E 1500 W Road

**Figure 19 U.S. 24/40, Near the Lawrence Airport, Between E 1500 W Road to E 1500 Road**

## 3.2 Test Conditions

The data collection methodology required several considerations:

- Traffic Speed: A vehicle's speed should not be impacted by the speed of a preceding vehicle. To avoid this, the minimum gap between two vehicles used in the analysis should be more than 4 seconds.
- Time (consistent with free flowing traffic): Traffic speed tends to fluctuate during various times of day. Congestion during peak hours may significantly reduce the overall vehicular speed of the facility. In order to achieve free flowing traffic; peak traffic hours should be avoided.
- Day: Typical weekdays are preferred, including Tuesday, Wednesday, and Thursday.
- Unusual Conditions: Unique events, such as inclement weather or holidays should be avoided.

## 3.3 Devices to be Tested

Four different types of technologies of traffic detectors were tested in this study to compare the speed distribution changes due to their presence on or off roads.

- Pneumatic road tubes connected to automated vehicle classifier (9 units)
- Lidar gun (one unit)
- Autoscope, video image detection technology and camera mounted on a trailer (one unit)
- Smartsensor Digital Radar, mounted on a sign post (one unit)

The criteria used to select detectors for use were availability, demonstrated capability, compatibility with controllers in place at the field test locations and devices representative of current technology at the time if this research.

# CHAPTER 4 – DATA COLLECTION

To evaluate the affect on speed distribution due to various portable speed measurement devices, speeds were collected using four different speed measurement devices. Data were collected at three sites for five weeks. Due to the limited number of devices and in order to efficiently utilize the time in one particular week, three different devices were used at all three different sites.

While recording the speeds by various devices, it was very important to know, what was the speed of the drivers before they saw the test device or the base speed. Base speed was measured using pneumatic tubes. Pneumatic tubes were placed upstream and downstream of the test sites with the test site in between, as shown in Figure 20 and 21. The distance between the tubes and devices were such that drivers couldn't see the device installed at test location when they crossed the tubes. Further, for the analysis it was very important to consider the effect of pneumatic tubes as well. Therefore, for the first two weeks only pneumatic tubes were installed at upstream, test and downstream locations.

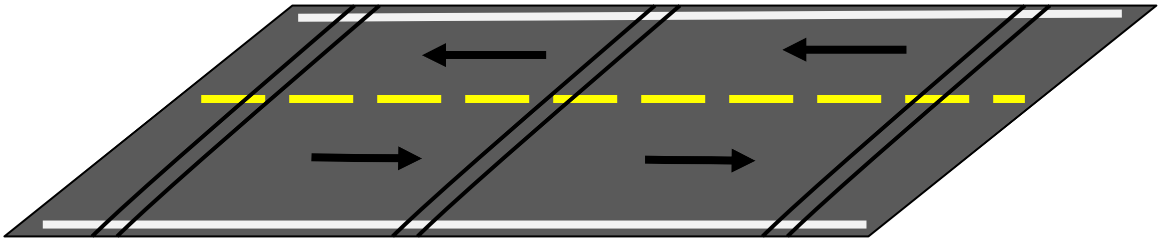


**Figure 20 Pneumatic Tubes at Upstream, Test and Downstream Locations**

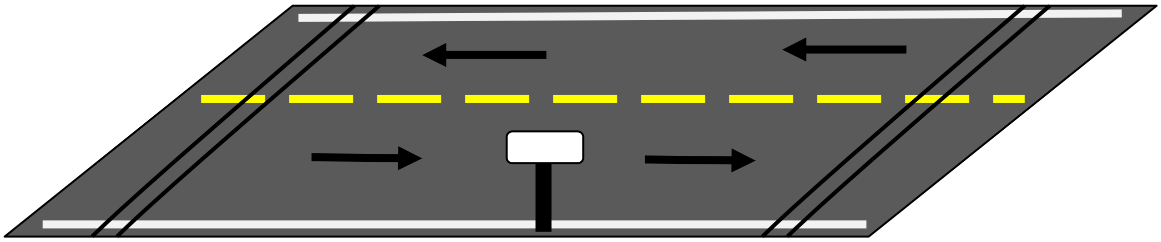


**Figure 21 Pneumatic Tubes at Upstream and Downstream Locations and Device at the Test Location**

Devices were installed on the three sites on May 18, 2010 and were at the sites until June 24, 2010. Data were collected only on Tuesdays, Wednesdays and Thursdays. In order to get free-flowing traffic, data were collected between 10:00 a.m. to 3:00 p.m. and only the clear day data were used. Table 3 shows the data collection schedule.

**Table 3 Data Collection Schedule**

| | Week 1 (May 18- May 20) | Week 2 (May 25- May 27) | Week 3(June 1 - June 3) | Week 4 (June 8 - June 10) | Week 5 (June 15 - June 17) | Week 6 (June 22 - June 24 |
|---|---|---|---|---|---|---|
| **Site 1 ( US 59)** | Pneumatic Tube | Pneumatic Tube | Autoscope | Lidar Gun | Smartsensor | Pneumatic Tube |
| **Site 2 ( US 24)** | Pneumatic Tube | Pneumatic Tube | Smartsensor | Autoscope | Lidar Gun | XXX |
| **Site 3 (US24/40)** | Pneumatic Tube | Pneumatic Tube | Lidar Gun | Smartsensor | Autoscope | XXX |

XXX- Data not collected

Three data sets were collected at three different sites. Each site had three different locations. Site 1 was at US 59, South of Oskaloosa, between 62nd street and 70th street. Site 2 was at US 24, between west of US 59 and US 24 intersection and mile post 385. Site 3 was at US24/40, near the Lawrence Airport, between E 1500 road and E 1600 road. Three locations at each site were named as upstream, test and downstream. Upstream was the location where the vehicle first entered the site and downstream being the end location of the site. Table 4 gives distances between upstream, test and downstream locations.

**Table 4 Distance Between Upstream, Test and Middle Locations**

| Site | Distance Between Upstream and Test Locations | Distance Between Test and Downstream Locations |
|---|---|---|
| 1 | 1785 ft | 1760 ft |
| 2 | 4746 ft | 3254 ft |
| 3 | 7590 ft | 2513 ft |

The length of each site varied based on the availability of sign posts to which the devices were attached, slopes on the roadside where the devices were placed and driveways from where the Lidar gun data were collected.

***Data Collection Using Pneumatic Tubes:*** Throughout the data collection pneumatic tubes were always present at the upstream and downstream locations. In order to compare them with other devices they were also laid at the test locations for two weeks. Pneumatic tubes are intrusive portable speed measurement devices; therefore the data collection crew had to enter the road to install them. To install the pneumatic tubes at least two people were required. Once the location was decided, a pair of tubes were laid across the road at an approximate distance of two feet. The tubes were first nailed at one end and then were straightened and pulled from another end tightly. While one person was holding the tube end tightly another person entered the road and taped the tubes to the pavement using bitumen tape as shown in Figure 22. Once the tubes were laid properly, the another end was attached to the automatic traffic counter as shown in Figure 23. The counter was then setup for the data collection and locked and chained to a fixed object to prevent it from getting stolen or vandalized.

**Figure 22 Bitumen tape**

An example of pneumatic tubes laid on the road are shown in Figure 24. Once the setup was complete the device started collecting the data. Pneumatic tubes were replaced if any cuts or cracks were found on the tubes or if the automated vehicle classifier was not recording data.

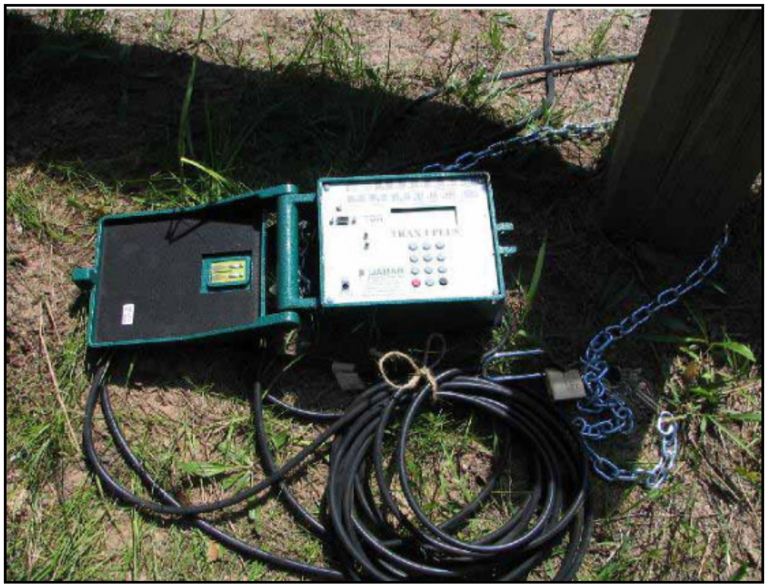


Figure 23 Automated Traffic Counter

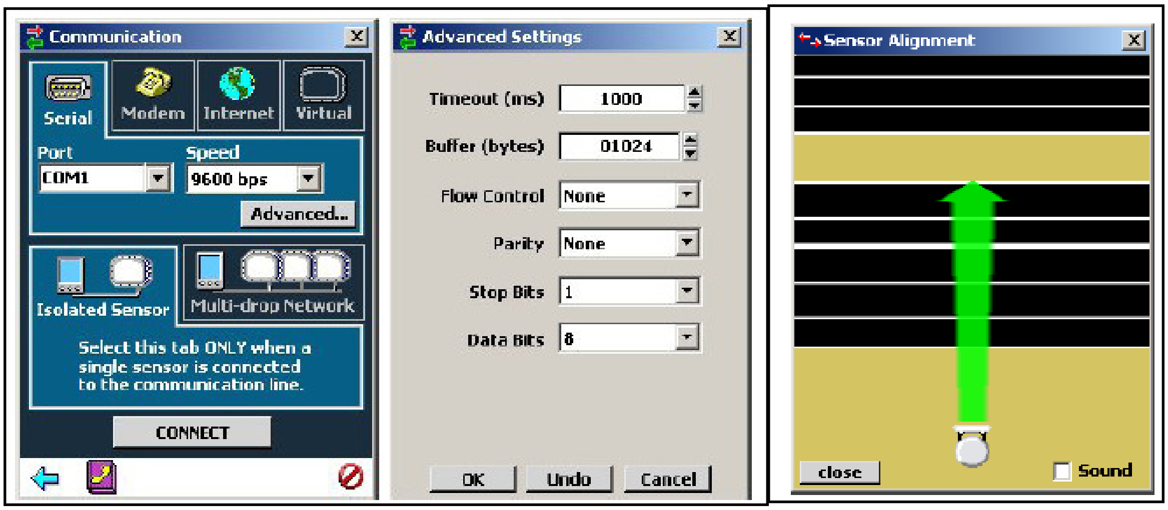
Figure 24 Pneumatic Tubes Laid on Road

***Data Collection using Smartsensor:*** The Smartsensor is a non-intrusive device; therefore the crew could setup the device without disrupting the traffic. The Smartsensor system is an assembly which looks like a white box, shown in Figure 25, battery cabinet, and bracket to hold the device and stainless steel hose clamp as shown in Figure 26. The device was first attached to a fixed object using the bracket and hose clamp such that it was facing perpendicular to the traffic flow as shown in Figure 29. If the distance from the first detection lane was between six feet and eleven feet, the device was mounted at a minimum mounting height of nine feet. The placement height of the device depended on the offset from the first detection lane. In this study the device was installed approximately six feet away from the lane.

**Figure 25 Smartsensor Device** **Figure 26 Stainless Steel Hose Clamp**

**Figure 27 Smartsensor Setup**

The power/communication cable attached to the battery cabinet was then connected to the Smarsonsor. The cable was secured to the pole with minimum slack to avoid undue movement from the wind. To confirm the configuration of the lanes in the Smartsensor, the connection was formed with the laptop using a serial cable. Once the connection was established the sensor alignment was oriented as shown in Figure 28 and the device was ready to collect the data. The Smartsensor unit was checked twice daily for the battery backup. To save the battery, the device was switched on and off daily. Figure 29 shows the Smartsensor installed on a signpost with the cabinet at the base of the post.



Port: COM1

Speed: 9600 bps

Select this tab ONLY when a single sensor is connected to the communication line.

Timeout (ms): 1000

Buffer (bytes): 01024

Flow Control: None

Parity: None

Stop Bits: 1

Data Bits: 8

**Figure 28 Smartsensor Communication Setup and Sensor Alignment**

**Figure 29 Smartsensor Installed on Signpost with the Cabinet at the Base of the Post**

***Data Collection using Autoscope:*** The Autoscope - like the Smartsensor - is a non-intrusive portable speed measurement device. Installation of this device takes about two to three hours. The Autoscope system works with a camera, set of batteries, recorder, hard disk, mini television as shown in Figure 30 and a trailer with cabinet as shown in Figure 31. The trailer was located between 30 and 50 feet from the road.

**Figure 30 Battery, Recorder, Hard Disk and TV Setup for the Autoscope System**

**Figure 31 Trailer with Cabinet for the Autoscope System**

The camera was mounted on the post attached to the trailer and raised to a desirable height. The mini television set inside the cabinet was connected to the camera. The height of the camera was adjusted such that it focused on the lanes and covered all the passing vehicles. The mini television set inside the cabinet helped locate the proper orientation of the camera. Once the camera was set, the recorder, hard disk and batteries were connected to it to record and store the video. In order to make sure that data were collected continuously, the battery and hard disk were checked twice daily. To save the battery the devices were switched on and off daily. Figure 32 shows trailer with the camera mounted on it.

**Figure 32 Autoscope System with Camera Trailer**

***Data Collection using Lidar gun:*** Data collection using the Lidar gun was a manual process. A red Ford Focus was used for the data collection. The car was parked approximately 30 to 40 feet from the road as shown in Figures 33 and 34. A crew of two people performed the data collection. One person operated the Lidar gun and another person noted speed and time of the vehicle passing. The vehicles were captured only after they had crossed upstream location. The Lidar guns were charged every day.

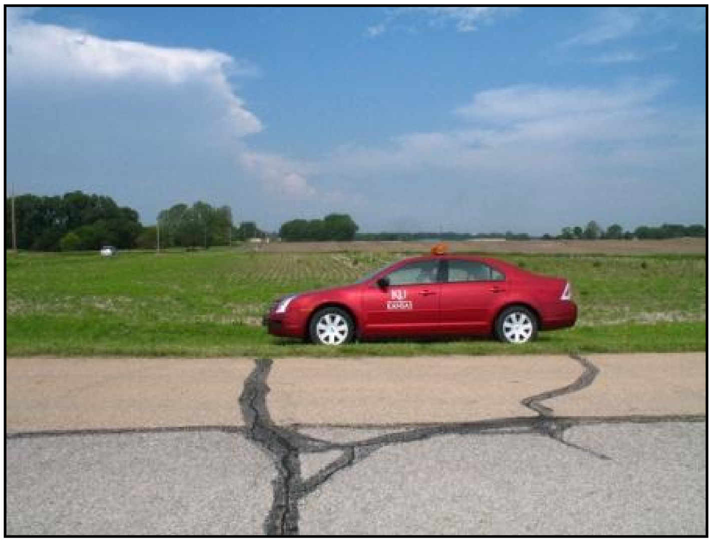
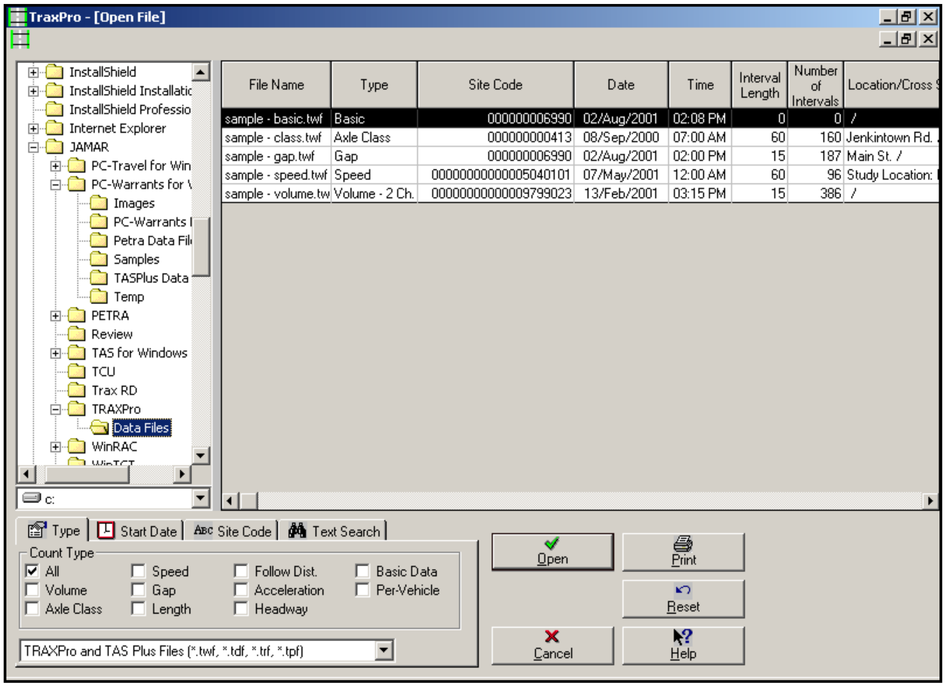


**Figure 33 Car Parked Perpendicular to the Road for Lidar Gun Data Collection**

**Figure 34 Approximately 30 to 40 Feet from the Road for Lidar Gun Data Collection**

Once the data collection was complete, data were then extracted in the office. Pneumatic tube data were extracted using the TRAXPro software, as shown in Figure 35. Each unit was connected to the computer and data were then extracted using the software. Smartsensor data were extracted using IQ Smartsensor Manager, as shown in Figure 36. The device was connected to the battery cabinet and the computer and the data were extracted using the software. For the Autoscope data extraction, the device captures the video and to obtain speed from the video, the video player, TV, computer and Autoscope rack vision are attached to each other and a connection with the communication server is established. Further, for every site, a separate calibration was required. Figure 37 shows how the calibration was done in the software. Once the calibration was done, speed and count detectors were edited and the speeds and counts were extracted. Because the Lidar gun data collection was a manual procedure, the speed and time data were noted on a note pad in the field, requiring no extraction later.



| File Name | Type | Site Code | Date | Time | Interval Length | Number of Intervals | Location/Cross |
|---|---|---|---|---|---|---|---|
| sample - basic.twf | Basic | 000000006990 | 02/Aug/2001 | 02:08 PM | 0 | 0 | / |
| sample - class.twf | Axle Class | 000000000413 | 08/Sep/2000 | 07:00 AM | 60 | 160 | Jenkintown Rd. |
| sample - gap.twf | Gap | 000000006990 | 02/Aug/2001 | 02:00 PM | 15 | 187 | Main St. / |
| sample - speed.twf | Speed | 00000000000005040101 | 07/May/2001 | 12:00 AM | 60 | 96 | Study Location: |
| sample - volume.tw | Volume - 2 Ch. | 00000000000009799023 | 13/Feb/2001 | 03:15 PM | 15 | 386 | / |

Count Type
☑ All ☐ Speed ☐ Follow Dist. ☐ Basic Data
☐ Volume ☐ Gap ☐ Acceleration ☐ Per-Vehicle
☐ Axle Class ☐ Length ☐ Headway

TRAXPro and TAS Plus Files (*.twf, *.tdf, *.trf, *.tpf)

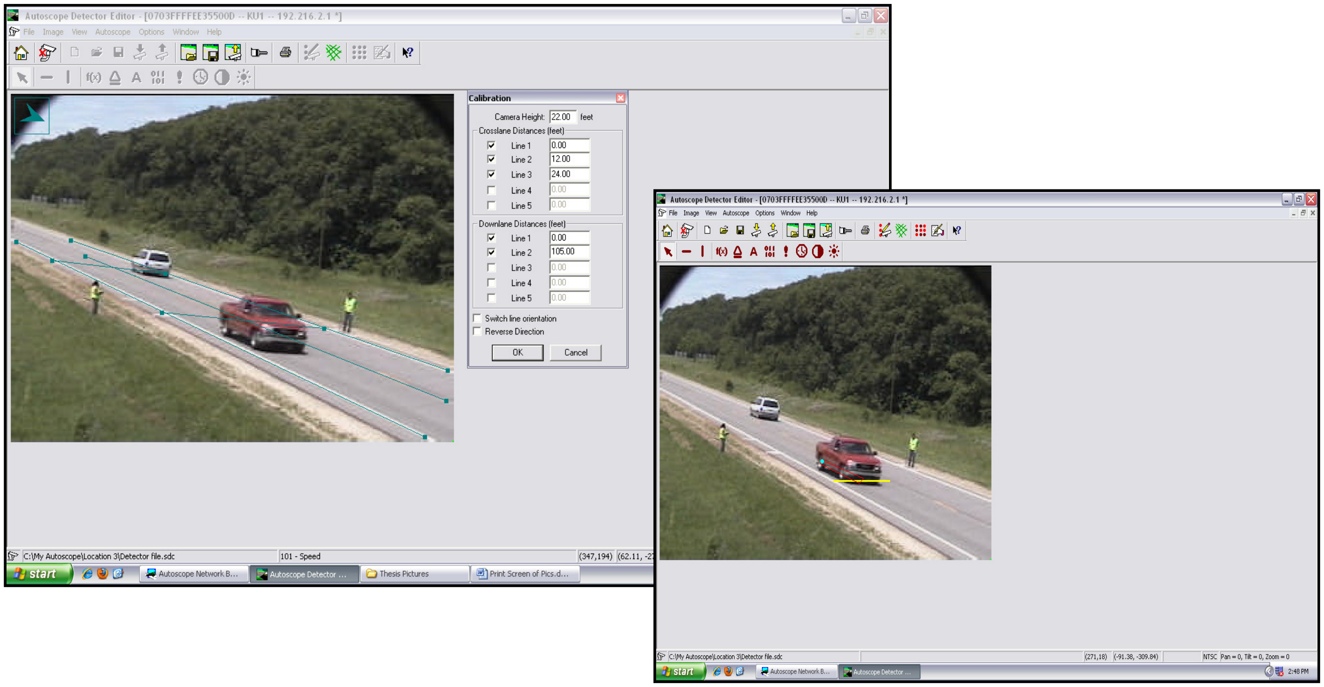
**Figure 35 Data Extraction from Automated Vehicle Classifier Using TRAXPro Software**

1. Sensor Alignment (verify and adjust sensor alignment)

2. Lane Configuration (view the automatic lane configuration and edit the saved lane configuration)

3. Lane Verification (verify lane detection accuracy using sidebar data displays of volume, speed, class, and presence; use adjustment tool to tweak lane performance)

Figure 36 Data Extraction from Smartsensor Using IQ Smartsensor



Calibration

Camera Height: 22.00 feet

Crosslane Distances (feet)

☑ Line 1 0.00
☑ Line 2 12.00
☑ Line 3 24.00
☐ Line 4 0.00
☐ Line 5 0.00

Downlane Distances (feet)

☑ Line 1 0.00
☑ Line 2 105.00
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

☐ Switch line orientation
☐ Reverse Direction

Figure 37 Data Extraction from Autoscope Using Autoscope Software

## 4.1 Data Discrepancy

Once data were extracted, it was formatted and was carefully observed. It was found that data extracted from various devices had discrepancies.

As pneumatic tubes are laid on the pavement, cracks and cuts were found almost every day, because of which the data were not continuous and were missing at certain times. It was also observed that a few counters displayed either very high values or very low values without any specific reasons. Some counters captured vehicles but all the other details displayed were zero. Also, one of the counters when brought back to the office for the data extraction did not display any data even though it collected data at the location, this was due to some counter computer failure. Because of these reasons, a large portion of the data could not be used.

The Autoscope system even after being switched on, sometimes stopped on its own and did not capture any video.

The Smartsensor system did not display speeds of individual vehicles; rather it displayed the average speeds of vehicles passing every 10 seconds. Therefore, due to the unsuitable format lot of data had to be deleted. Whenever in a 10-second time frame, zero, two or more than two vehicles were present, that data were deleted. The only Smartsensor data used for the study were the ones when only single vehicles were present in a given 10 second time frame.

The Lidar gun data were collected manually, therefore not every vehicle could be captured. Therefore some data were lost even while using the Lidar gun as well.

After carefully studying all the data, it was decided that due to the inconsistency, data from Sites 1 and 3 were not used and data from Site 2 only was used for the analysis. Table 5 indicates the data that could and could not be used for the analysis.

**Table 5 Data collection Schedule with Record of Unsuitable Data**

| | Week 1 (May 18-May 20) | Week 2 (May 25-May 27) | Week 3(June 1 - June 3) | Week 4 (June 8 - June 10) | Week 5 (June 15 - June 17) | Week 6 (June 22 - June 24 |
|---|---|---|---|---|---|---|
| **Site 1 ( US 59)** | Pneumatic Tube * | Pneumatic Tube * | Autoscope * | Lidar Gun* | Smartsensor* | Pneumatic Tube* |
| **Site 2 ( US 24)** | Pneumatic Tube | Pneumatic Tube* | Smartsensor | Autoscope | Lidar Gun | XXX |
| **Site 3 (US24/40)** | Pneumatic Tube* | Pneumatic Tube* | Lidar Gun* | Smartsensor* | Autoscope* | XXX |

*- Unsuitable Data
XXX- Data not collected

# CHAPTER 5 – DATA ANALYSIS

The review of literature shows that most of the researchers have used the average speed and percent exceeding the speed limit to study the effect on speeds. Independent sample t-tests were performed on the speed data with confidence intervals (CI) of 95 percent. The upstream, test site data and downstream data of each week with each other and all the upstream test and downstream data were compared with each other.

The posted speed limit at all three locations was 65 mph, and the observed average speed for all five weeks at the upstream location was between 57.5 mph to 59 mph. Upstream location data for all five weeks at Site 2 is presented in Figure 38. As mentioned in previous chapters, none of the locations were close to any intersections, work zones, curves, parking zones or crosswalks, therefore, there was no apparent reason why drivers would reduce their speed. It was assumed that there was an error in the counter, because it consistently displayed reduced speeds. To confirm this, upstream pneumatic tubes speeds were compared with the test pneumatic tube locations. The test location data displayed average speeds that were more realistic and close to the posted speed. To adjust this error the average upstream pneumatic tube speed was subtracted from average test pneumatic tube speed of the first week. The difference found was 9 mph, this factor was added to all the upstream location average speeds. For example, the average speed in the first week at upstream location was 57.6 mph and average speed in the first week at test location was 66.6 mph. Both the speeds were subtracted and a difference of 9 mph was found. This 9 mph difference was then added to the recorded upstream average speed (57.6 mph) and the new upstream average speed of 66.6 mph was found. The adjusted upstream pneumatic tube speeds for all five weeks were used for the further analysis. Figure 39 shows the adjusted speed values.

As pneumatic tubes installed at the upstream location were used as a device to collect the base data, it was important to observe drivers behavior over five weeks at this location. Also, the comparison of the upstream and test speeds when pneumatic tubes were installed at both the locations was important. Consistent speeds would strengthen the assumption that drivers react similarly while crossing pneumatic tubes and the comparison of the Smartsensor, Autoscope and Lidar gun data with pneumatic tubes data would be from similar and not random speeds.

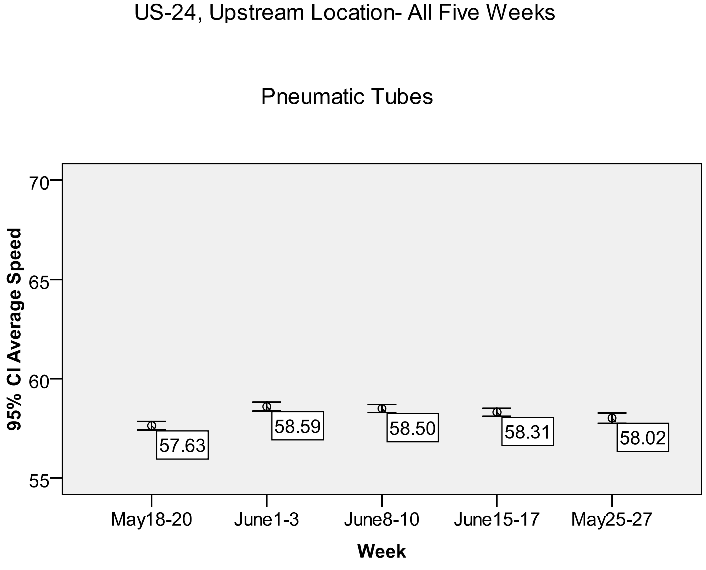


**Figure 39 Upstream Average Speeds, Pneumatic Tubes for All Five Weeks with Error**

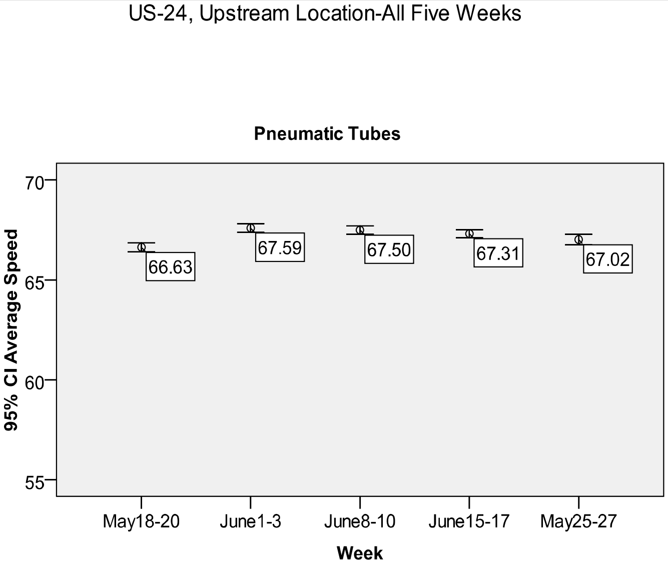


**Figure 38 Upstream Average Speeds-Pneumatic Tubes for All Five Weeks with Adjusted Speeds**

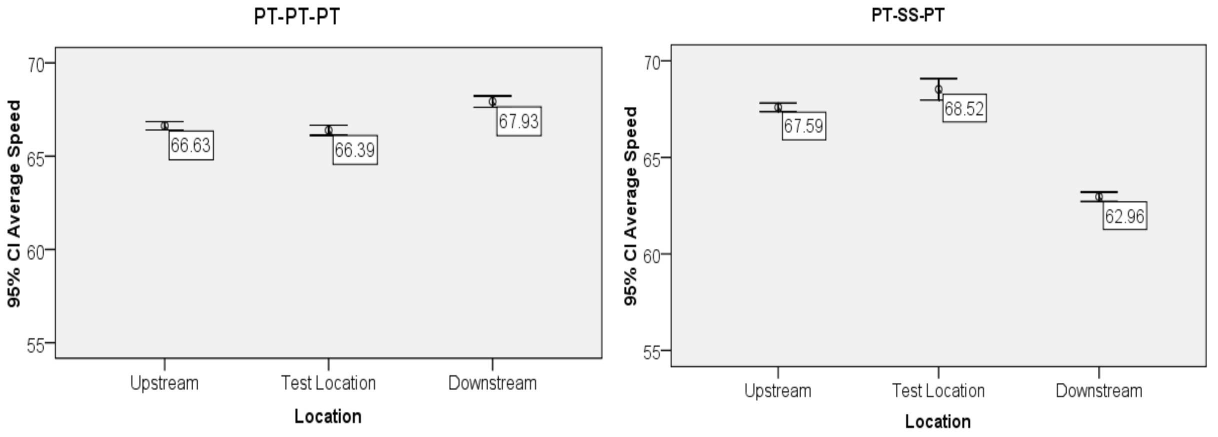
Upstream, test and downstream locations were compared with each other on a weekly basis using independent sample t-tests, with the confidence interval of 95 percent. Table 6 summarizes the average values, standard deviation, variances and total number of samples for each location for all five weeks.

**Table 6 Average Speeds at All Locations for Five Week at Site 2**

| Week | Date | Location | Device | Average | Std Deviation | Variance | N |
|---|---|---|---|---|---|---|---|
| Week 1 | May18-May20 | Upstream | Pneumatic Tube | 66.63 | 4.76 | 22.66 | 1754 |
| | | Test | Pneumatic Tube | 66.39 | 5.62 | 31.56 | 1635 |
| | | Downstream | Pneumatic Tube | 67.93 | 6.16 | 38.00 | 1585 |
| Week 2 | June1-June3 | Upstream | Pneumatic Tube | 67.59 | 4.73 | 22.37 | 1741 |
| | | Test | Smartsensor | 68.52 | 8.67 | 75.13 | 940 |
| | | Downstream | Pneumatic Tube | 62.96 | 4.97 | 24.74 | 1605 |
| Week 3 | June8-June10 | Upstream | Pneumatic Tube | 67.50 | 4.60 | 21.14 | 1865 |
| | | Test | Autoscope | 60.33 | 5.96 | 35.54 | 1422 |
| | | Downstream | Pneumatic Tube | 67.09 | 6.16 | 37.93 | 1482 |
| Week 4 | June15-June17 | Upstream | Pneumatic Tube | 67.31 | 4.29 | 18.37 | 1711 |
| | | Test | Lidar Gun | 59.55 | 5.16 | 26.64 | 1200 |
| | | Downstream | Pneumatic Tube | 72.97 | 6.61 | 43.75 | 1309 |
| Week 5 | June25-June27 | Upstream | Pneumatic Tube | 67.02 | 4.72 | 22.31 | 1254 |
| | | Test | Pneumatic Tube | * | * | * | * |
| | | Downstream | Pneumatic Tube | 66.69 | 6.49 | 42.18 | 1369 |

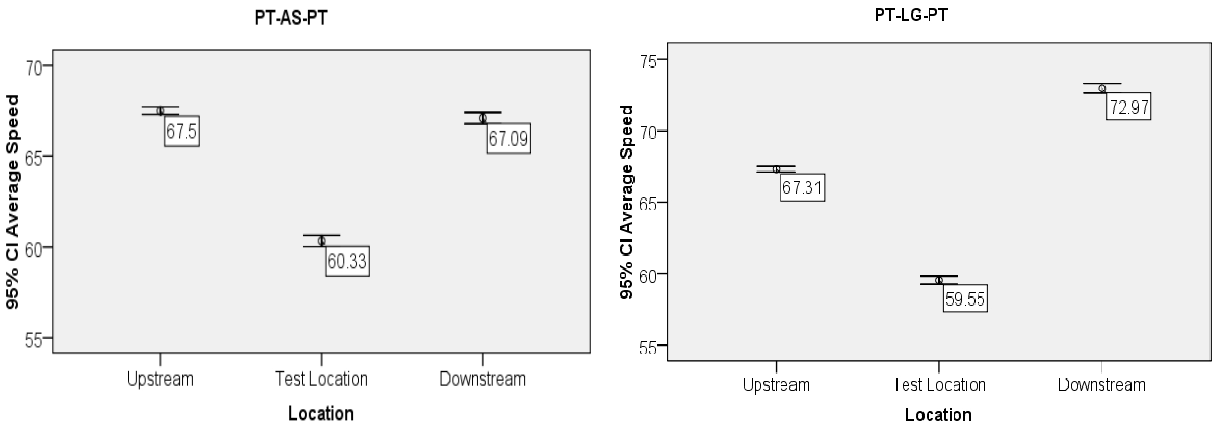
* –Data Missing

Figure 40 shows the comparison of average speeds at the upstream, test and downstream locations for each week. In Figure 40 (a), when pneumatic tubes were installed at all three locations. The P-value when upstream and test locations were compared was greater than 0.05 and equals 0.180. Therefore, there was no significant difference in average speeds between the upstream and test locations. There was approximately a 1.5 mph increase in average speed at the downstream location and the difference was significant.



(a) US-24, May 18-20, Week 1

(b) US-24, June 1-3, Week 2



(c) US-24, June 8-10, Week 3

(d) US-24, June 15-17, Week 4

**Legend:**

PT: Pneumatic Tube
SS: Smartsensor
AS: Autoscope
LG: Lidar Gun

**Figure 40 Effect on Average Speed Distribution Due to the Presence of Various Devices**

In the second week, Figure 40(b) when the Smartsensor system was installed at the test location, drivers at the test location increased their speeds by almost 1 mph and then reduced to 5.5 mph by the downstream location. The P-values indicated significant difference in speeds when upstream with test location and downstream with test location were compared. This is possibly because the size of Smartsensor is small and drivers did not notice it until they came close to it and by the time they realized they had crossed the test location and were almost at the downstream location.

In the third week, the Autoscope with trailer was installed approximately 35 feet from the road side. Both the trailer and the camera were visible from a distance, and a drop in speeds at the test location was observed, as shown in Figure 40 (c). Drivers reduced speeds by about 7 mph. But once they had crossed the test location they regained their speeds. P-values were less than 0.05 therefore it was concluded that there was significant difference in speeds.

In the fourth week the Lidar gun was used to measure speeds. A significant drop of approximately 8 mph was observed at the test location. Just like previous week, drivers increased their speeds downstream after crossing the test location, as shown in Figure 40 (d). The P-values again indicated significant difference in speeds. The data collection crew was about 30 to 40 feet away from the road in a red Ford Focus. At first this might have given drivers an impression of police presence, and they reduced their speeds, but, after passing the test location, they must have realized that there were no police present.

Figure 41 presents the summary of difference in average speed distributions. Considering average speed at the upstream location as the base speed, the differences in average speeds at the test and downstream locations when compared to the upstream location were determined.

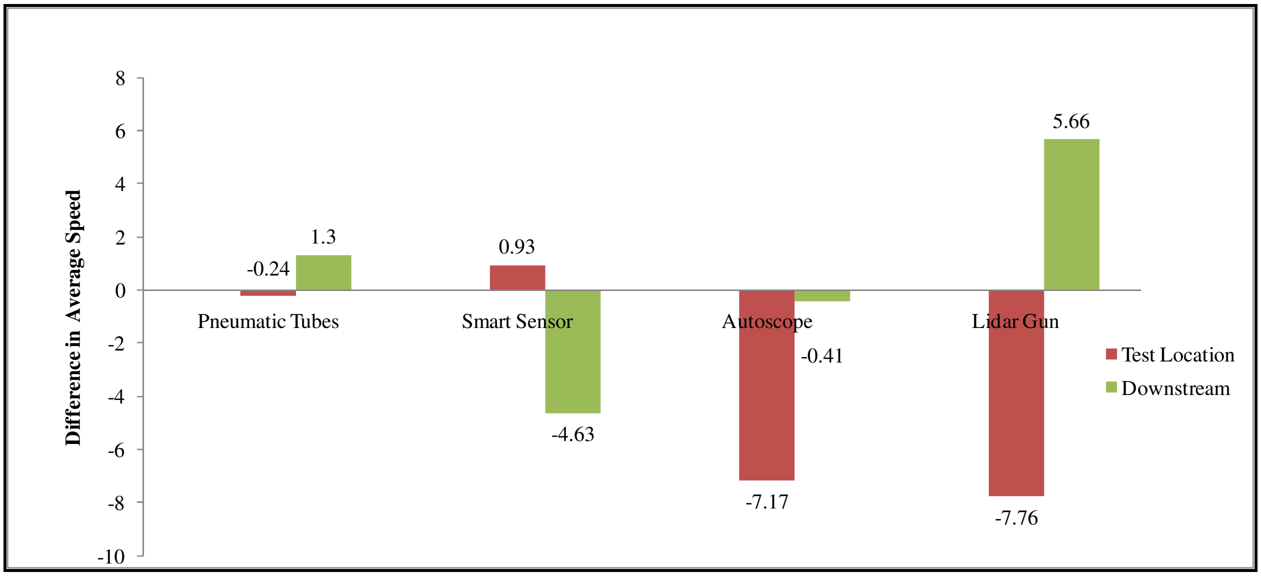


**Figure 41 Summary of Difference in the Speed Distributions Compared to the Upstream Location**

## 5.1 Effect on Speeds of Drivers Driving above the 85th Percentile Speed

It was interesting to analyze drivers driving above the 85th percentile speed when the devices were installed. To observe this effect, the top 15 percent of vehicles at the upstream location for each week were isolated and each and every vehicle was tracked through the test and downstream locations. Paired t-tests were performed with a confidence intervals of 95 percent to observe driver behavior. Table 7 summarizes the mean values, 85th percentile speeds and total number of samples for each location for all five weeks.

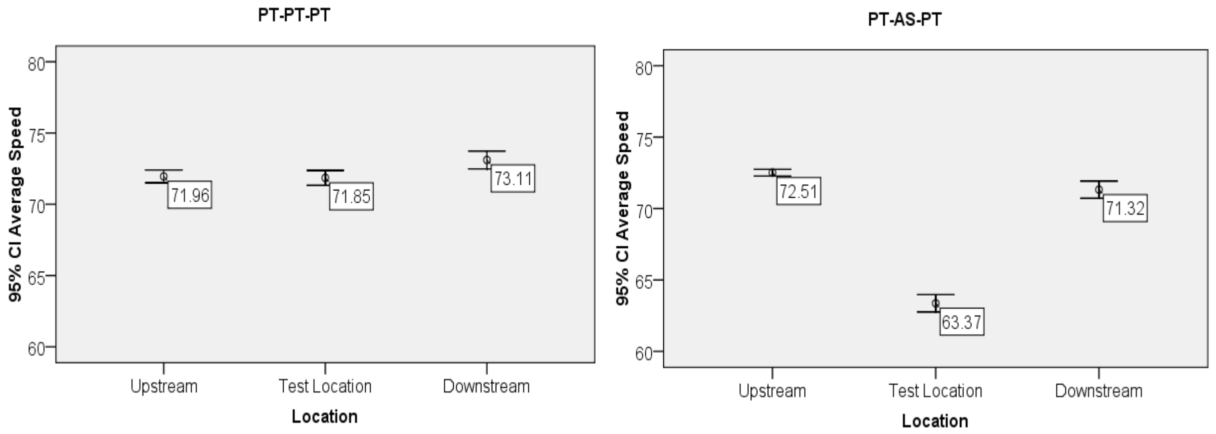
Smartsensor data could not be used as the device presents data for every 10 seconds, unlike pneumatic tube data which displays individual vehicle speeds. Due to this type of Smartsensor data format, individual vehicles could not be tracked throughout, hence the effect could not be observed.

**Table 7 85th Percentile Speeds at All Locations for Five Weeks at Site 2**

| Week | Date | Location | Device | Mean | Std Deviation | N |
|---|---|---|---|---|---|---|
| Week 1 | May18-May20 | Upstream | Pneumatic Tube | 71.96 | 3.23 | 200 |
| | | Test | Pneumatic Tube | 71.85 | 3.73 | 200 |
| | | Downstream | Pneumatic Tube | 73.11 | 4.46 | 200 |
| Week 2 | June1-June3 | Upstream | Pneumatic Tube | ** | ** | ** |
| | | Test | Smartsensor | ** | ** | ** |
| | | Downstream | Pneumatic Tube | ** | ** | ** |
| Week 3 | June8-June10 | Upstream | Pneumatic Tube | 72.51 | 1.97 | 268 |
| | | Test | Autoscope | 63.37 | 5.05 | 268 |
| | | Downstream | Pneumatic Tube | 71.32 | 5.04 | 268 |
| Week 4 | June15-June17 | Upstream | Pneumatic Tube | 72.54 | 2.13 | 163 |
| | | Test | Lidar Gun | 61.79 | 4.86 | 163 |
| | | Downstream | Pneumatic Tube | 76.24 | 5.71 | 163 |
| Week 5 | June25-June27 | Upstream | Pneumatic Tube | 67.02 | * | # |
| | | Test | Pneumatic Tube | * | * | * |
| | | Downstream | Pneumatic Tube | 66.69 | * | # |

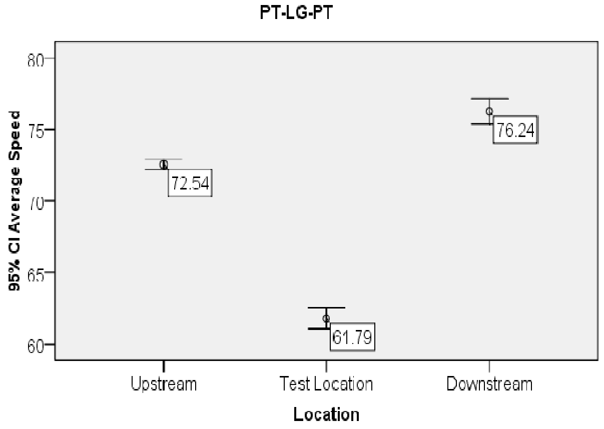
*- Data Missing
**- Data in unsuitable format
# Test not performed

Figure 42 shows the effect on the average speeds of the fastest 15 percent of drivers. In Figure 42 (a) with pneumatic tubes at all three locations when the fastest 15 percent of drivers were compared, it was found that there was no significant difference in the average speeds at the upstream and test locations with the P-value of 0.764> 0.05, however significant difference in average speeds was found when the downstream location was compared with the test location.



(a) US-24, May 18-20, Week 1

(b) US-24, June 8-10, Week 3



(c) US-24, June 15-17, Week 4

**Legend:**

PT: Pneumatic Tube
SS: Smartsensor
AS: Autoscope
LG: Lidar Gun

**Figure 42 Effect on Speeds of Drivers Driving Above the 85th Percentile Speed**

In Figure 42 (b) when the Autoscope was installed at the test location, there was significant drop in average speed observed with the P-value less than 0.05. The difference in average speed was approximately 9 mph. However, drivers regained their speeds by the downstream location. Significant difference in P-values was found when compared.

Figure 42 (c) shows that a similar effect was observed when the Lidar gun was used to collect speed data. The average speed of the drivers was reduced by 9.1 mph, but they increased their speeds by 8.0 mph at the downstream location. The P-values indicated significant difference in speeds when upstream with test location and downstream with test location were compared.

Figure 43 presents the summary of differences in speed distributions of the fastest 15 percent of the drivers. Considering speed at the upstream location as the base speed, the differences in average speed at the test location and downstream locations when compared to the upstream location are displayed below.

**Figure 43 Summary of Difference in Speed Distribution of Fastest 15 Percent Drivers Compared to the Upstream Location**

## 5.2 Comparison of Devices Based on Ease in Installation and Labor Hours

Accuracy and driver behavior are not the only governing factors while selecting the devices. It is equally important to consider other factors like ease of installation, labor hours, safety, data extraction, reliability etc.

**Pneumatic Tubes with Automated vehicle classifiers:**

- Though they are considered to be very accurate (16), safety is the biggest issue with pneumatic tubes as the crew has to enter the roadway to install the tubes.
- Cracks and cuts in tubes were frequently found in this study. Therefore, equipment reliability could be questioned.
- Installation of one set of tubes requires about one hour. Additionally tubes and counters must be inspected on a daily basis.

**Smartsensors:**

- Installation of this device was completed in about one hour.
- The device is very sensitive to winds as the change in direction of the device can affect the results.
- It is powered from a battery which can run up to 72 hours. Therefore, it does not require daily inspection.

**Autoscope with Camera Trailer:**

- Installation of this device requires lot of time and assistance. The trailer needs to be attached to a truck to be transferred to the site. Once the trailer is set at the location, the camera is mounted on it. The battery, small television, recorder and the hard disk are setup inside the trailer cabinet. Proper setup can take up to two to three hours.

- As this device records the video, battery consumption is very high. Therefore, frequent inspection is important in order to record continuous data.
- Accuracy of these data does not only depend much on the recording, but also on the calibration and extraction of the data which is done once the data are already collected.
- Extraction of data takes exactly the same time the data are recorded. Therefore, there can be extensive additional time spent in the office when this device is used.

**Lidar Gun:**

- A study performed by Gates et al. (16) claims that this device is one of the most accurate devices when compared with several types of tubes and radar technology, but as the data is collected manually this device requires at least one person at site all the time. Many person-hours are often required to achieve a suitable sample size.
- If the traffic volume is high all the vehicles cannot be captured.
- The data may be biased due to the conspicuity of the data collector; also the data have to be captured within a certain distance as the average operating range is about 800 feet.

# CHAPTER 6-FINDINGS AND RECOMMENDATIONS

Based on this research, the following are the findings:

- Out of all four devices, the largest reduction in speeds were observed when the Lidar gun was used. Their accuracy cannot be questioned but they are probably not the most suitable device for speed measurement unless the user can be made inconspicuous. Also, collecting data by being inconspicuous is also difficult, as the average operating range is about 800 feet. Considering the Lidar gun's effect on speed distribution and its effectiveness in reducing speeds, it can be concluded they should rather be used as a speed control device and not as speed measurement device.
- The Autoscope camera system displayed results that were similar to the Lidar gun. The presence of a big trailer with a camera appears to effect the drivers' behavior. Probably installing the trailer at a distance, where the trailer is not easily seen by the drivers at the same time without compromising with the quality of the video is another alternative.
- While the Smartsensor was installed people increased their speeds initially and then reduced it. This can be because of the fact that the device is small in size and not visible from distance and by the time drivers react they have crossed test location and are at the downstream location. The effect on the speed distribution can clearly be seen in downstream speed values, which was almost 5.5 mph less than the test location.
- There was no significant difference in speeds at the upstream and the test locations when pneumatic tubes were installed, also the speeds at the upstream location for all five weeks were consistent.
- Similar effects were observed when drivers driving above the 85th percentile speeds were compared. High-speed drivers reacted most to the Lidar guns and then to the Autoscope

with a camera trailer. No significant differences in speed were observed when pneumatic tube speeds at the upstream and the test locations were compared.

- The idea of this study was to use the devices the way they are actually used by the private agencies or departments of transportation. For studies similar to this, the Smartsensor is attached to the post and the data gets recorded itself, but when the device is used like this the format of the data when extracted displays the speeds in 10 second time frame. This means that the device averages the speeds of vehicles that pass within 10 seconds. Due to this format Smartsensor data could not be used to evaluate the drivers driving above 85th percentile speeds as individual vehicle could not be tracked.
- A significant difference in average speeds was observed when pneumatic tubes, Lidar gun, Samrtsensor and Autoscope were compared. The results indicated that drivers reduced their speed most when they saw the Lidar gun, results of Autoscope were not very different, there was significant drop in speed when camera trailer was present at the test location. The Smartsensor - being small - was not noticed until drivers came close to it but eventually drivers did react to it as well and reduced their speed. Based on the results of the study performed, it can be concluded that even though these devices are accurate and very commonly used by several private agencies and departments of transportation, they are not interchangeable with other devices and their use for the same study is not recommended. A significant difference in speed was observed when these devices were compared. Therefore, it is not recommended to use these devices together for the same study.
- The pattern of driver behavior was similar when Lidar gun and Autoscope with camera trailer were used. The drivers decreased their speed before the test location and increased

their speed after crossing the test location. However, the pattern of driver behavior was different when Smartsensor was installed, as mentioned before drivers reduced their speeds after crossing the test location.

- As long as individual vehicle data are not required, the Smartsensor is recommended for traffic data collection. Also, considering installation ease, labor hours, convenience and safety, the Smartsensor proved better than any other device tested in this study. The Smartsensor does give individual vehicle data, provided at least one person is always present at site with the laptop. For the studies where huge amount of data are required this can be a difficult process; also it should also be considered that collecting data with the presence of the data collector can influence the drivers.
- Studies where budget is a constraint and many test locations are to be studied, pneumatic tubes are recommended. Pneumatic tubes along with automatic traffic counters are cheaper when compared to devices like the Smartsensor, Autoscope and Lidar gun.
- Despite the time of installation cost of entire system, frequent battery changes, the Autoscope is recommended for studies where video is needed. Also, as mentioned in Chapter 4 the extraction of data is equally time consuming.
- It was realized that in any study where the data are being collected for more than a day, it is not just important ensure that data are being collected but it is equally significant to simultaneously keep the track of what data are being collected or in other words does the data that are being collected make sense. Also, the calibration of devices should be performed before using them.

## 6.1 Future Research

Huge technological advancements have taken place in recent years in the field of non-intrusive portable speed measurement devices, making them more reliable, accurate, easy to use and safe. Due to these reasons and several other reasons such devices are increasingly becoming more popular amongst private firms and departments of transportation. A study comparing exclusively non-intrusive portable devices should be done to evaluate their effect on speed distribution due to their presence on the roadside.

From the review of literature, it was found that the pneumatic tubes are very popular among departments of transportation, 49 out of 50 states use them for various types of traffic studies. During our study some problems were encountered with the pneumatic tubes like frequent cuts and cracks causing loss of data. It would be interesting to see if the same situation could be replicated, what caused these problems and what steps can be taken to prevent such situations. Parameters, such that traffic volume, weather, vehicle classification, could be used to perform a detailed study.

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