Traffic Data Collection Improvements

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February 2014

Research Project
Final Report 2014RIC51B

LRRB
LOCAL ROAD RESEARCH BOARD

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16. Abstract (Limit: 200 words)

The Local Road Research Board (LRRB), with assistance from Sibley County and the Minnesota Department of Transportation (MnDOT), conducted a field evaluation of traffic data collection sensors. This study was initiated to explore low-cost and non-intrusive options to collect traffic data as possible alternatives to traditional methods such as tube counts, which require personnel to work close to or on the roadway rather than from a safer roadside position, as some non-intrusive sensors allow. This project reviewed new developments and alternatives to conventional road tube, inductive loop and piezo sensor data collection.

This project conducted a comparison of multiple traffic data collection sensors along on a rural two-lane road with low traffic volumes (Sibley County State Aid Highway 9) in both winter and spring conditions. The project gathered information on ease of deployment, accuracy, and costs associated with each technology. The following sensors were installed and monitored as part of this study: Countingcars.com COUNTcam, Miovision Scout, JAMAR Radar Recorder, Wavetronix SmartSensor HD, Houston Radar Armadillo Tracker, Sensys VSN240F (Sensys), JAMAR Stealth Stud, Road Tubes with PicoCount 2500 classifier.

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Traffic Data Collection Improvements

Final Report

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Executive Summary

The Local Road Research Board (LRRB), with assistance from Sibley County and the Minnesota Department of Transportation (MnDOT), conducted a field evaluation of traffic data collection sensors. This study was initiated to explore low-cost and non-intrusive options to collect traffic data as possible alternatives to traditional methods such as tube counts, which require personnel to work close to or on the roadway rather than from a safer roadside position as some non-intrusive sensors allow. This project reviewed new developments and alternatives to conventional road tube, inductive loop and piezo sensor data collection.

This project conducted a comparison of multiple traffic data collection sensors along Sibley County State Aid Highway (CSAH) 9 in both winter and spring conditions. The project gathered information on ease of deployment, accuracy, and costs associated with each technology.

The review of new developments and alternatives is important for historical trend analysis, forecasting, planning for future infrastructure improvements and expansions, and to measure traffic safety and roadway pavement use in various locations and scenarios.

The following sensors were installed and monitored as part of this study:

- Countingcars.com COUNTcam (COUNTcam)
- Miovision Scout (Scout)
- JAMAR Radar Recorder (Radar Recorder)
- Wavetronix SmartSensor HD (Wavetronix HD)
- Houston Radar Armadillo Tracker (Houston Radar)
- Sensys VSN240F (Sensys)
- JAMAR Stealth Stud (Stealth Stud)
- Road Tubes with PicoCount 2500 classifier (Road Tubes)

Please note that the JAMAR Stealth Stud was damaged in the field, therefore no findings are report in the following tables (see details on page 25).

The study was conducted on a rural two-lane road with low traffic volumes. The baseline data for this project was from a calibrated loop-piezo-piezo-loop automatic traffic recorder (ATR) site recently installed by MnDOT.

Data Accuracy Findings

The following table gives a summary of the sensor accuracy results and a qualitative rating for the sensor's ease of use including installation and data processing. The volume data is based on how well the sensor matched the ATR's baseline volume for a 24-hour period. The speed data is based on how well the sensor matched the ATR's detected average vehicle speeds. The classification is based on how well the sensor matched the ATR's baseline's axle-based classification translated to a length-based classification. Please note that the baseline has some inherent error that accounts for some of the reported error.

Data Accuracy Findings for each Sensor

Sensor	Volume Percent Error	Speed Percent Error	Length Classification Percent Error	Ease of Use	Cost
COUNTcam	2.4%	Sensor does not record	7.1%	Very easy	$1,499 + $1,995 (software)
Scout	1.8%	Sensor does not record	8.4%	Very easy	$5,000 + pole + $6/hr of processing
Radar Recorder	1.0%	1.2%	7.7%	Easy installation, but requires road geometry measurement for setup	$4,145
Wavetronix HD	2.4%	1.2%	4.5%	Easy setup, but requires portable trailer or roadside infrastructure for mounting	$5,500 + trailer/pole
Houston Radar	4.1%	3.5%	*See Note	Easy installation, but requires careful aiming	$2,500 + pole
Sensys	1.5%	5.9%	14.8%	Very easy	$3,000
Road Tubes	6.8%	4.2%	16.5%	Very easy	$500

* Sensor does not differentiate between single-unit and multi-unit trucks. Analysis was performed by combining these vehicle length bins. The sensor differentiated passenger vehicles from trucks with 8.7 percent error.

Note: the ATR baseline has some inherent error. The results shown simply demonstrate how well the sensor data matched the ATR data.

Overall Findings

The overall findings for each sensor – based on communication options, ease of set up, safety considerations, deployment, required personnel, accuracy, ease of collecting and processing data, remote availability, and ability for data integration – are outlined on the following pages. The results indicate that while there is no detector currently on the market that meets all desired functionality, there are viable alternative options to the traditional road tubes that can be used for data collection on most county roads in Minnesota. City practitioners should consider the pros and cons of each detector to determine what is appropriate for their situation.

Overall Findings for each Sensor

		Video		**Radar**		**Doppler**	**Magnetometer**	**Tube Counter**	●: Excellent ◐: Good ○: Poor
Requirement		**COUNTcam**	**Scout**	**Radar Recorder**	**Wavetronix HD**	**Houston Radar**	**Sensys**	**Road Tubes**	**Notes**
Communication	Communication options	●	●	●	●	●	●	●	All sensors have appropriate communication options given their capabilities, primarily via local serial or USB connection
Sensor Installation	Hardware ease of setup and use	●	●	◐	◐	○	○	●	**Radar Recorder**: Careful aiming and field measuring is required **Wavetronix HD**: High mounting height requires portable pole tip up pole or trailer if onsite mounting location is not available **Houston Radar**: Very precise aiming is needed and requires significant trial and error **Sensys**: Installation requires core drilling equipment
	Software ease of setup and use	●	●	◐	●	●	◐	●	**Radar Recorder**: Requires input of field measurements into software **Sensys**: Access point must be reconfigured to access sensors
	Sensor setup in a range of climate conditions	●	●	●	●	●	●	○	**Road Tubes**: Should not be set in cold weather when snow plows may pull them up

		Video		Radar		Doppler	Magnetometer	Tube Counter	
Requirement		**COUNTcam**	**Scout**	**Radar Recorder**	**Wavetronix HD**	**Houston Radar**	**Sensys**	**Road Tubes**	●: Excellent ◐: Good ○: Poor **Notes**
Sensor Installation	Safety considerations (County personnel, the traveling public and traffic control needs)	●	●	◐	●	◐	○	○	**Radar Recorder**: Requires personnel to measure distance to subject lanes **Houston Radar**: Sensor must be mounted within 12 feet of the curb
	Deployment duration in a temporary application	◐	◐	●	○	●	○	●	●: 72+ hours of consecutive data collection is possible ◐: 24+ hours of consecutive data collection is possible ○: Special customization needs to be made to accommodate temporary data collection, such as mounting on a portable trailer
	Personnel and resources needed for installation	●	●	●	●	●	◐	●	**Sensys**: Requires short duration lane closure to install in-pavement sensors
Data Accuracy	Volume accuracy	●	●	●	●	◐	●	◐	●: Less than 3 percent error ◐: 3 to 10 percent error ○: Greater than 10 percent error
	Speed accuracy	N/A	N/A	●	●	●	◐	●	●: Less than 5 mph error ◐: 5 to 10 mph error N/A: Sensor does not record speed
	Vehicle classification accuracy	●	●	●	●	●	◐	◐	●: 0 to 10 percent error ◐: 10 to 20 percent error ○: More than 20 percent error
Data Post Process	Ease of collecting and processing data	◐	●	●	●	●	●	●	**COUNTcam**: Video must be counted in the office
	Ability for sensor data to be available remotely	○	○	○	●	○	●	○	●: Sensor reports live data through remote connection ○: Sensor data can only be downloaded from the sensor (**Houston Radar**: Plans to offer this capability in the future).
	Ability for data integration with MnDOT traffic analysis requirements and software	●	●	●	●	●	●	●	All sensors provide data in a format that can be imported into MnDOT's data analysis software

Chapter 1. Introduction

1.1 Overview

The LRRB, with assistance from Sibley County and MnDOT, conducted a field study of traffic data collection sensors. The project looked at several traffic data collection sensors and both qualitatively and quantitatively reviewed each sensor for use in a county data collection scenario.

Currently, most of the county highway traffic data collection in Minnesota is conducted using road tubes. This study looked at other low-cost non-intrusive options that collect data for long durations.

Traffic volume data is used for a variety of purposes including historical trend analysis, forecasting, planning for future infrastructure improvements and expansions. Other traffic data parameters, such as speed and vehicle classification, are becoming more important as a measure of traffic safety and roadway pavement use. Collecting this data can be done using a variety of different technologies. It is important to continuously review the new developments and search for alternatives that are as or more effective than those commonly used today (road tube, inductive loop, and piezo data collection methods).

The results will be useful to Minnesota cities and counties engineers and transportation professionals but is focused at technical personnel with a good understanding of traffic data collection needs.

1.2 Research Goals

The primary goal is to observe the installation and performance of vehicle detection technologies and to compare them to conventional road tube and MnDOT's permanent automatic traffic recorder (ATR) vehicle detection technology. Each sensor was monitored to determine the sensor's specific functionality.

Goal 1: Evaluate sensor product features and deployment characteristics

- Identify communication requirements and options
- Evaluate sensor hardware ease of setup and use
- Evaluate software ease of setup and use
- Evaluate sensor setup in a range of climate conditions
- Evaluate safety considerations related to County personnel, the traveling public, and traffic control needs
- Identify the duration each sensor can be deployed in a temporary application
- Identify personnel and resources needed for installation
- Identify sensor system lifecycle cost

Goal 2: Determine the system detection characteristics and accuracy

- Determine what types of data each sensor can collect (volume, speed, classification)
- Evaluate sensor count accuracy
- Evaluate sensor speed accuracy
- Evaluate sensor classification accuracy

Goal 3: Evaluate data requirements and integration with other systems

- Document ease of collecting and processing data
- Document ability for sensor data integration with a GIS workflow
- Document ability for sensor data integration with MnDOT traffic analysis requirements and software

1.3 Equipment Testing

Traffic detection technology representing the following technology groups was evaluated based on direction from the project's Technical Advisory Panel (TAP):

Video:	Processes images either manually or via computer algorithms processes.
Side-Fire Radar:	Side-fire beams placed along a roadway reflect back to the sensor to detect vehicles.
Doppler:	Measures the relative velocity of an object moving through its target range.
Magnetometer:	Detects vehicles based on the disruption of the Earth's magnetic field by metal vehicles.
Pneumatic Tube Counter:	Transmits information to a counting device after a pulse is created when vehicles drive over a tube.

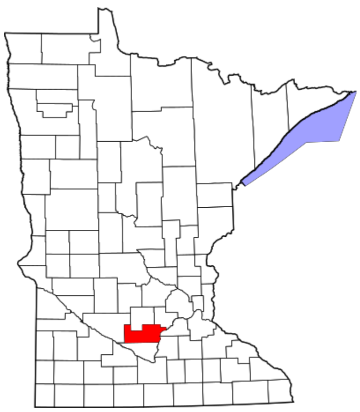
Specific sensors within the above technology groups were assessed to evaluate sensor product features and deployment characteristics, determine system detection characteristics and accuracy, and evaluate data requirements and integration with other systems. Specific information about sensors within each of the above groups is available in Section 3 – Methodology.

Chapter 2. Methodology

Each sensor was evaluated based on its specific functionality in a range of weather conditions for data characteristics and accuracy, as well as data requirements and integration with other systems. This section describes the test site and technologies, as well as the testing hardware, software, baselines, sensors, and tests conducted for the project.

2.1 Test Site Description

The test site selected by Sibley County, MnDOT State Aid, and MnDOT Transportation Data and Analysis (TDA) is located on Sibley CSAH 9, one mile north of Arlington, Minnesota. The test site consists of a typical two-lane roadway in the middle of farm fields and provided relatively high traffic volumes for this area as well as a variety of vehicle classes.



Sibley County

Test Site Location

MnDOT installed an ATR at the test site in 2012. The ATR covered each lane of traffic at the test site was equipped with dual loop-piezo-piezo-loop detectors. These sensors provided an accurate volume and axle-based classification baseline.

2.2 Data Collection Timeframes

Data was collected during both winter and spring to determine if climate affects device performance. The winter deployment was January 28, 2013 through February 7, 2013. The weather in Arlington during this time ranged from a low of -12 degrees to high of 34 degrees Fahrenheit. Although there was little precipitation during this time, the area did experience winds ranging from three to 30 miles per hour during deployment.

The spring deployment was a two-part process that took place over the week of May 20, 2013 and June 10, 2013. The weather in Arlington during this time ranged from a low of 39 degrees to a high of 86 degrees Fahrenheit. Precipitation during deployment ranged from 0.00 inches to 1.65 inches, with an average precipitation of 0.14 inches. Wind speed maximums averaged to 16 mph throughout the testing weeks.

2.3 Sensors Monitored

The primary goal of the LRRB project is to compare vehicle detection technologies (video, side-fire radar, doppler, and magnetometer) to conventional road tube and permanent ATR vehicle detection technology. Each sensor was observed to determine the sensor's specific functionality.

Table 2.1 Vehicle Detection Technologies *(images of each are provided in table 2.2)*

Technology	Principle of Operation	Stated Capabilities	Limitations
Video	Traffic data is generated by processing video images either manually or via computer algorithms processes by manual counting methods or computer algorithms to generate traffic data.	Video technology can be used to collect volume, speed, occupancy, density, and classification. Depending on the device, data collection of 40 to 120 hours or more of traffic video per battery charge is available.	Inclement weather may affect the video image quality and reduce system performance.
Side-Fire Radar	Side-fire beams placed along a roadway reflect back to the sensor to detect vehicles. Radar sensors calculate the distance to the detected vehicles based upon the delay time of the signal from the continuous signal emitted.	Volume, classification based on vehicle length (not axle configuration), speed, and headway.	Can experience dead detection zones and "ghost" vehicles when installed in areas with guard rails, fencing, or other obstructions.
Doppler	Measures the relative velocity of an object moving through its target range.	Detect vehicle speed and volumes.	Radar sensors can experience dead detection zones and "ghost" vehicles when installed in areas with barriers, fencing, or other obstructions.
Magnetometer	Detects vehicles based on the disruption of the Earth's magnetic field by metal vehicles.	Detect volume, classification, headway, presence, and speed with algorithms or in a speed trap configuration. Not affected by poor weather conditions.	Sensors are either core-drilled into the pavement or are installed beneath the pavement. Sensors that are installed in the pavement require a lane closure during installation.
Pneumatic Tube Counter	A pulse is created when vehicles drive over a tube and is transmitted to a counting device.	Vehicle volume and classification.	May report inaccurate volumes when truck volumes are high, tubes do not perform well in cold weather conditions.

Table 2.2 Vehicle Detection Sensors

Technology	Sensor	Image	Sensor Characteristics
Video	**COUNTcam**		• Pole-mounted camera • Side-fire, roadside mounted • Battery life of 40+ hours • Records video for manual counting in office • Weather may affect image quality
	Scout		• Pole-mounted camera • One-week battery life • No software required • Upload video to internet for processing • Weather may affect image quality
Side-Fire Radar	**Radar Recorder**		• Pole mounted radar sensor • Battery-powered • Range up to 100 feet • Can experience dead detection zones and "ghost" vehicles in areas with obstructions
	Wavetronix HD		• Pole-mounted • Detection range of 250 feet • Detects up to 22 lanes of traffic • Can experience dead detection zones and "ghost" vehicles in areas with obstructions
Doppler	**Houston Radar**		• Pole-mounted • GPS/Geo stamp data • Two-week battery life or solar power options • Can experience dead detection zones and "ghost" vehicles in areas with obstructions
Magnetometer	**Stealth Stud**		• Core drilled into pavement • Solar powered • Wireless • Requires directional conduit boring unless installed during new construction
	Sensys		• Pucks are core drilled into pavement • Access point is pole mounted • Self-calibrating and reusable • Battery powered with 10-year battery life
Pneumatic Tube Counter	**Road Tubes**		• Affix to roadway • Battery operated • Axle-based classification • May be inaccurate when truck volumes are high; does not perform well in cold weather

2.4 Baseline Description

Three types of baseline data were collected – volume, speed, and classification – using PEEK ADR 3000 in conjunction with loop-piezo-piezo-loop (LPPL) in-road sensors. The LPPL baseline was chosen as it is widely accepted as an accurate method for obtaining traffic data.

Traffic Data Parameters

<u>Volume</u>
The LPPL detectors were used to determine the baseline data for traffic volume.

<u>Speed</u>
Speed outputs obtained from the LPPL provided an accurate baseline measure of vehicle speeds as the LPPL configuration acts as a speed trap. As a vehicle passes over the first and last loops a time stamp for each pass is created. An algorithm in the PEEK 3000 can then determine the speed of each passing vehicle. Per vehicle speed records were collected.

<u>Classification</u>
ATR baseline data was recorded for both length and axle-based classification. Due to variation in the classification parameters among the sensors all length and class data was standardized using the length-based classification scheme.

2.5 Approach

The primary goal of the project was to compare vehicle detection technologies to conventional road tube and permanent ATR vehicle detection technology. Each sensor was monitored to determine the sensor's specific functionality. The below chart outlines the objectives associated with each goal, as well as our approach to accomplishing each objective.

Goal 1: Evaluate sensor product features and deployment characteristics

Objective	Approach
Identify communication requirements and options	• Investigated communication requirements and capabilities (Ethernet, wireless, etc.) of each sensor
Evaluate sensor hardware ease of setup and use	• Evaluated and documented initial setup procedure for each sensor • Recorded the time, equipment, and tools needed to set up each sensor
Evaluate software ease of setup and use	• Determined software setup procedures. Investigated availability and procurement options. • Performed and documented configuration, such as the aiming tool for the Wavetronix HD, in the field
Evaluate sensor setup in a range of climate conditions	• Evaluated setup difficulty during both warm weather conditions and non-ideal weather conditions, such as cold weather or rain/snow
Evaluate safety considerations related to County personnel, the traveling public, and traffic control needs	• Safety metrics for each sensor is based on duration of device setup and proximity to the roadway • Documented the necessity of a shoulder or roadway closure for sensor installation and/or removal
Identify the duration each sensor can be deployed in a temporary application	• The duration of temporary sensor deployment was based upon battery life and charge time • Investigated necessary accommodations to make typically permanent components into temporarily deployable data collectors with solar power or battery power options
Identify personnel and resources needed for installation	• Provided personnel and resources (tools, computers, vehicles for transport) recommendations for each sensor based upon installation process, software requirements, and data processing needs
Identify sensor system lifecycle cost	• Determined lifecycle cost based on information from the manufacturers and vendors, as well as associated labor costs • This analysis was based on deployment in Minnesota climate conditions and use cases

Goal 2: Determine the system detection characteristics and accuracy

Objective	Approach
Determine what types of data each sensor can collect (volume, speed, classification)	• Investigated product literature and interviewed sensor manufacturers to demonstrate the sensors' detection capabilities
Evaluate sensor count accuracy	• Evaluated sensor accuracy for reporting binned vehicle counts • Count periods were 15-minute periods over the course of one week per season • Collected data and compared it to baseline data to determine the count percent error after the test period
Evaluate sensor speed accuracy	• Binned speed sensor data into five mile per hour increments and 15-minute bins • Analyzed daily speed bin totals and reported as a percentage of correct speed detections per bin • Displayed speed data graphically to compare sensors to the baseline data
Evaluate sensor classification accuracy	• Evaluated sensors based on their ability to report aggregated vehicle classification over 15-minute periods • Recorded both wheel-based lengths and axle-based classification in the ATR baseline • Compared sensors to the baseline for length-based classification

Goal 3: Evaluate data requirements and integration with other systems

Objective	Approach
Document ease of collecting and processing data	• Documented the process required for obtaining and processing the sensor data • Included a brief description of the data format and sample data
Document ability for sensor data integration with a GIS workflow	• Conducted interviews with Sibley County and MnDOT to determine the compatibility of the sensor data with GIS workflows where applicable
Document ability for sensor data integration with MnDOT traffic analysis requirements and software	• Investigated the GIS data format needed for use with local, state, and federal data collection agencies

2.6 Test Methodology

The following represents a generalized set of testing criteria and procedures for the data analysis performed. The objective of data analysis was to create a meaningful representation of the output data from each sensor to be compared to baseline data for the traffic parameters of volume, speed, and classification.

Field Test Procedures

Field testing was conducted over the course of one week in the winter and two weeks in the spring. The sensors were evaluated for their ability to be deployed in any temperature range and to function if there is snow/ice on the ground.

Where possible, effort was made to conduct data collection concurrently so each sensor was subject to the same traffic conditions and the results are directly comparable. Data was collected for one continuous week where possible. Some sensors could only be deployed for a short period of time due to technical or project limitations. For example, Miovision offered to donate two hours of analysis time per season, so effort was made to record data under various conditions for those two hours.

Tests were conducted with aggregated data rather than per-vehicle records due to the number of sensors tested and the duration of the deployment.

Analysis Methods

Raw data was reported in per-vehicle records or a binned data format. Per vehicle records collect data for every vehicle including the time the vehicle passed the sensor, the vehicle speed (accurate to one tenth of a mile per hour) and vehicle length or classification.

The raw data from each sensor was entered into Excel spreadsheets for review. The 24-hour period for each of the sensors was binned into 15-minute increments and filtered to view volume, speed, and classification. The results from the data sorting were placed side by side with the baseline ATR data to establish sensor accuracy for the areas of volume, speed, and classification.

Scatter plots of the volume data were created on a per-day basis as a visual representation of the count performance of each sensor in relation to the baseline. Histograms of the speed bin frequencies were created to provide a visual representation of how each sensor performed in relation to the baseline.

Total percent difference was used to measure sensor performance in collecting volume, speed, and classification data. This metric indicates how close the volume data collected from the sensors is to the baseline data in the form of summed totals.

Chapter 3. Results

3.1 Data Analysis Results

Three weeks of data were recorded in total. Within those three weeks, one day per week was selected to be closely analyzed. The days were selected in order to maximize the number of sensors for comparison:

- January 29, 2013
- May 24, 2013
- June 11, 2013

Morning and afternoon peak periods, along with the full 24-hour data, were compiled and analyzed. Volume, speed, and classification data are compared with the baseline ATR.

To depict different results during different times of the day, three analysis periods were studied:

- Extended morning peak period from 5:00AM to 11:00AM (morning peak)
- Extended afternoon peak period from 2:00PM to 8:00PM (afternoon peak)
- Full 24-hour segment (24-hour)

Please note that the JAMAR Stealth Stud was damaged in the field, therefore no findings are report in the following tables (see details on page 25).

Note: the ATR baseline has some inherent error. The results shown simply demonstrate how well the sensor data matched the ATR data.

Volume Accuracy

The absolute percent error in volume experienced by each sensor was documented for both northbound and southbound for the morning peak, afternoon peak, and over a 24-hour period for each analyzed day. Absolute percent error is calculated by summing the absolute value of volume differences per 15-minute bin and dividing by the total number of vehicles. Full details on absolute percent error are located in Appendix A.

Table 3.1 Volume Percent Error Summary

Sensor	Percent Error
COUNTcam	2.4%
Scout	1.8%
Radar Recorder	1.0%
Wavetronix HD	2.4%
Houston Radar	4.1%
Sensys	1.5%
Road Tubes	6.8%

Sensor Speed Accuracy

Sensor speed data were binned into five mile per hour increments. The COUNTcam and Scout do not report speed information and are, therefore, omitted from the three analysis days. Excel pivot tables and sorting functions were used to bin the data into five mile per hour speed segments. Full details on morning and afternoon peak data, as well as separate north and southbound tabulations, are located in Appendix B.

Table 3.2 Speed Percent Error Summary

Sensor	Percent Error*
COUNTcam	N/A**
Scout	N/A**
Radar Recorder	1.2%
Wavetronix HD	1.2%
Houston Radar	3.5%
Sensys	5.9%
Road Tubes	4.2%

* Absolute average of full day average speed
** Sensor does not record speed

Sensor Classification Accuracy

As with the speed classification, not all of the sensors in the evaluation had classification capabilities. In addition, further comparison was hindered by devices with different classification schemes built into the data recording device. Due to the variation in classification reporting, the data was standardized using length-based classification. The below is based on 24-hour segment for all three dates. Full details on sensor classification accuracy are located in Appendix C.

Table 3.3 Classification Accuracy Summary

Sensor	Percent Matching Baseline
COUNTcam	93%
Scout	92%
Radar Recorder	92%
Wavetronix HD	96%
Houston Radar	91%*
Sensys	83%
Road Tubes	84%

* Sensor does not differentiate between single-unit and multi-unit trucks. Analysis was performed by combining these vehicle length bins. The sensor differentiated passenger vehicles from trucks with 8.7 percent error.

3.2 Detailed Sensor Accuracy and Cost Results Summary

The following table gives a high-level summary of the sensor accuracy results and a qualitative rating for the sensor's ease of use including installation and data processing. The volume data is based on how well the sensor matched the ATR's baseline volume for a 24-hour period. The speed data is based on how well the sensor matched the ATR's baseline for 5 mph speed bins. The classification is based on how well the sensor matched the ATR's baseline's axle-based classification translated to a length-based classification. Please note that the baseline has some inherent error that accounts for some of the reported error.

Table 3.4 Data Accuracy Findings for each Sensor

Sensor	Volume Percent Error	Speed Percent Error	Length Classification Percent Error	Ease of Use	Cost
COUNTcam	2.4%	Sensor does not record	7.1%	Very easy	$1,499 + $1,995 (software)
Scout	1.8%	Sensor does not record	8.4%	Very easy	$5,000 + pole + $6/hr of processing
Radar Recorder	1.0%	1.2%	7.7%	Easy installation, but requires road geometry measurement for setup	$4,145
Wavetronix HD	2.4%	1.2%	4.5%	Easy setup, but requires portable trailer or roadside infrastructure for mounting	$5,500 + trailer/pole
Houston Radar	4.1%	3.5%	*See Note	Easy installation, but requires careful aiming	$2,500 + pole
Sensys	1.5%	5.9%	14.8%	Very easy	$3,000
Road Tubes	6.8%	4.2%	16.5%	Very easy	$500

* Sensor does not differentiate between single-unit and multi-unit trucks. Analysis was performed by combining these vehicle length bins. The sensor differentiated passenger vehicles from trucks with 8.7 percent error.

Note: the ATR baseline has some inherent error. The results shown simply demonstrate how well the sensor data matched the ATR data.

3.3 Overall Summary

The overall findings for each sensor – based on communication options, ease of set up, safety considerations, deployment, required personnel, accuracy, ease of collecting and processing data, remote availability, and ability for data integration – are outlined below. Additional analysis on each sensor can be found following this summary.

Table 3.5 Overall Findings for each Sensor

		Video		Radar		Doppler	Magnetometer	Tube Counter	●: Excellent ◐: Good ○: Poor
Requirement		**COUNTcam**	**Scout**	**Radar Recorder**	**Wavetronix HD**	**Houston Radar**	**Sensys**	**Road Tubes**	**Notes**
Communication	Communication options	●	●	●	●	●	●	●	All sensors have appropriate communication options given their capabilities, primarily via local serial or USB connection
Sensor Installation	Hardware ease of setup and use	●	●	◐	◐	○	○	●	**Radar Recorder**: Careful aiming and field measuring is required **Wavetronix HD**: High mounting height requires portable pole tip up pole or trailer if onsite mounting location is not available **Houston Radar**: Very precise aiming is needed and requires significant trial and error **Sensys**: Installation requires core drilling equipment
	Software ease of setup and use	●	●	◐	●	●	◐	●	**Radar Recorder**: Requires input of field measurements into software **Sensys**: Access point must be reconfigured to access sensors
	Sensor setup in a range of climate conditions	●	●	●	●	●	●	○	**Road Tubes**: Should not be set in cold weather when snow plows may pull them up

Requirement		Video		Radar		Doppler	Magnetometer	Tube Counter	Notes
		COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes	●: Excellent ◐: Good ○: Poor
Sensor Installation	Safety considerations (County personnel, the traveling public and traffic control needs)	●	●	◐	●	◐	○	○	**Radar Recorder**: Requires personnel to measure distance to subject lanes **Houston Radar**: Personnel must aim sensor close to roadway
	Deployment duration in a temporary application	◐	◐	●	○	●	○	●	●: 72+ hours of consecutive data collection is possible ◐: 24+ hours of consecutive data collection is possible ○: Special customization needs to be made to accommodate temporary data collection, such as mounting on a portable trailer
	Personnel and resources needed for installation	●	●	●	●	●	◐	●	**Sensys**: Requires short duration lane closure to install in-pavement sensors
Data Accuracy	Volume accuracy	●	●	●	●	◐	●	◐	●: Less than 3 percent error ◐: 3 to 10 percent error ○: Greater than 10 percent error
	Speed accuracy	N/A	N/A	●	●	●	◐	●	●: Less than 5 mph error ◐: 5 to 10 mph error N/A: Sensor does not record speed
	Vehicle classification accuracy	●	●	●	●	●	◐	◐	●: 0 to 10 percent error ◐: 10 to 20 percent error ○: More than 20 percent error
Data Post Process	Ease of collecting and processing data	◐	●	●	●	●	●	●	**COUNTcam**: Video must be counted in the office
	Ability for sensor data to be available remotely	○	○	○	●	○	●	○	●: Sensor reports live data through remote connection ○: Sensor data can only be downloaded from the sensor (**Houston Radar**: Plans to offer this capability in the future).
	Ability for data integration with MnDOT traffic analysis requirements and software	●	●	●	●	●	●	●	All sensors provide data in a format that can be imported into MnDOT's data analysis software

3.4 Detailed Sensor Observations

This section presents the results of the observations, grouped by sensor.

COUNTcam

Description

The COUNTcam is a camera and video recording device that records video of traffic for later manual counting and classification in the office.

The video recording device consists of a weatherproof box and a detached small black "bullet" camera. The basic equipment is shown below. The bullet camera can be connected to a thin aluminum pole that can be attached to roadside infrastructure with hose clamps.

Deployment

The amount of time for which the COUNTcam can be deployed is dependent on the device's battery size and the capacity of the SD cards used. The base system can record up to five days (120 hours) or more. The COUNTcam can be installed roadside with no interruption to the flow of traffic. Installation of the COUNTcam can be performed by one person. It is important to properly install the equipment, especially securing the camera so it does not move or rotate.

Cost

The COUNTcam hardware costs $1,499 to $3,299 per system depending on the battery capacity and number of camera feeds. The lowest cost unit would be applicable for most county road applications. The COUNTcam software costs $1,995 and the optional COUNTpad costs range from $219 to $749 depending on the model. The basic model would be applicable for most county applications.

Data

An operator needs to manually count the video, so this process can include volume and classification data. Pedestrian, bicycle, or other transportation modes can also be monitored since the device's basic function is to record video. Accuracy depends on careful deployment and analysis. Good quality video requires appropriate lighting conditions and camera placement. There were some visibility issues due to precipitation collecting on the camera lens during the field observations.

Miovision Scout

Description

Scout is a camera and video recording device. Once the video is collected it can be uploaded to Miovision for processing. No manual processing is needed. Data is stored on an SD card which can be transferred to a computer for uploading to Miovision. The Scout consists of a sturdy pole attachment mount, a telescoping camera pole assembly, and Video Capture Unit (VCU). The collapsed telescoping Scout is approximately four feet tall and can be extended to a height of 25 feet. The device and mount weigh 17 pounds and the compact design allows for easy transport.

Video Collection Unit

Scout Telescoping Pole Mounted on a Post

Deployment

The Scout is designed to be installed roadside to a pole. The 25-foot height of the telescoping pole allowed for an installation further back from the roadway at a safe distance.

At the test site the installation took approximately 25 minutes for two people during winter conditions and could be deployed in ideal weather conditions by one person in approximately 30 minutes, including mounting and recording setup. The Scout assembly can be taken down in roughly 10 to 15 minutes.

The Scout can be deployed with the internal battery for up to 72 hours. There is an optional power pack that extends this duration to seven days.

Cost

The Scout costs about $5,000 and analysis time is paid for separately (approximately $6 per hour of processing time for a two-lane road).

Data

Can collect volume and classification data. Miovision's TDO website offers data analysis services such as trip generation, gap studies, automatic license plate reader studies, origin-destination studies, travel time, and parking studies.

JAMAR Radar Recorder

Description

The Radar Recorder is housed in waterproof box which weighs 15 pounds with the base system. The package includes the required cables, TraxPro software, and two batteries.

The Radar Recorder can be deployed for seven days on the initial battery charge. An additional battery can be added for 14 days of data collection. There are solar powered accessories for the Radar Recorder that increase the deployment capabilities to six months or more.

The Radar Recorder was designed to be installed along the roadway up to 80 feet from the far lane of traffic. Onsite personnel must enter the roadway to determine the distance to configure the radar. Onsite installation and configuration in winter conditions took just under 90 minutes with two operators.

Deployment

It was installed at a 45 degree angle to the roadway using the provided mounting bracket. Hose clamps were used to affix the mounting bracket to a pole located on the west side of CSAH 9. The Radar Recorder must be configured in the field using a laptop, the provided software, and a RS-232 serial cable. Configuration using JAMAR's TraxPro software prompts for site-specific information such as distance to each lane of traffic, and height of the sensor above the roadway. These parameters must be field measured. JAMAR added remote Bluetooth monitoring and setup after the conclusion of the test.

Radar Recorder Onsite Install and Configuration

Once configured, the sensor immediately begins recording. The initial detections can be verified by viewing small LEDs that illuminate upon each detection.

Cost

The Radar Recorder costs $4,145 and includes the installation kit, TraxPro software with five licenses, two batteries, and user's manual.

Data

Collects volume, speed, length, and gap data.

Wavetronix HD

Description

The Wavetronix HD deployed for this evaluation was part of MnDOT's portable Wavetronix trailer. The trailer features a sensor installed on a 25-foot telescoping mast, solar panels, and battery packs. Once deployed, a field laptop was used to configure the sensor. If a trailer is not available, the sensor can be mounted on a "tip-up" pole and attached to roadside infrastructure or could be mounted directly to roadside hardware. The software, SmartSensor Manager HD, can be downloaded from Wavetronix's website at no additional cost.

Deployment

Sensor configuration and data collection was performed using a RS-232 nine-pin serial cable, but Internet or other wireless options are also available. Once a connection is established, automatic configuration begins by selecting "Sensor Alignment." Due to the low volume on the roadway, the sensor was unable to auto-configure and a manual lane configuration of the roadway was performed. Proper operation was confirmed in both directions by driving multiple passes of a truck in both directions.

MnDOT's Wavetronix HD Trailer

The sensor was contained on an integrated trailer so installation was quick. Wavetronix HD is a sidefire radar that is installed alongside the roadway. Installation of the sensor causes no disruption to traffic and the sensor could be deployed and configured onsite by one person. In winter weather conditions the Wavetronix HD took approximately 50 minutes to set up.

The spring deployment of the sensor ran into connectivity issues stemming from a connection in the trailer system, not the sensor itself. Due to these issues, a second week of data collection was performed on June 10th, 2013. Onsite a handheld Trimble device (handheld computer) was used to configure the sensor utilizing the automatic lane detection feature.

Cost

The sensor costs about $5,500 including the mounting bracket and 100-foot cable harness. To ease setup time, additional hardware for mounting and providing power must be purchased separately. The cost ranges from about $500 (tip-up pole and battery box) to $25,000 (full trailer system).

Data

Can collect per vehicle speed, length, class, and assignment data, but per vehicle data can only be viewed in real time on a portable computer.

Houston Radar Armadillo Tracker

Description

The Houston Radar is a small 3lbs polycarbonate box that can be attached to roadside hardware such as a pole. This box is powered on using a small key at the bottom of the device.

The Houston Radar was designed to be installed along the roadway up to 12 feet away from the side of the road or in a middle median no more than 12 feet wide. The roadside deployment option allows for personnel to safely install and remove the sensor without entering traffic lanes. Personnel can wirelessly retrieve data from their vehicles. The Armadillo Tracker can be deployed for two weeks on a single charge.

Houston Radar Installation (Image Source: Houston Radar)

Deployment

The lightweight design allows for quick installation and removal of the device in less than 10 minutes. No computer is required for installation as the device has a beeper function to confirm proper operation and accurate logging of passing vehicles. The device is installed between five and 12 feet above the roadway, so a ladder may be required for installation.

Cost

The Houston Radar costs about $2,500 and includes a rapid charging cable, a 12VDC car charger, PC side long range Bluetooth adaptor, and mounting clamps. An optional solar charger kit is available for $433. Data analysis software is available at no cost, but was not used during this project. A GPS option is available for $299 that automatically segregates data sets. A cellular modem option is planned to be offered in the future.

Data

Collects volume and speed data on a per vehicle basis for up to four lanes. Data is downloaded directly via an USB cable provided with the sensor. The data reported includes date, time, classification, and speed.

Sensys VSN240-F

Description

Sensys is in-pavement vehicle detection. A series of six sensors were installed in the roadway and remotely connected to a data collection device installed on a 30-foot pole approximately 30 feet from the roadway. A traffic cabinet was installed to house the various components needed for this system such as modem, power, and cabling. Access point and APCC installation and calibration were done by Sensys staff onsite. The data is viewed on a hosted Internet website called “hosted SNAPS” (Sensys Networks Archive, Proxy, and Statistics).

Deployment

Because the sensors need to be cored into the pavement the installation requires traffic control including a full lane closure for about 30 minutes per lane. Once the sensor is deployed and configured, the data can be viewed and downloaded from the SNAPS website.

The Sensys setup is not designed for a portable application, but could easily be implemented in this fashion with the addition of a roadside post and polycarbonate enclosure with batteries.

Cost

A full setup costs approximately $3,000 and would require some additional work (two to four hours) by the agency to accommodate a temporary application. The listed cost is for the hardware only; the installation also requires a coring rig.

Data

Collects both per vehicle and binned data for volume, speed, and length.

JAMAR Stealth Stud

Description

The JAMAR Stealth Stud is a solar-powered vehicle counter that is installed in the roadway for traffic data collection. Data is then downloaded wirelessly from the sensor to a portable computer via a USB adapter.

Deployment

The Stealth Stud was installed in one lane at the test site using the installation kit. The sensor was flush with the pavement, although it bulges up in the middle of the sensor and thus protrudes above the pavement surface. Significant effort was made to communicate with the sensor in the early winter. However, before testing commenced, the sensor was damaged by a snow plow and later efforts to communicate with the sensor were unsuccessful.

Damaged Stealth Stud

Stealth Stud

Cost

The Stealth Stud costs $1,450 per sensor and includes the installation kit, user’s manual, and software for downloading data from the sensor. Each detected lane would require one sensor. The listed cost is for the hardware only; the installation also requires a coring rig.

Data

Collects volume only.

Road Tubes

Description

Road tubes were laid across the traffic lanes. Two tubes were used to capture vehicle classification data. The tubes were secured by wrapping cable wire loop (figure eight) around the tube at the end of pavement, and then securing the cable around a large 3/4” diameter bolt in the ground. The Road Tubes classifier was attached to the end of the tubes on the cabinet side of the road. Data was collected using the Road Tubes classifier system, which is powered internally. Users can communicate with the classifier via USB.

Deployment

The road tubes were deployed for a week during the May testing period. The tubes successfully recorded the entire week of data, from installation to takedown. After a week of testing, little wear was noticed on the tubes.

Cost

The Road Tubes costs about $400, and a complete setup including tubes and a chain costs about $500.

Data

The road tubes collect both per vehicle and binned data for volume, speed, and vehicle class.

Chapter 4. Conclusions and Next Steps

This project observed several traffic detection options and compared their capabilities. While there is no detector currently on the market that meets all desired functionality, this study concludes that there are viable alternative options to the traditional road tubes for data collection on most county roads in Minnesota.

Many of the equipment options can be deployed from the roadside but require more time to set up than road tubes. Despite this extra installation time, it may be desirable to use a non-intrusive sensor because it provides safety advantages since personnel do not need to be in the road. This project also showed the different types of classification that the alternative sensors offer. While road tubes with a classifier can offer axle-based classification, the alternative sensors generally use length-based detection to varying success.

The detectors performed better than road tubes in volume and speed accuracy. The COUNTcam and Scout do not record speeds, however. Costs for the detectors are in the thousands of dollars and can be even higher when considering additional equipment such as poles, trailers, or software necessary for deployment and analysis.

One of the most significant issues with the study was the lack of traffic for calibration purposes. On a low-volume road, an operator may have to wait for 10 to 15 minutes to see even a minimal amount of traffic to make sure that the sensor has been set up properly. This is not a concern in high-volume areas.

Appendix A: Volume Data Analysis Tables

The percent error for volume per sensor was documented for the morning and evening periods for each analyzed day. Absolute percent error is calculated by summing the absolute value of volume differences per 15-minute bin and dividing by the total number of vehicles.

Table A.1 Volume Percent Error – Combined Morning and Afternoon Peak

	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
Percent Error*	2.4%	1.8%	1.0%	2.4%	4.1%	1.5%	6.8%

*Absolute average of morning and afternoon percent error.

The summarized data above was calculated based on the following two tables.

Table A.2 Volume Percent Error – Morning Peak Period

	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
Northbound 1/29/2013	-1.4%	0.0%	1.4%	-0.7%	No Data	-1.4%	No Data
Southbound 1/29/2013	0.0%	1.7%	0.6%	-0.6%	No Data	0.0%	No Data
Northbound 5/24/2013	-6.0%	-2.8%	No Data	No Data	5.2%	No Data	-5.2%
Southbound 5/24/2013	0.0%	0.0%	No Data	No Data	-3.9%	No Data	-3.9%
Northbound 6/11/2013	No Data	No Data	No Data	-2.0%	-3.6%	No Data	No Data
Southbound 6/11/2013	No Data	No Data	No Data	-1.3%	5.7%	No Data	No Data

Table A.3 Volume Percent Error – Afternoon Peak Period

	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
Northbound 1/29/2013	0.0%	0.6%	0.0%	0.0%	No Data	-2.3%	No Data
Southbound 1/29/2013	-2.6%	-1.3%	-2.1%	-1.5%	No Data	-2.1%	No Data
Northbound 5/24/2013	-5.8%	-6.4%	No Data	No Data	0.8%	No Data	-8.3%
Southbound 5/24/2013	3.0%	-1.7%	No Data	No Data	-1.7%	No Data	-9.6%
Northbound 6/11/2013	No Data	No Data	No Data	-5.1%	-7.0%	No Data	No Data
Southbound 6/11/2013	No Data	No Data	No Data	-8.0%	-4.9%	No Data	No Data

Table A.4 Southbound Volume Comparison – Morning Peak Period – 1/29/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	2	0	No Data	2	2	No Data	2	No Data
05:15 - 05:30 AM	2	4		2	2		1	
05:30 - 05:45 AM	6	6		6	6		6	
05:45 - 06:00 AM	3	3		3	3		3	
06:00 - 06:15 AM	5	4	5	5	5		5	
06:15 - 06:30 AM	3	3	3	3	3		3	
06:30 - 06:45 AM	13	14	13	13	13		13	
06:45 - 07:00 AM	10	10	11	10	10		10	
07:00 - 07:15 AM	10	10	9	10	10		10	
07:15 - 07:30 AM	9	10	10	10	9		9	
07:30 - 07:45 AM	6	6	10	6	6		6	
07:45 - 08:00 AM	13	12	10	12	12		12	
08:00 - 08:15 AM	4	4	4	5	5		5	
08:15 - 08:30 AM	0	0	0	0	0		0	
08:30 - 08:45 AM	7	8	8	8	7		7	
08:45 - 09:00 AM	7	7	7	7	7		7	
09:00 - 09:15 AM	4	2	3	3	3		3	
09:15 - 09:30 AM	9	9	10	9	9		9	
09:30 - 09:45 AM	11	11	11	11	11		11	
09:45 - 10:00 AM	10	10	9	10	10		10	
10:00 - 10:15 AM	8	8	No Data	8	8		8	
10:15 - 10:30 AM	2	1		2	2		2	
10:30 - 10:45 AM	9	10		9	9		10	
10:45 - 11:00 AM	6	7		6	6		7	
Total	**159**	**159**	**N/A**	**160**	**158**		**159**	
Percent Error	**N/A**	**0.0%**	**1.7%**	**0.6%**	**-0.6%**		**0.0%**	

Figure A.1 - Volume Comparison Southbound Morning Peak Period 1/29/2013

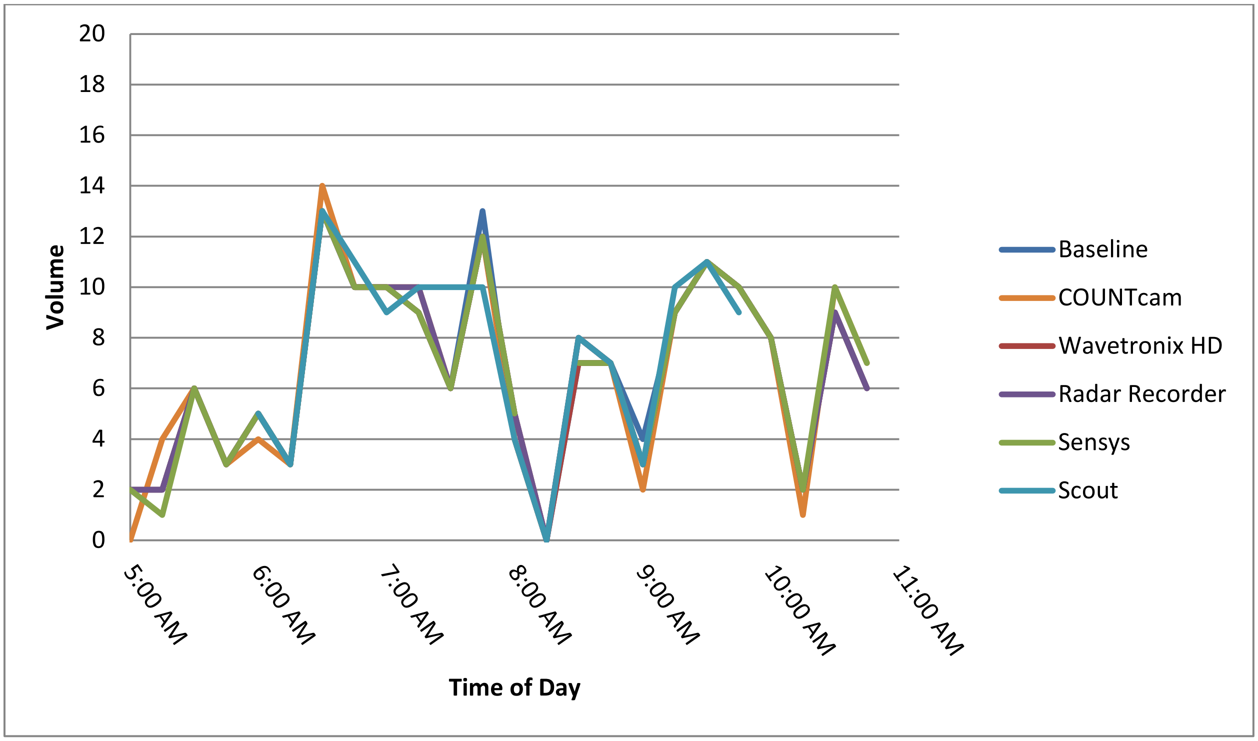


Table A.5 Southbound Volume Comparison – Morning Peak Period – 5/24/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	3	2	3	No Data	No Data	3	No Data	3
05:15 - 05:30 AM	1	1	1			1		1
05:30 - 05:45 AM	5	5	5			5		5
05:45 - 06:00 AM	9	9	9			9		8
06:00 - 06:15 AM	4	4	4			4		5
06:15 - 06:30 AM	8	8	8			8		7
06:30 - 06:45 AM	3	4	3			3		3
06:45 - 07:00 AM	9	10	9			8		9
07:00 - 07:15 AM	10	10	10			10		10
07:15 - 07:30 AM	9	9	10			8		7
07:30 - 07:45 AM	9	9	8			10		9
07:45 - 08:00 AM	10	11	11			10		10
08:00 - 08:15 AM	7	8	6			7		7
08:15 - 08:30 AM	5	5	5			5		5
08:30 - 08:45 AM	5	5	5			5		5
08:45 - 09:00 AM	7	6	7			7		6
09:00 - 09:15 AM	7	7	No Data			6		7
09:15 - 09:30 AM	15	15				15		15
09:30 - 09:45 AM	12	11				12		11
09:45 - 10:00 AM	7	5				5		5
10:00 - 10:15 AM	8	9				8		9
10:15 - 10:30 AM	6	7				6		6
10:30 - 10:45 AM	7	7				7		7
10:45 - 11:00 AM	12	11				9		11
Total	**178**	**178**	**N/A**			**171**		**171**
Percent Error	**N/A**	**0.0%**	**0.0%**			**-3.9%**		**-3.9%**

Figure A.2 - Volume Comparison Southbound Morning Peak Period 5/24/2013

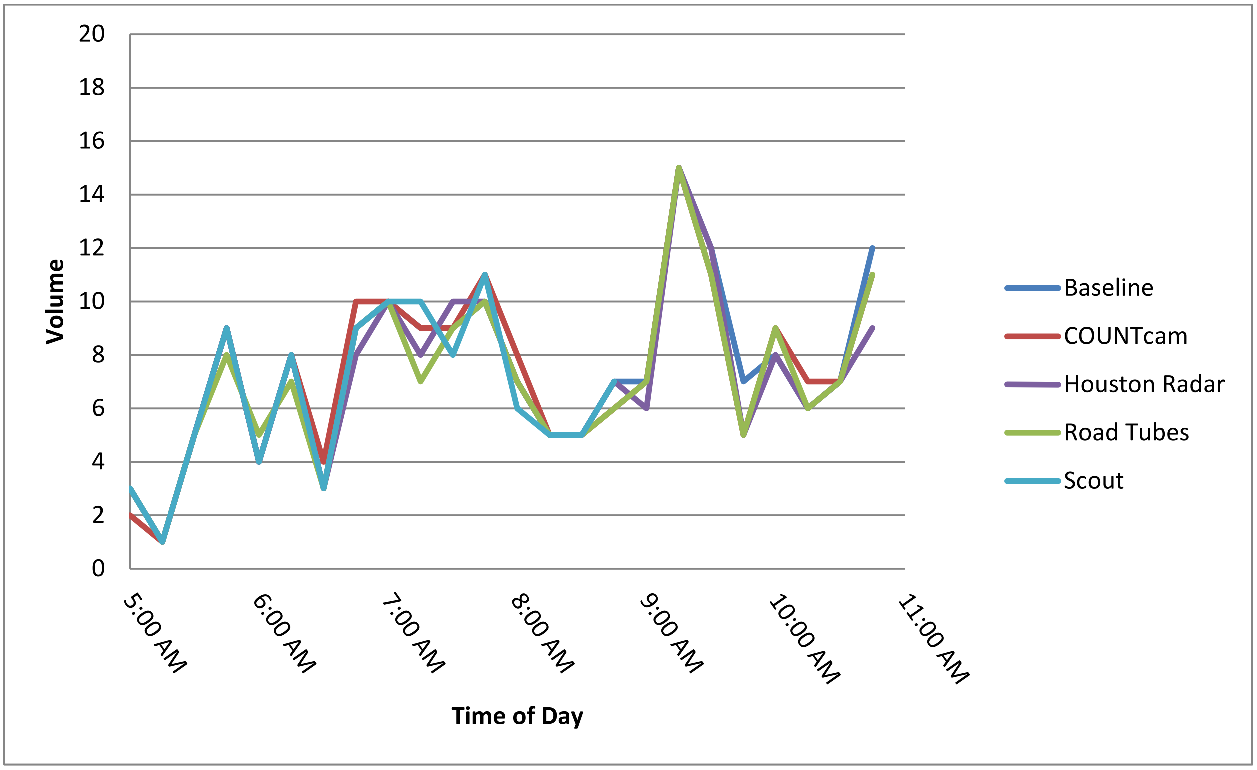


Table A.6 Southbound Volume Comparison – Morning Peak Period – 6/11/2013

Legend

(white)	Baseline values
(light green)	Less than 15% error from baseline
(orange)	15% - 30% error from baseline
(red)	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	2	No Data	No Data	No Data	2	2	No Data	No Data
05:15 - 05:30 AM	4				4	6		
05:30 - 05:45 AM	5				5	5		
05:45 - 06:00 AM	6				5	5		
06:00 - 06:15 AM	11				11	11		
06:15 - 06:30 AM	8				9	9		
06:30 - 06:45 AM	6				6	6		
06:45 - 07:00 AM	5				4	4		
07:00 - 07:15 AM	10				10	13		
07:15 - 07:30 AM	5				6	5		
07:30 - 07:45 AM	6				6	6		
07:45 - 08:00 AM	10				7	10		
08:00 - 08:15 AM	5				8	6		
08:15 - 08:30 AM	10				9	11		
08:30 - 08:45 AM	4				4	3		
08:45 - 09:00 AM	12				13	14		
09:00 - 09:15 AM	3				3	4		
09:15 - 09:30 AM	10				9	10		
09:30 - 09:45 AM	8				8	8		
09:45 - 10:00 AM	5				5	7		
10:00 - 10:15 AM	6				7	6		
10:15 - 10:30 AM	11				10	10		
10:30 - 10:45 AM	4				3	4		
10:45 - 11:00 AM	3				3	3		
Total	**159**				**157**	**168**		
Percent Error	**N/A**				**-1.3%**	**5.7%**		

Figure A.3 – Volume Comparison Southbound Morning Peak Period 6/11/2013

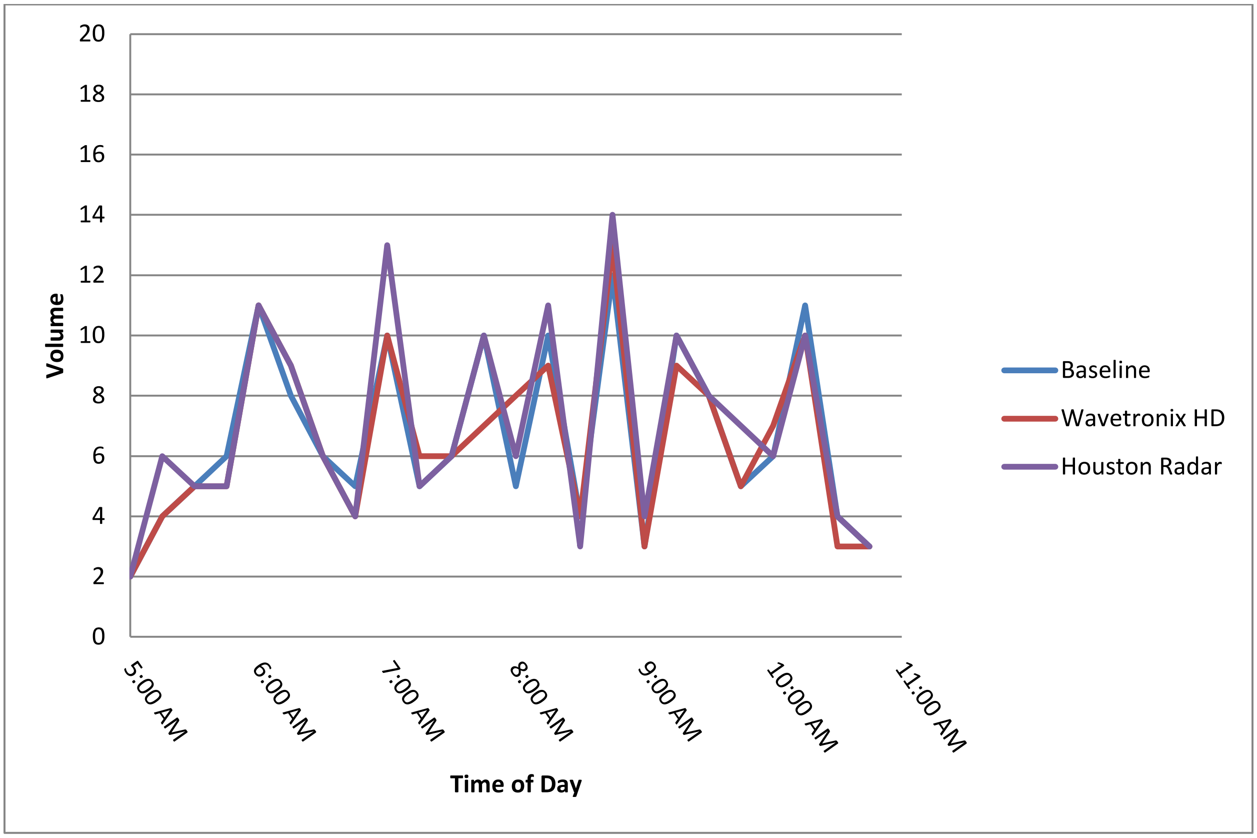


Table A.7 Northbound Volume Comparison – Morning Peak Period – 1/29/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	1	1	No Data	1	1	No Data	1	No Data
05:15 - 05:30 AM	5	4		4	4		4	
05:30 - 05:45 AM	3	3		5	5		5	
05:45 - 06:00 AM	6	7		5	5		5	
06:00 - 06:15 AM	4	7	6	6	6		6	
06:15 - 06:30 AM	6	4	4	4	4		4	
06:30 - 06:45 AM	3	3	3	3	3		3	
06:45 - 07:00 AM	2	3	5	3	3		3	
07:00 - 07:15 AM	9	9	9	11	10		10	
07:15 - 07:30 AM	5	4	3	4	4		3	
07:30 - 07:45 AM	6	6	7	7	7		7	
07:45 - 08:00 AM	6	6	6	6	6		7	
08:00 - 08:15 AM	10	9	7	9	8		8	
08:15 - 08:30 AM	8	7	8	8	8		8	
08:30 - 08:45 AM	6	5	5	5	5		5	
08:45 - 09:00 AM	2	2	2	2	2		2	
09:00 - 09:15 AM	7	7	9	8	7		7	
09:15 - 09:30 AM	9	9	10	9	9		9	
09:30 - 09:45 AM	5	7	4	5	5		5	
09:45 - 10:00 AM	6	5	6	6	6		6	
10:00 - 10:15 AM	6	7	No Data	6	6		6	
10:15 - 10:30 AM	10	9		10	10		10	
10:30 - 10:45 AM	9	9		9	9		9	
10:45 - 11:00 AM	4	3		4	4		3	
Total	**138**	**136**	**N/A**	**140**	**137**		**136**	
Percent Error	**N/A**	**-1.4%**	**0.0%**	**1.4%**	**-0.7%**		**-1.4%**	

Figure A.4 - Volume Comparison Northbound Morning Peak Period 1/29/2013

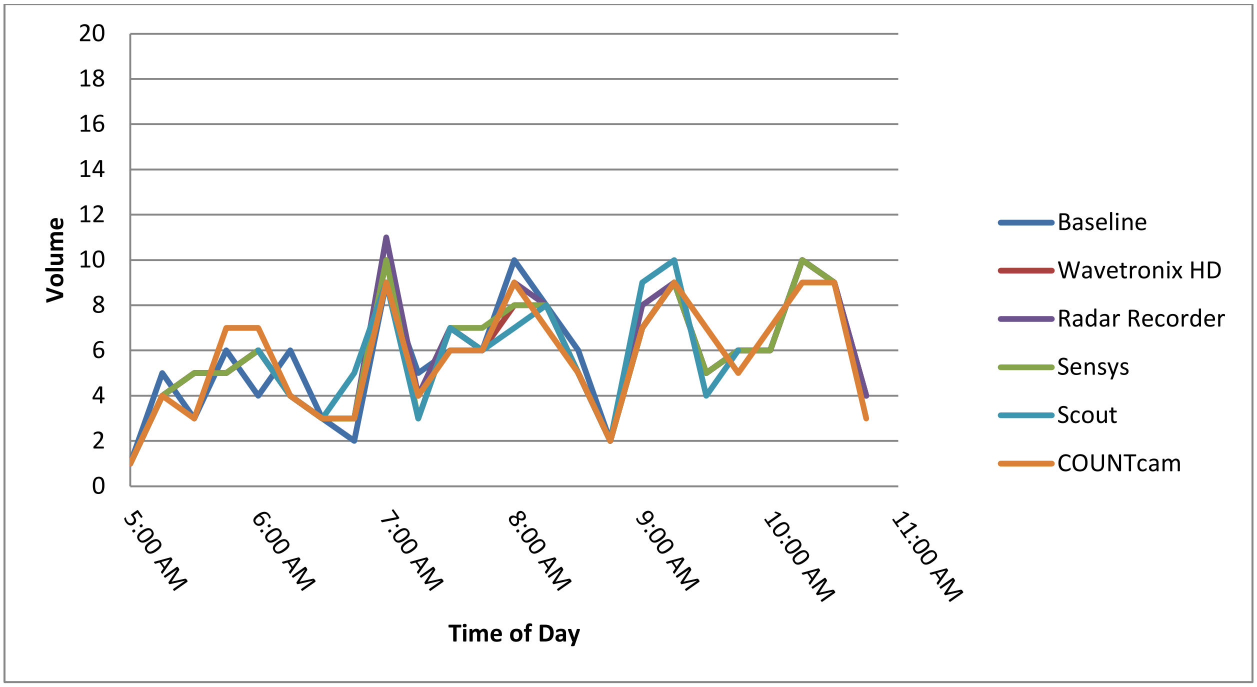


Table A.8 Northbound Volume Comparison – Morning Peak Period – 5/24/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	3	3	3	No Data	No Data	3	No Data	3
05:15 - 05:30 AM	4	4	4			4		4
05:30 - 05:45 AM	9	9	9			9		9
05:45 - 06:00 AM	3	3	3			3		3
06:00 - 06:15 AM	1	1	1			1		1
06:15 - 06:30 AM	10	7	8			8		6
06:30 - 06:45 AM	9	10	9			10		10
06:45 - 07:00 AM	11	11	11			15		13
07:00 - 07:15 AM	17	16	18			20		18
07:15 - 07:30 AM	18	18	17			18		18
07:30 - 07:45 AM	7	6	7			7		5
07:45 - 08:00 AM	10	12	10			10		12
08:00 - 08:15 AM	7	7	9			9		8
08:15 - 08:30 AM	9	8	6			10		8
08:30 - 08:45 AM	11	11	11			12		11
08:45 - 09:00 AM	14	11	13			15		12
09:00 - 09:15 AM	7	8	No Data			7		8
09:15 - 09:30 AM	13	12				14		10
09:30 - 09:45 AM	16	12				12		12
09:45 - 10:00 AM	12	12				17		12
10:00 - 10:15 AM	6	4				5		4
10:15 - 10:30 AM	11	11				10		10
10:30 - 10:45 AM	10	8				8		8
10:45 - 11:00 AM	15	15				18		16
Total	**233**	**219**	**N/A**			**245**		**221**
Percent Error	**N/A**	**-6.0%**	**-2.8%**			**5.2%**		**-5.2%**

Figure A.5 - Volume Comparison Northbound Morning Peak Period 5/24/2013

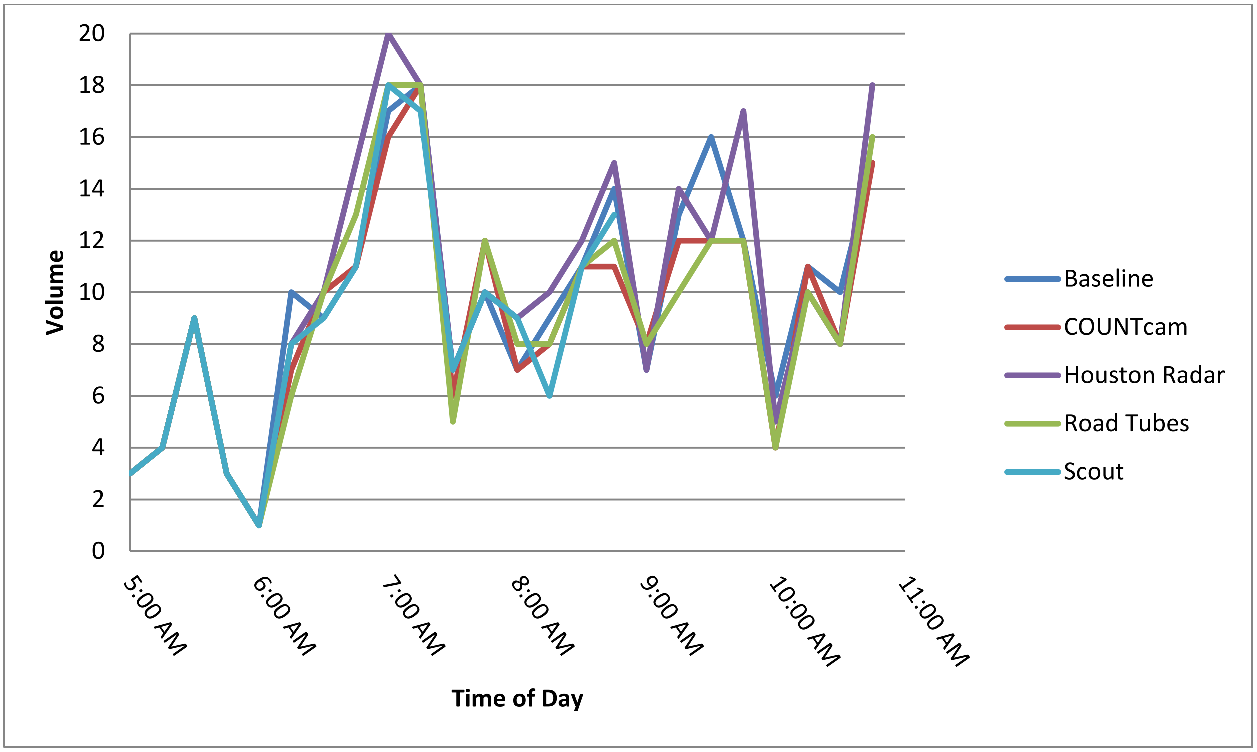


Table A.9 Northbound Volume Comparison – Morning Peak Period – 6/11/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
05:00 - 05:15 AM	2	No Data	No Data	No Data	3	2	No Data	No Data
05:15 - 05:30 AM	3				3	3		
05:30 - 05:45 AM	10				10	10		
05:45 - 06:00 AM	1				0	1		
06:00 - 06:15 AM	5				4	4		
06:15 - 06:30 AM	10				9	9		
06:30 - 06:45 AM	12				12	12		
06:45 - 07:00 AM	4				5	4		
07:00 - 07:15 AM	8				7	8		
07:15 - 07:30 AM	13				13	12		
07:30 - 07:45 AM	15				14	14		
07:45 - 08:00 AM	8				9	9		
08:00 - 08:15 AM	14				13	13		
08:15 - 08:30 AM	8				9	8		
08:30 - 08:45 AM	8				8	8		
08:45 - 09:00 AM	5				6	5		
09:00 - 09:15 AM	8				8	8		
09:15 - 09:30 AM	5				5	5		
09:30 - 09:45 AM	13				13	13		
09:45 - 10:00 AM	9				8	9		
10:00 - 10:15 AM	9				8	7		
10:15 - 10:30 AM	10				8	9		
10:30 - 10:45 AM	7				8	7		
10:45 - 11:00 AM	10				10	10		
Total	**197**				**193**	**190**		
Percent Error	**N/A**				**-2.0%**	**-3.6%**		

Figure A.6 - Volume Comparison Northbound Morning Peak Period 6/11/2013

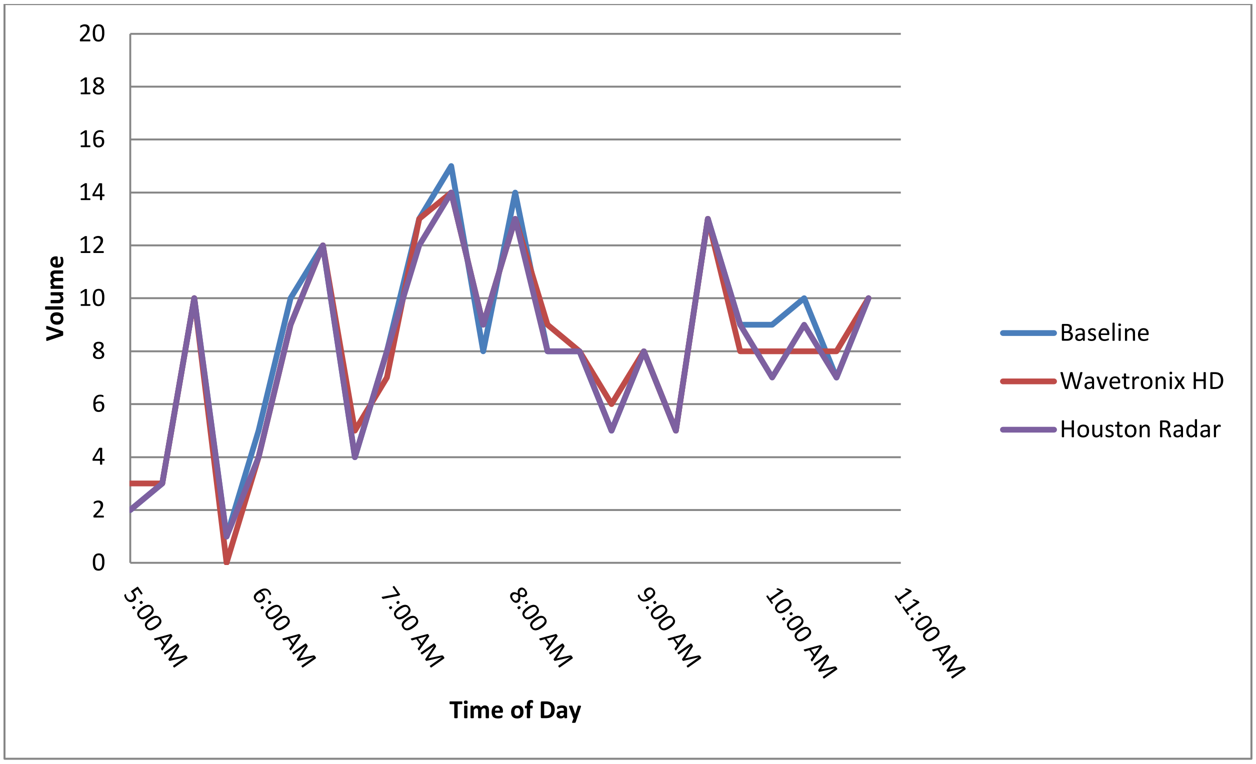


Table A.10 Southbound Volume Comparison – Afternoon Peak Period – 1/29/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	6	5	6	6	6	No Data	6	No Data
02:15 - 02:30 PM	7	7	5	6	6		6	
02:30 - 02:45 PM	6	4	6	6	6		6	
02:45 - 03:00 PM	6	8	6	6	6		6	
03:00 - 03:15 PM	10	8	10	9	10		8	
03:15 - 03:30 PM	10	12	10	9	10		11	
03:30 - 03:45 PM	11	10	12	11	11		10	
03:45 - 04:00 PM	17	18	16	17	17		19	
04:00 - 04:15 PM	14	14	13	13	14		12	
04:15 - 04:30 PM	12	11	12	11	11		12	
04:30 - 04:45 PM	11	10	12	11	11		11	
04:45 - 05:00 PM	9	9	9	8	8		8	
05:00 - 05:15 PM	11	12	11	12	12		12	
05:15 - 05:30 PM	9	8	9	9	9		9	
05:30 - 05:45 PM	10	11	10	10	10		10	
05:45 - 06:00 PM	10	8	10	11	10		9	
06:00 - 06:15 PM	4	5	No Data	4	4		4	
06:15 - 06:30 PM	8	8		8	7		7	
06:30 - 06:45 PM	6	4		5	5		5	
06:45 - 07:00 PM	5	6		6	6		6	
07:00 - 07:15 PM	2	2		2	2		2	
07:15 - 07:30 PM	2	1		2	2		2	
07:30 - 07:45 PM	5	6		5	5		5	
07:45 - 08:00 PM	4	3		4	4		5	
Total	**195**	**190**	**N/A**	**191**	**192**		**191**	
Percent Error	**N/A**	**-2.6%**	**-1.3%**	**-2.1%**	**-1.5%**		**-2.1%**	

Figure A.7 - Volume Comparison Southbound Afternoon Peak Period 1/29/2013

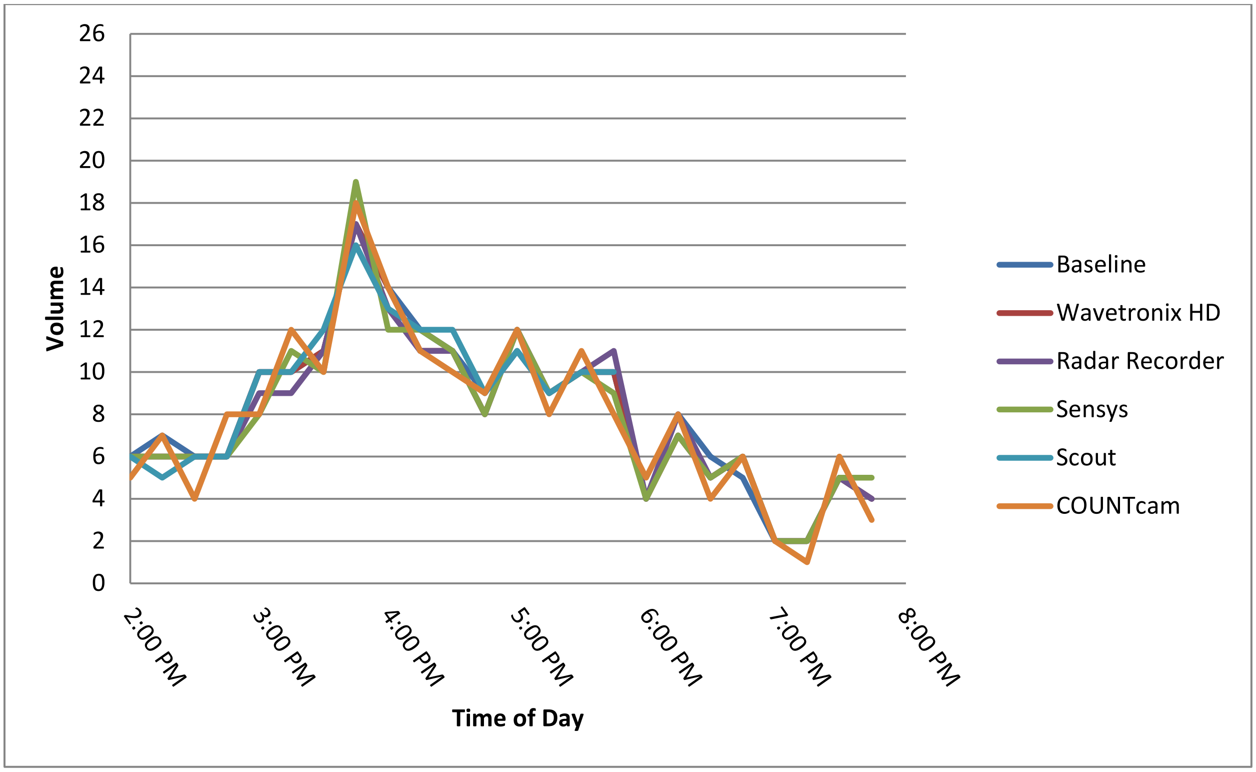


Table A.11 Southbound Volume Comparison – Afternoon Peak Period – 5/24/2013

Legend

(white)	Baseline values
(light green)	Less than 15% error from baseline
(orange)	15% - 30% error from baseline
(red)	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	13	15	13	No Data	No Data	15	No Data	14
02:15 - 02:30 PM	12	12	12			12		12
02:30 - 02:45 PM	14	14	15			14		9
02:45 - 03:00 PM	10	11	11			11		11
03:00 - 03:15 PM	15	14	14			15		13
03:15 - 03:30 PM	15	16	16			15		15
03:30 - 03:45 PM	15	14	13			14		14
03:45 - 04:00 PM	14	13	13			13		13
04:00 - 04:15 PM	18	17	19			18		15
04:15 - 04:30 PM	12	10	10			10		9
04:30 - 04:45 PM	25	22	25			25		18
04:45 - 05:00 PM	15	23	14			15		18
05:00 - 05:15 PM	16	19	No Data			16		14
05:15 - 05:30 PM	12	13				12		10
05:30 - 05:45 PM	12	10				10		9
05:45 - 06:00 PM	14	14				13		12
06:00 - 06:15 PM	13	12				13		12
06:15 - 06:30 PM	7	8				7		7
06:30 - 06:45 PM	8	8				8		7
06:45 - 07:00 PM	9	10				9		9
07:00 - 07:15 PM	5	6				5		6
07:15 - 07:30 PM	12	14				12		11
07:30 - 07:45 PM	10	11				9		10
07:45 - 08:00 PM	5	4				5		4
Total	**301**	**310**	**N/A**			**296**		**272**
Percent Error	**N/A**	**3.0%**	**-1.7%**			**-1.7%**		**-9.6%**

Figure A.8 - Volume Comparison Southbound Afternoon Peak Period 5/24/2013

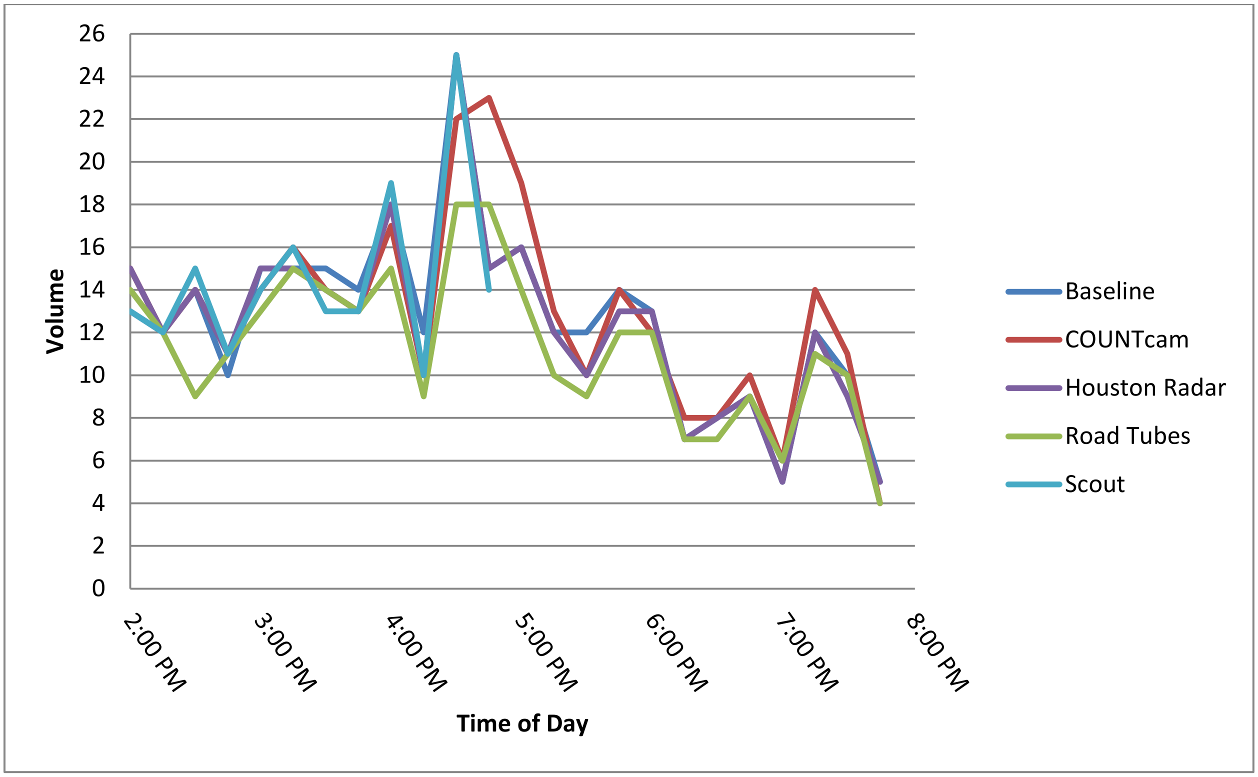


Table A.12 Southbound Volume Comparison – Afternoon Peak Period – 6/11/2013

Legend

(white)	Baseline values
(light green)	Less than 15% error from baseline
(yellow)	15% - 30% error from baseline
(red)	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	12	No Data	No Data	No Data	9	14	No Data	No Data
02:15 - 02:30 PM	12				12	13		
02:30 - 02:45 PM	10				10	9		
02:45 - 03:00 PM	12				10	11		
03:00 - 03:15 PM	18				17	17		
03:15 - 03:30 PM	16				13	15		
03:30 - 03:45 PM	14				16	14		
03:45 - 04:00 PM	11				10	11		
04:00 - 04:15 PM	13				11	11		
04:15 - 04:30 PM	15				11	9		
04:30 - 04:45 PM	14				11	13		
04:45 - 05:00 PM	15				16	15		
05:00 - 05:15 PM	17				12	13		
05:15 - 05:30 PM	19				17	19		
05:30 - 05:45 PM	12				12	10		
05:45 - 06:00 PM	15				15	16		
06:00 - 06:15 PM	11				11	11		
06:15 - 06:30 PM	12				13	12		
06:30 - 06:45 PM	9				8	7		
06:45 - 07:00 PM	5				6	7		
07:00 - 07:15 PM	7				5	8		
07:15 - 07:30 PM	10				12	10		
07:30 - 07:45 PM	4				3	3		
07:45 - 08:00 PM	4				4	5		
Total	**287**				**264**	**273**		
Percent Error	**N/A**				**-8.0%**	**-4.9%**		

Figure A.9 - Volume Comparison Southbound Afternoon Peak Period 6/11/2013

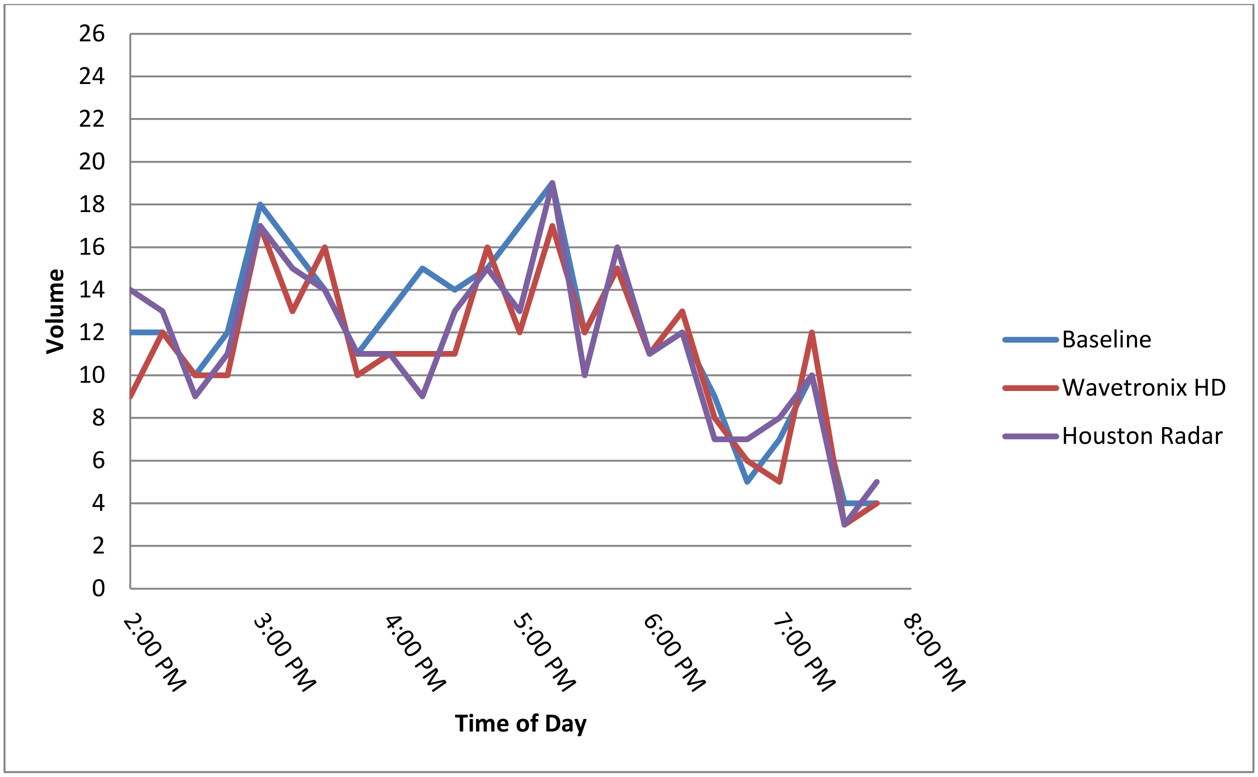


Table A.13 Northbound Volume Comparison – Afternoon Peak Period – 1/29/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	7	9	7	7	7	No Data	7	No Data
02:15 - 02:30 PM	9	8	9	9	10		9	
02:30 - 02:45 PM	8	9	8	8	8		8	
02:45 - 03:00 PM	8	8	8	8	8		8	
03:00 - 03:15 PM	5	5	7	5	5		5	
03:15 - 03:30 PM	11	11	10	11	11		11	
03:30 - 03:45 PM	13	13	13	13	13		13	
03:45 - 04:00 PM	13	13	13	14	13		13	
04:00 - 04:15 PM	14	14	13	14	13		13	
04:15 - 04:30 PM	14	13	15	14	14		14	
04:30 - 04:45 PM	15	15	13	14	14		13	
04:45 - 05:00 PM	15	14	15	15	15		15	
05:00 - 05:15 PM	9	8	9	8	7		7	
05:15 - 05:30 PM	20	21	21	22	23		23	
05:30 - 05:45 PM	8	8	9	8	8		8	
05:45 - 06:00 PM	11	11	11	11	11		11	
06:00 - 06:15 PM	10	10	No Data	10	10		9	
06:15 - 06:30 PM	6	6		5	6		4	
06:30 - 06:45 PM	4	4		4	4		4	
06:45 - 07:00 PM	2	2		2	2		2	
07:00 - 07:15 PM	4	4		4	4		4	
07:15 - 07:30 PM	4	3		4	4		4	
07:30 - 07:45 PM	3	4		3	3		3	
07:45 - 08:00 PM	3	3		3	3		3	
Total	**216**	**216**	**N/A**	**216**	**216**		**211**	
Percent Error	**N/A**	**0.0%**	**0.6%**	**0.0%**	**0.0%**		**-2.3%**	

Figure A.10 - Volume Comparison Northbound Afternoon Peak Period 1/29/2013

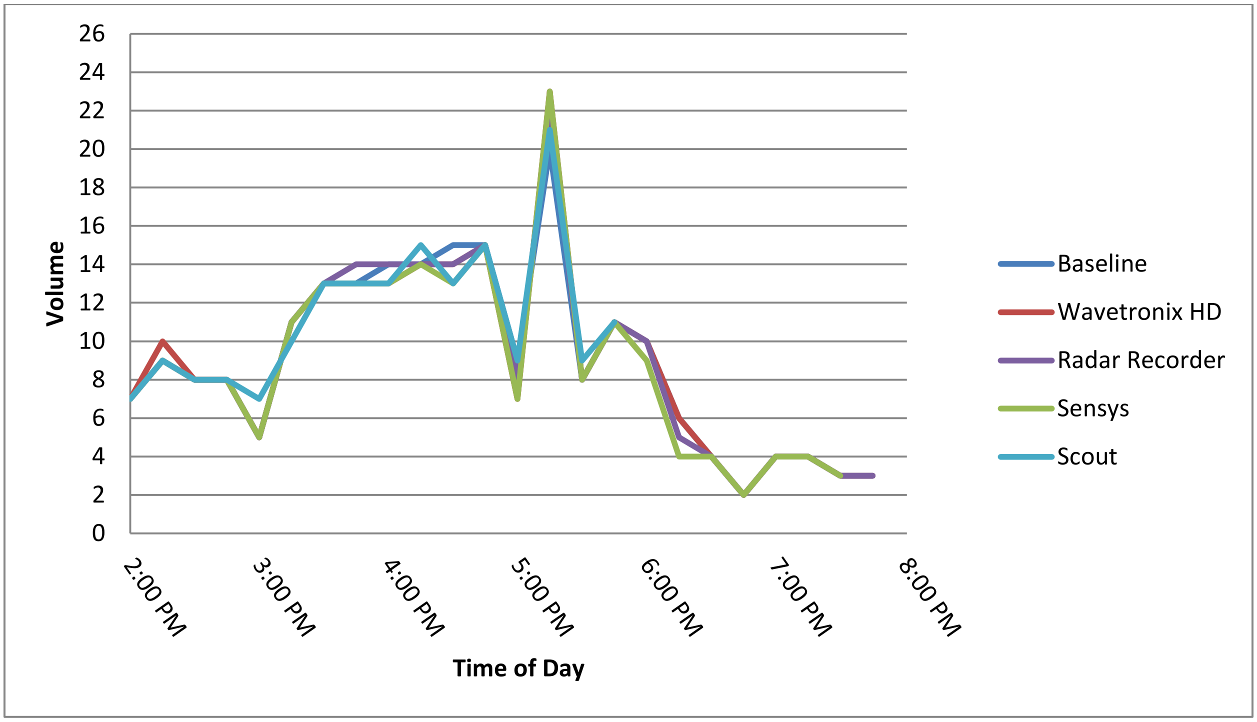


Table A.14 Northbound Volume Comparison – Afternoon Peak Period – 5/24/2013

Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	19	16	17	No Data	No Data	17	No Data	16
02:15 - 02:30 PM	20	19	18			22		19
02:30 - 02:45 PM	16	14	15			14		13
02:45 - 03:00 PM	14	10	12			12		11
03:00 - 03:15 PM	16	16	15			15		16
03:15 - 03:30 PM	22	21	21			21		19
03:30 - 03:45 PM	25	21	22			24		20
03:45 - 04:00 PM	17	18	17			20		18
04:00 - 04:15 PM	23	21	22			23		19
04:15 - 04:30 PM	21	20	23			25		20
04:30 - 04:45 PM	23	22	19			21		21
04:45 - 05:00 PM	18	17	18			18		15
05:00 - 05:15 PM	22	23	No Data			22		24
05:15 - 05:30 PM	11	10				10		6
05:30 - 05:45 PM	23	20				23		21
05:45 - 06:00 PM	14	14				14		14
06:00 - 06:15 PM	18	16				18		17
06:15 - 06:30 PM	22	22				22		21
06:30 - 06:45 PM	15	16				17		16
06:45 - 07:00 PM	5	5				6		5
07:00 - 07:15 PM	13	12				13		12
07:15 - 07:30 PM	11	12				11		12
07:30 - 07:45 PM	3	3				3		3
07:45 - 08:00 PM	5	5				8		5
Total	**396**	**373**	**N/A**			**399**		**363**
Percent Error	**N/A**	**-5.8%**	**-6.4%**			**0.8%**		**-8.3%**

Figure A.11 - Volume Comparison Northbound Afternoon Peak Period 5/24/2013

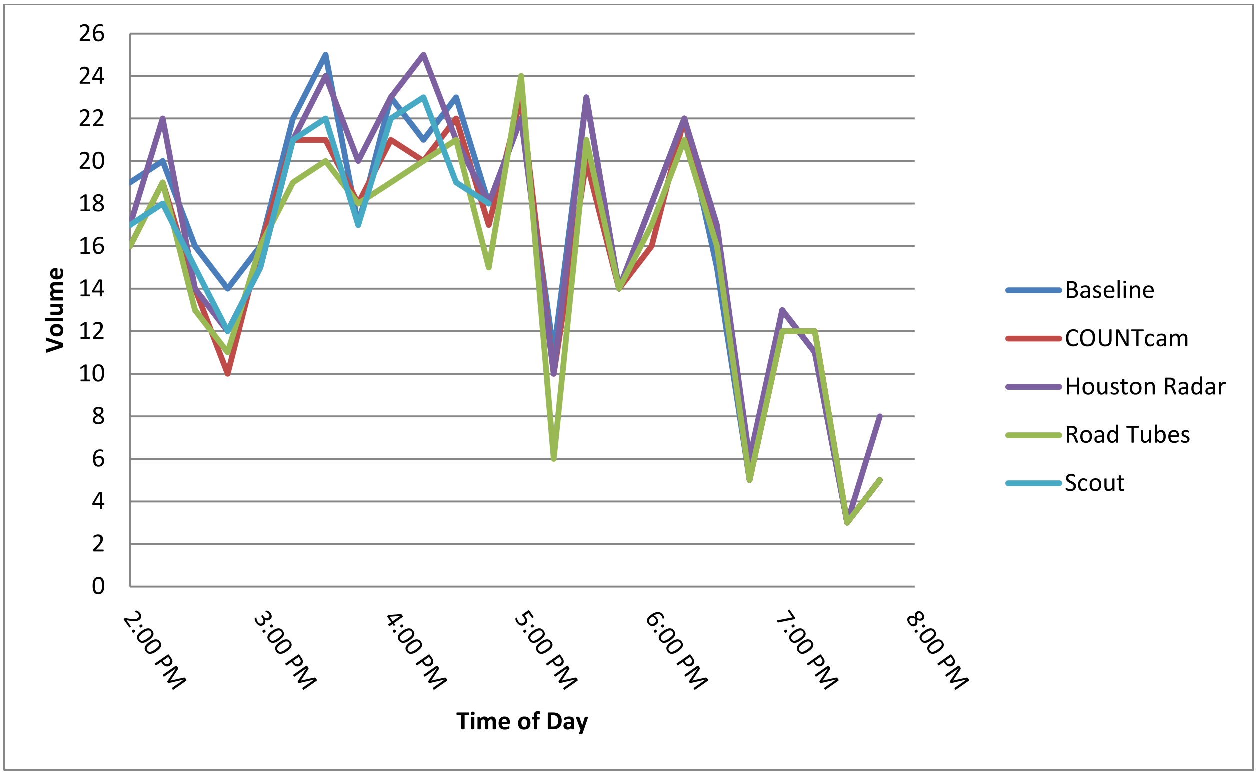


Table A.15 Northbound Volume Comparison – Afternoon Peak Period – 6/11/2013

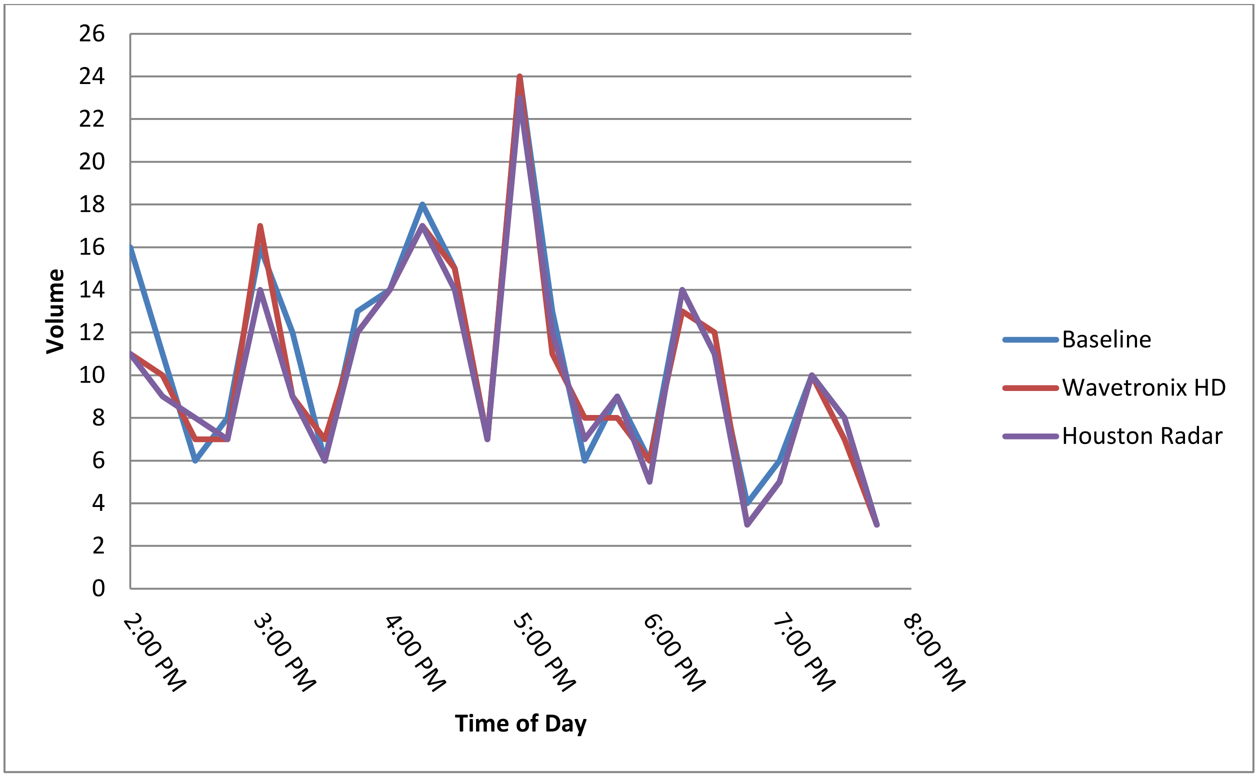
Legend

	Baseline values
	Less than 15% error from baseline
	15% - 30% error from baseline
	Greater than 30% error from baseline

* Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.
* The Stealth Stud sensor failed in the field, so it is not included in the table below.

Time	Baseline	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
02:00 - 02:15 PM	16	No Data	No Data	No Data	11	11	No Data	No Data
02:15 - 02:30 PM	11				10	9		
02:30 - 02:45 PM	6				7	8		
02:45 - 03:00 PM	8				7	7		
03:00 - 03:15 PM	16				17	14		
03:15 - 03:30 PM	12				9	9		
03:30 - 03:45 PM	6				7	6		
03:45 - 04:00 PM	13				12	12		
04:00 - 04:15 PM	14				14	14		
04:15 - 04:30 PM	18				17	17		
04:30 - 04:45 PM	15				15	14		
04:45 - 05:00 PM	7				7	7		
05:00 - 05:15 PM	24				24	23		
05:15 - 05:30 PM	13				11	12		
05:30 - 05:45 PM	6				8	7		
05:45 - 06:00 PM	9				8	9		
06:00 - 06:15 PM	6				6	5		
06:15 - 06:30 PM	14				13	14		
06:30 - 06:45 PM	11				12	11		
06:45 - 07:00 PM	4				3	3		
07:00 - 07:15 PM	6				5	5		
07:15 - 07:30 PM	10				10	10		
07:30 - 07:45 PM	8				7	8		
07:45 - 08:00 PM	3				3	3		
Total	**256**				**243**	**238**		
Percent Error	**N/A**				**-5.1%**	**-7.0%**		

Figure A.12 - Volume Comparison Northbound Afternoon Peak Period 6/11/2013



Appendix B: Speed Data Analysis Tables

Sensor speed data were binned into five mile per hour increments. The baseline and sensor data were compared per bin to determine an average percent error per period. The absolute average of these intervals is presented in the bottom row below.

Absent data is represented by cells displaying "No Data." These do not indicate failure of a particular sensor to record data, but rather that the sensor was not available or set to record.

The COUNTcam and Scout do not report speed information and are omitted.

	COUNTcam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
1/29/2013 Northbound	N/A*	N/A*	-1.3%	-1.8%	No Data	-8.9%	No Data
1/29/2013 Southbound			-1.0%	0.0%	No Data	-2.9%	No Data
5/24/2013 Northbound			No Data	No Data	-1.2%	No Data	-1.4%
5/24/2013 Southbound			No Data	No Data	-5.7%	No Data	-7.0%
6/11/2013 Northbound			No Data	-2.2%	-5.4%	No Data	No Data
6/11/2013 Southbound			No Data	-0.6%	-1.5%	No Data	No Data
Absolute Average Percent Error			**1.2%**	**1.2%**	**3.5%**	**5.9%**	**4.2%**

* This device does not record speeds

The detailed speed tables for each analysis period on each day follow. A bar chart is shown after each table.

Table B.1 Southbound Speed Comparison - 5:00AM to 11:00AM - 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	1			1	0		1	
15-20	0			0	0		0	
20-25	2			1	0		3	
25-30	2			3	0		3	
30-35	1			1	6		0	
35-40	13			11	13		14	
40-45	16			21	21		18	
45-50	18			18	20		24	
50-55	35			35	43		34	
55-60	50			48	39		44	
60-65	17			17	14		9	
65-70	4			4	2		3	
70-75	0			0	0		0	
>75	0			0	0		0	
Percent Error	**N/A**			**0.3%**	**-1.5%**		**-6.4%**	

* This device does not record speeds

Figure B. 1 - Southbound Speed Comparison - 5:00AM to 11:00AM - 1/29/2013

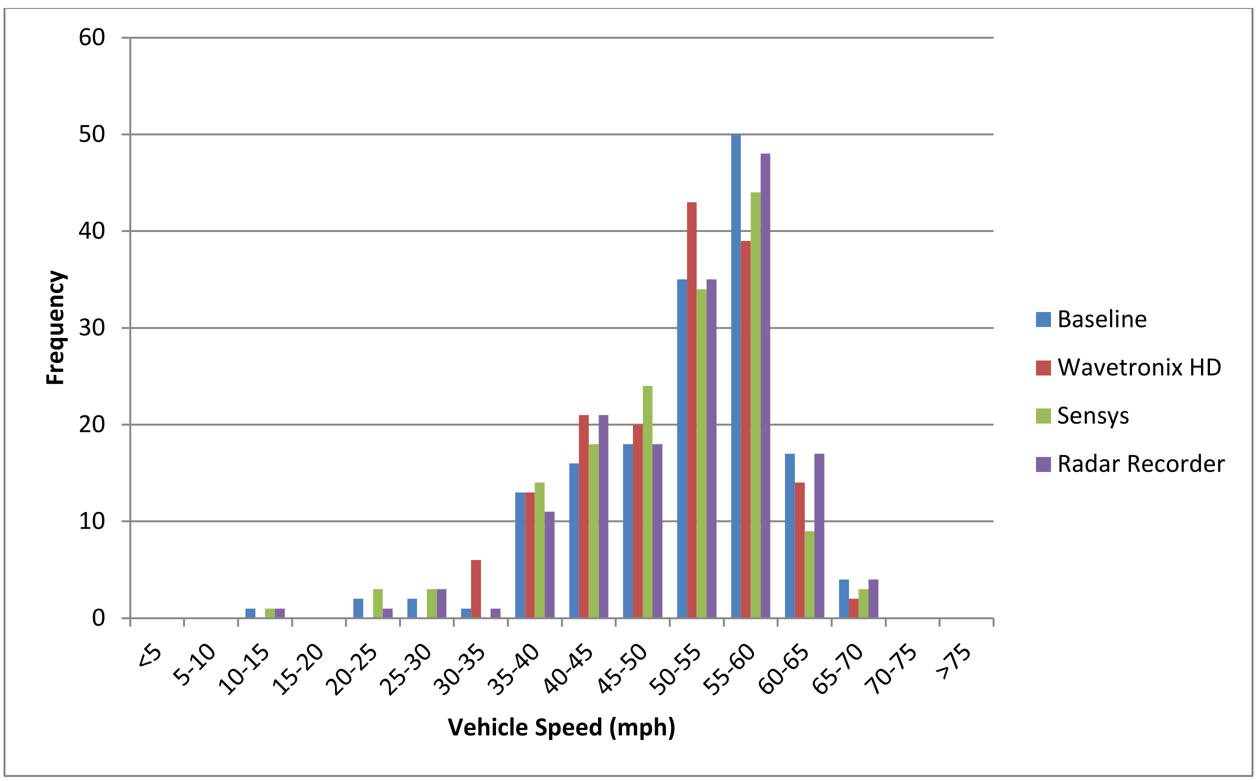


Table B.2 Northbound Speed Comparison - 5:00AM to 11:00AM - 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	0			0	0		0	
15-20	0			0	0		0	
20-25	0			0	0		0	
25-30	1			1	0		2	
30-35	2			2	3		1	
35-40	6			7	5		4	
40-45	9			6	8		6	
45-50	14			17	15		15	
50-55	37			33	27		31	
55-60	28			38	36		32	
60-65	33			29	34		26	
65-70	7			6	8		9	
70-75	1			1	1		2	
>75	0			0	0		0	
Percent Error	**N/A**			**-0.1%**	**1.2%**		**-3.3%**	

* This device does not record speeds

Figure B.2 - Northbound Speed Comparison - 5:00AM to 11:00AM - 1/29/2013

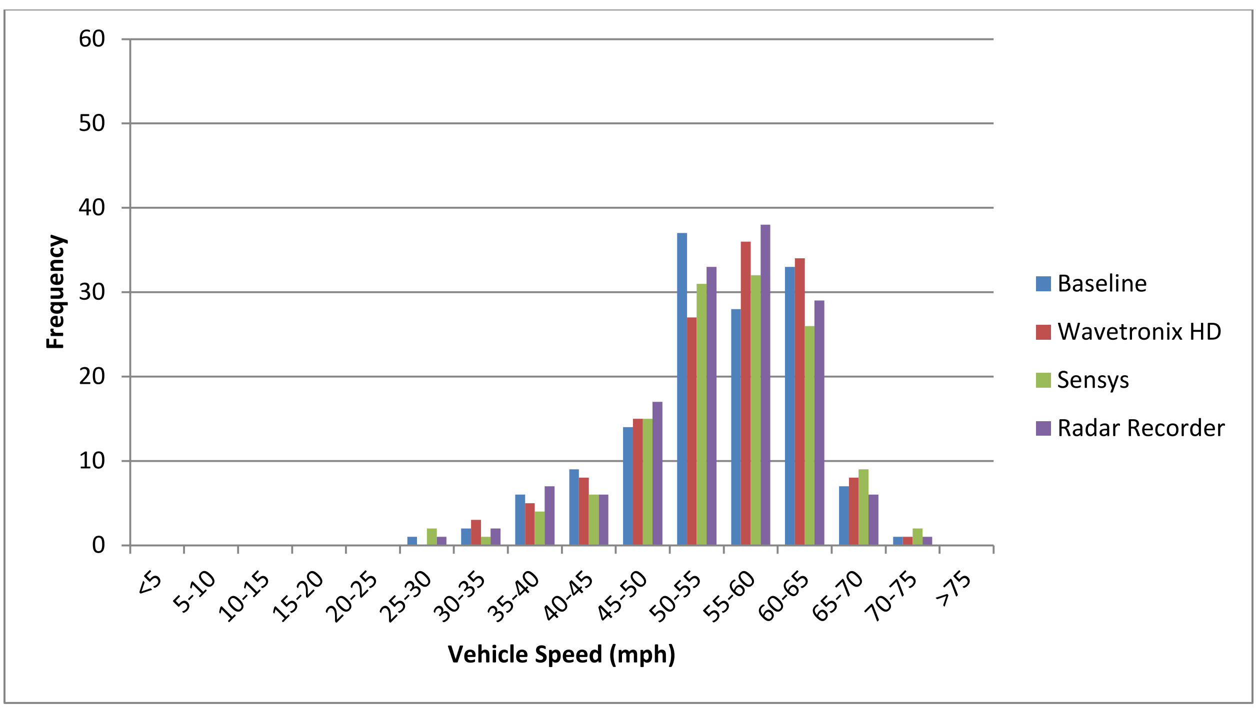


Table B.3 Southbound Speed Comparison - 5:00AM to 11:00AM - 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	0	No Data	0
5-10	0					0		0
10-15	0					0		0
15-20	0					0		1
20-25	0					0		0
25-30	1					0		0
30-35	0					0		1
35-40	1					0		1
40-45	1					1		1
45-50	5					13		5
50-55	9					33		10
55-60	77					134		86
60-65	109					51		87
65-70	26					11		26
70-75	1					0		1
>75	0					2		2
Percent Error	**N/A**					**-4.5%**		**-0.6%**

* This device does not record speeds

Figure B.3 - Southbound Speed Comparison - 5:00AM to 11:00AM - 5/24/2013

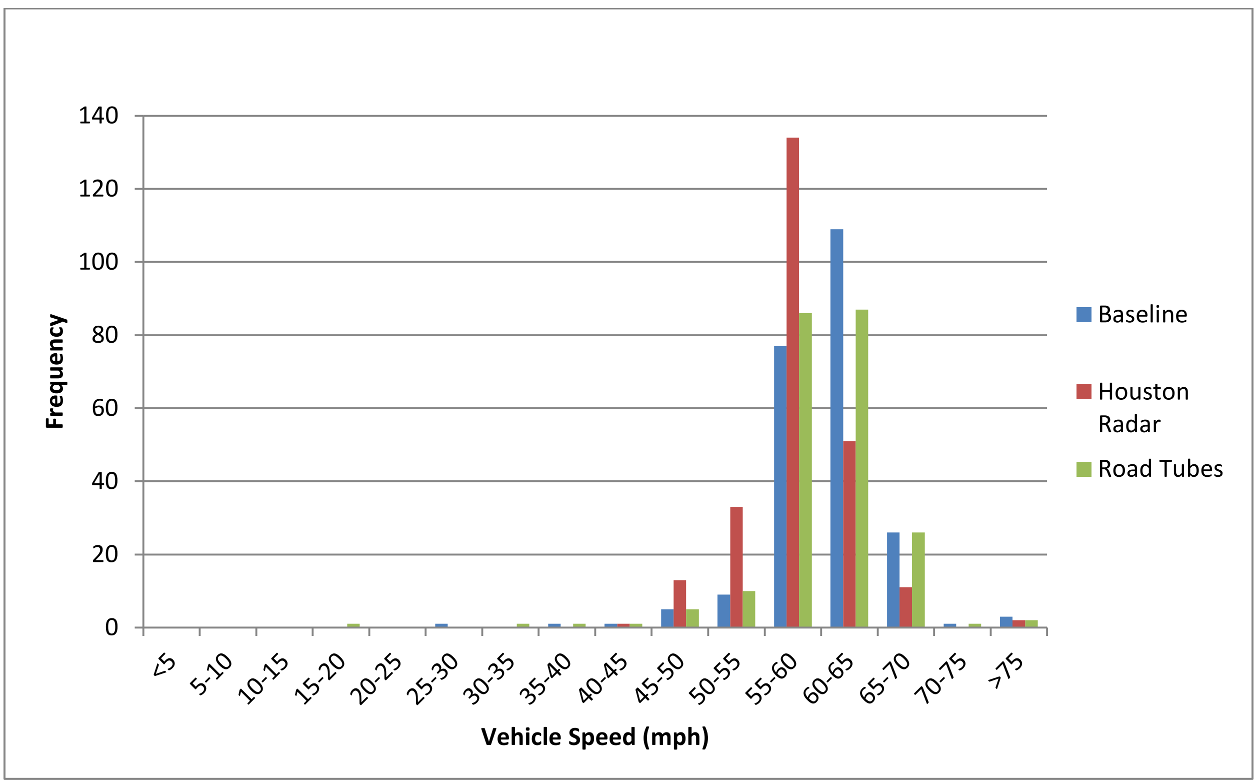


Table B.4 Northbound Speed Comparison - 5:00AM to 11:00AM - 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	0	No Data	0
5-10	0					0		0
10-15	0					0		0
15-20	0					0		0
20-25	0					0		0
25-30	0					0		0
30-35	0					0		1
35-40	0					0		0
40-45	0					1		1
45-50	1					8		5
50-55	5					11		8
55-60	8					77		49
60-65	66					57		83
65-70	81					14		17
70-75	12					1		4
>75	5					2		3
Percent Error	**N/A**					**-1.5%**		**-6.8%**

* This device does not record speeds

Figure B.4 - Northbound Speed Comparison - 5:00AM to 11:00AM - 5/24/2013

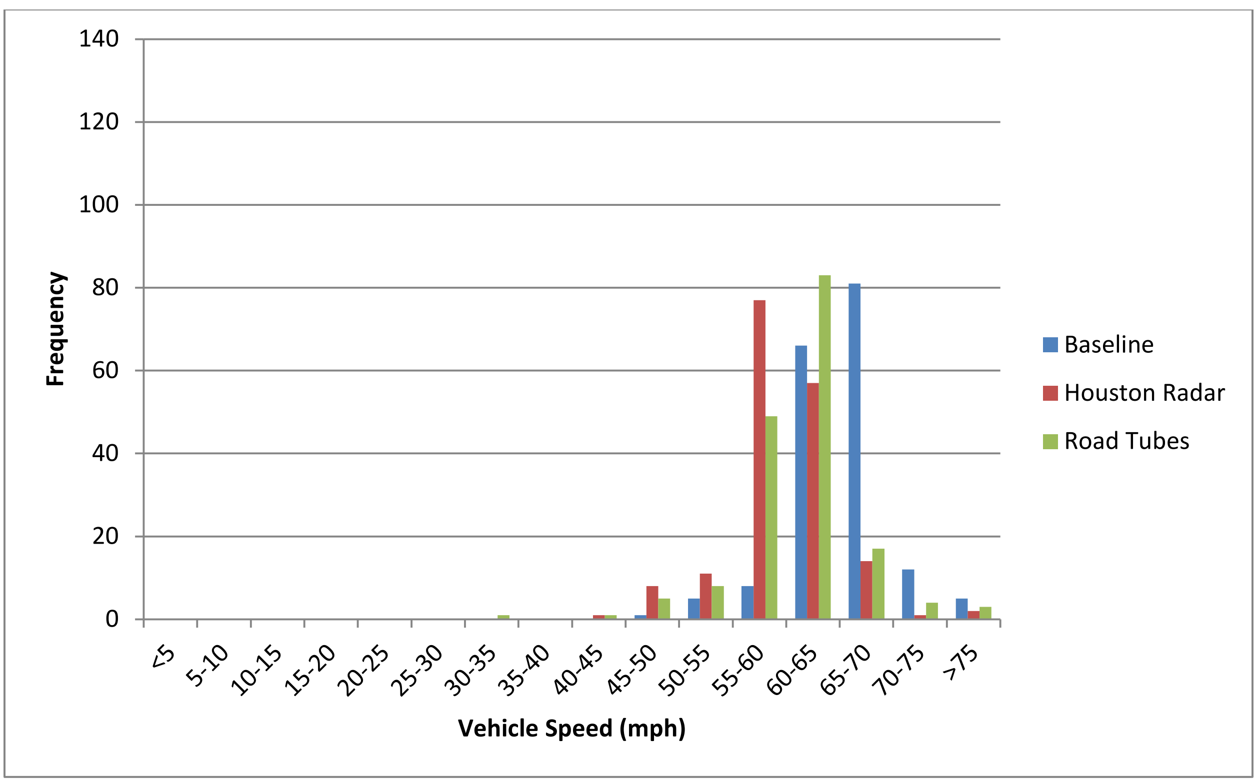


Table B.5 Southbound Speed Comparison - 5:00AM to 11:00AM - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	0		
10-15	1				0	0		
15-20	0				0	0		
20-25	1				0	2		
25-30	1				1	0		
30-35	0				1	1		
35-40	0				1	0		
40-45	2				2	2		
45-50	2				8	4		
50-55	29				36	33		
55-60	106				119	120		
60-65	94				64	62		
65-70	14				6	11		
70-75	2				3	2		
>75	4				2	1		
Percent Error	**N/A**				**-2.0%**	**-4.2%**		

* This device does not record speeds

Figure B.5 - Southbound Speed Comparison - 5:00AM to 11:00AM - 6/11/2013

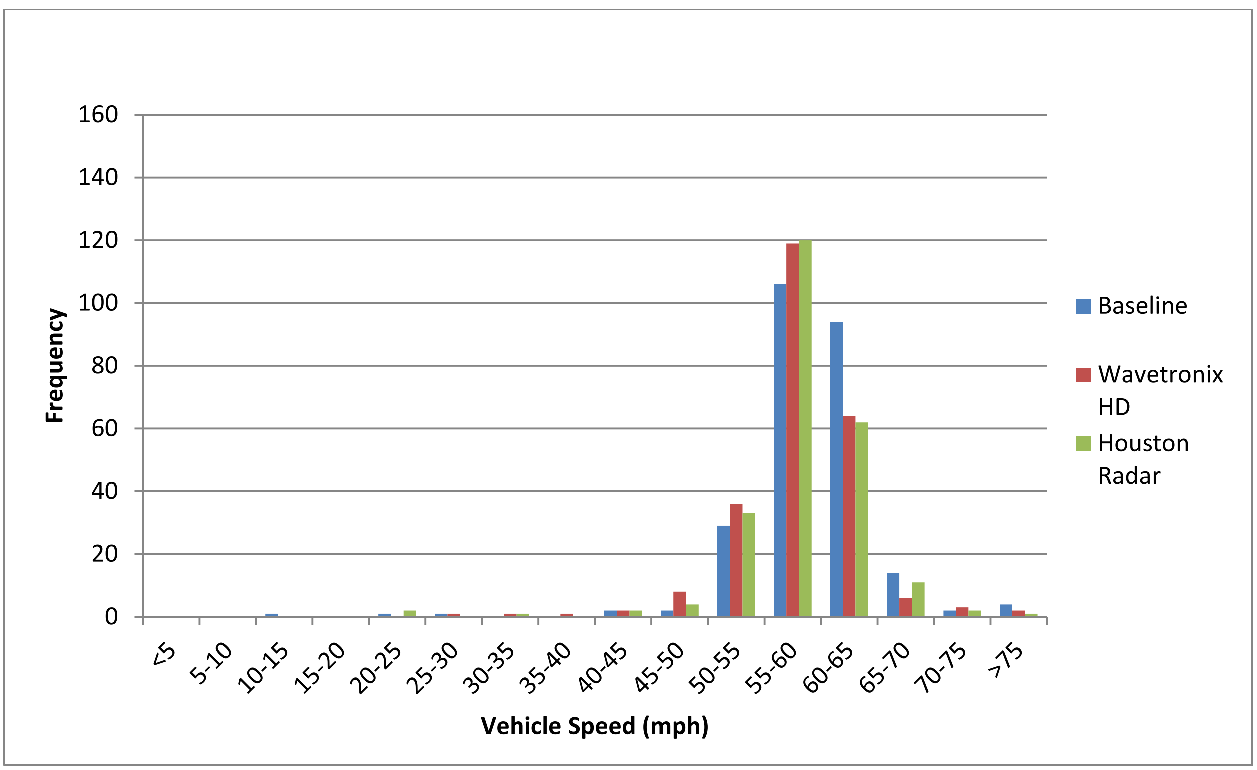


Table B.6 Northbound Speed Comparison - 5:00AM to 11:00AM - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	0		
10-15	0				0	0		
15-20	1				0	0		
20-25	0				0	0		
25-30	0				0	0		
30-35	1				1	1		
35-40	3				3	3		
40-45	2				5	3		
45-50	4				8	7		
50-55	24				50	40		
55-60	126				150	96		
60-65	92				41	95		
65-70	24				13	17		
70-75	9				1	2		
>75	1				1	0		
Percent Error	**N/A**				**-3.9%**	**-1.1%**		

* This device does not record speeds

Figure B.6 - Northbound Speed Comparison - 5:00AM to 11:00AM - 6/11/2013

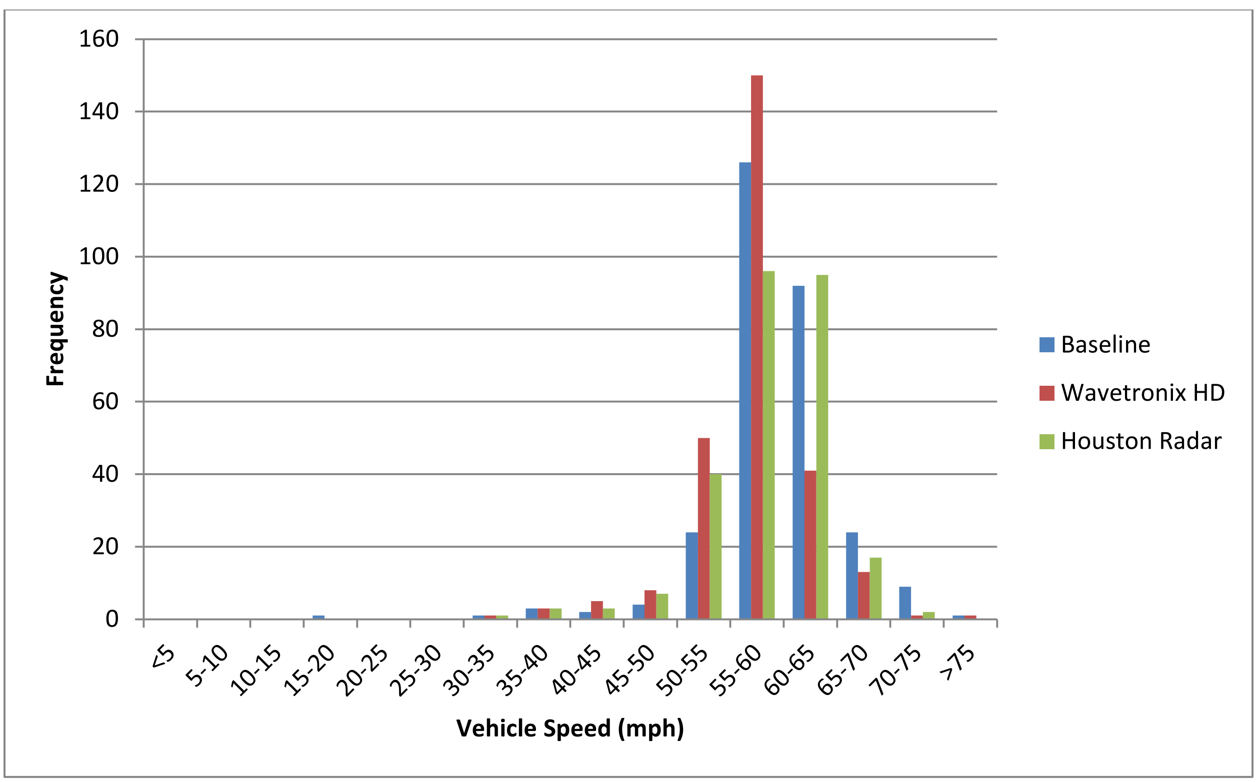


Table B.7 Southbound Speed Comparison - 2:00PM to 8:00PM - 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	0			0	0		0	
15-20	0			0	0		0	
20-25	0			0	0		0	
25-30	0			0	0		0	
30-35	0			0	0		0	
35-40	0			0	1		0	
40-45	1			3	0		1	
45-50	8			9	11		10	
50-55	19			31	33		30	
55-60	89			93	90		96	
60-65	63			48	48		35	
65-70	13			7	8		8	
70-75	1			0	1		0	
>75	0			0	0		0	
Percent Error	**N/A**			**-2.2%**	**-2.0%**		**3.4%**	

* This device does not record speeds

Figure B.7 - Southbound Speed Comparison - 2:00PM to 8:00PM - 1/29/2013

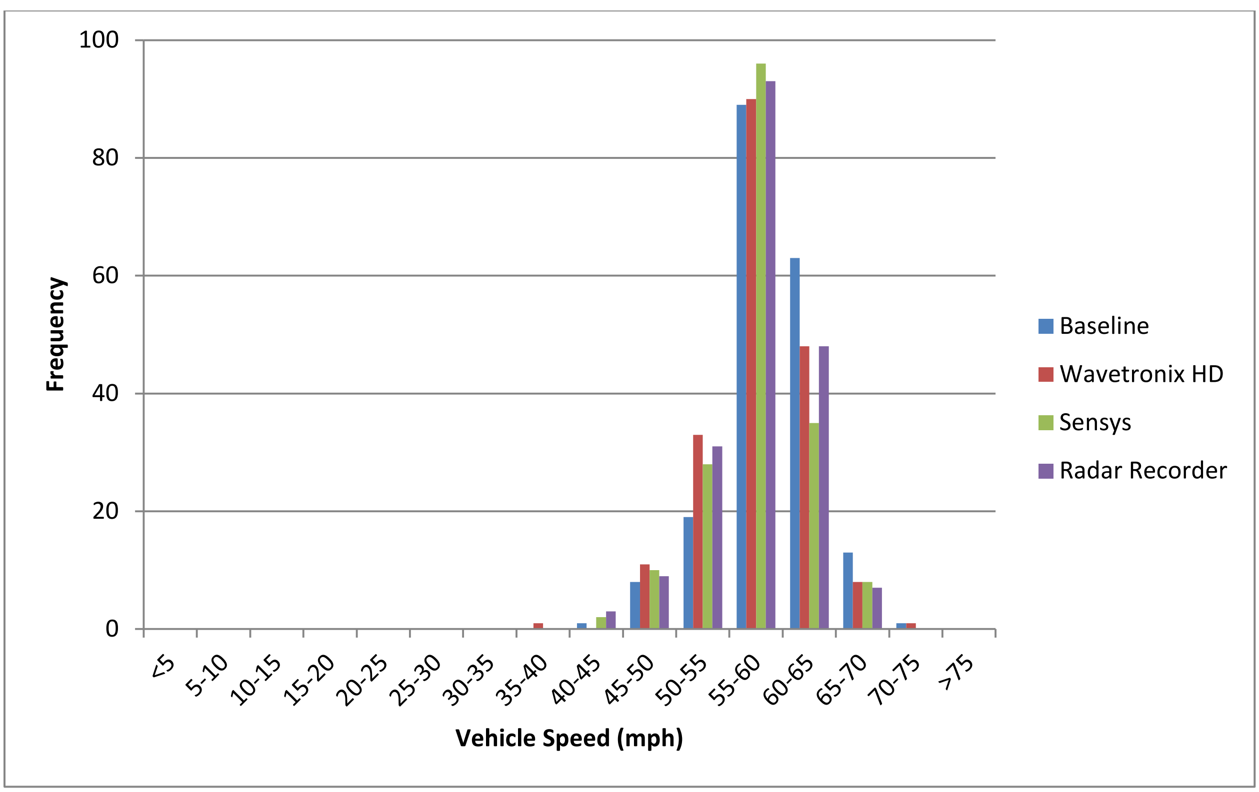


Table B.8 Northbound Speed Comparison - 2:00PM to 8:00PM - 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	0			0	0		0	
15-20	0			0	0		0	
20-25	0			0	0		0	
25-30	0			0	0		0	
30-35	0			0	0		0	
35-40	0			0	0		0	
40-45	2			2	1		1	
45-50	3			2	3		5	
50-55	17			24	35		15	
55-60	84			98	74		71	
60-65	92			76	85		87	
65-70	13			8	9		18	
70-75	5			6	8		5	
>75	0			0	1		4	
Percent Error	**N/A**			**-1.1%**	**-0.7%**		**-1.3%**	

* This device does not record speeds

Figure B.8 - Northbound Speed Comparison - 2:00PM to 8:00PM - 1/29/2013

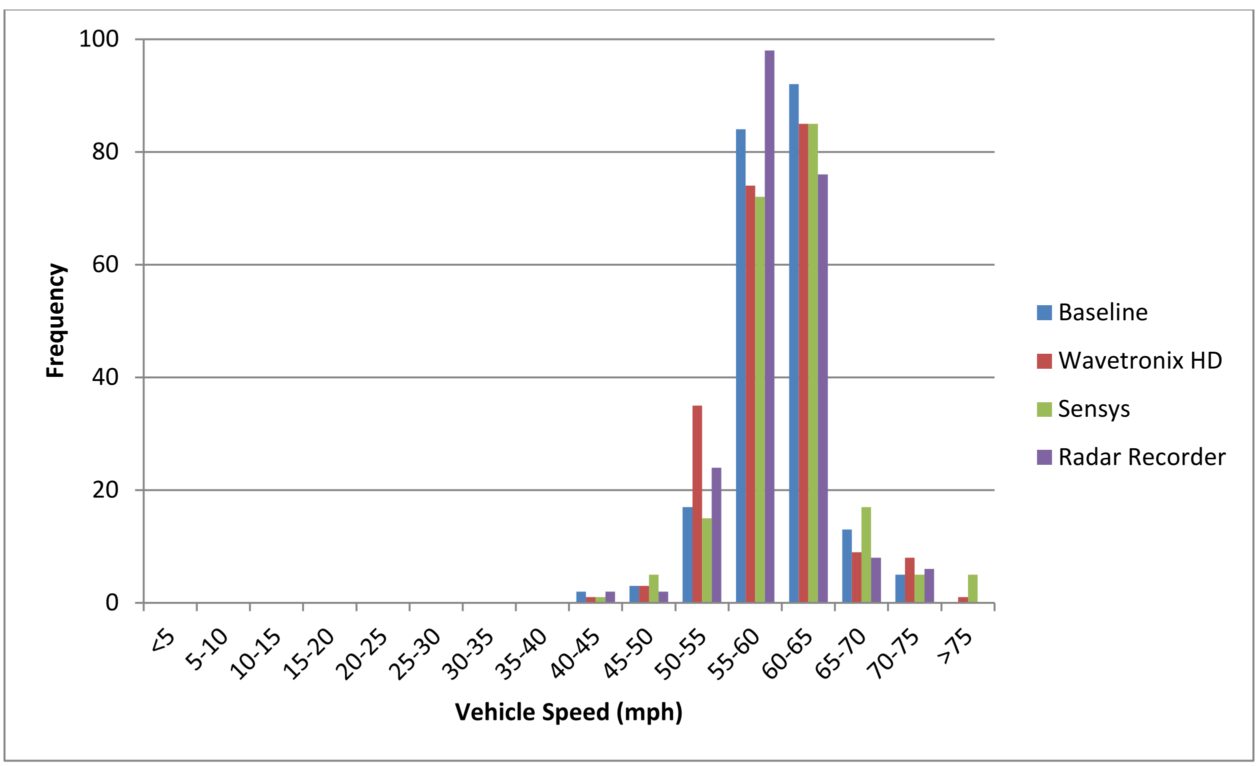


Table B.9 Southbound Speed Comparison - 2:00PM to 8:00PM - 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	0	No Data	0
5-10	0					0		0
10-15	0					0		0
15-20	0					0		0
20-25	0					0		0
25-30	0					0		1
30-35	0					0		2
35-40	1					1		1
40-45	0					5		2
45-50	10					17		6
50-55	33					76		40
55-60	118					198		141
60-65	197					88		147
65-70	27					11		18
70-75	6					3		4
>75	4					0		1
Percent Error	**N/A**					**-5.2%**		**-2.0%**

* This device does not record speeds

Figure B.9 - Southbound Speed Comparison - 2:00PM to 8:00PM - 5/24/2013

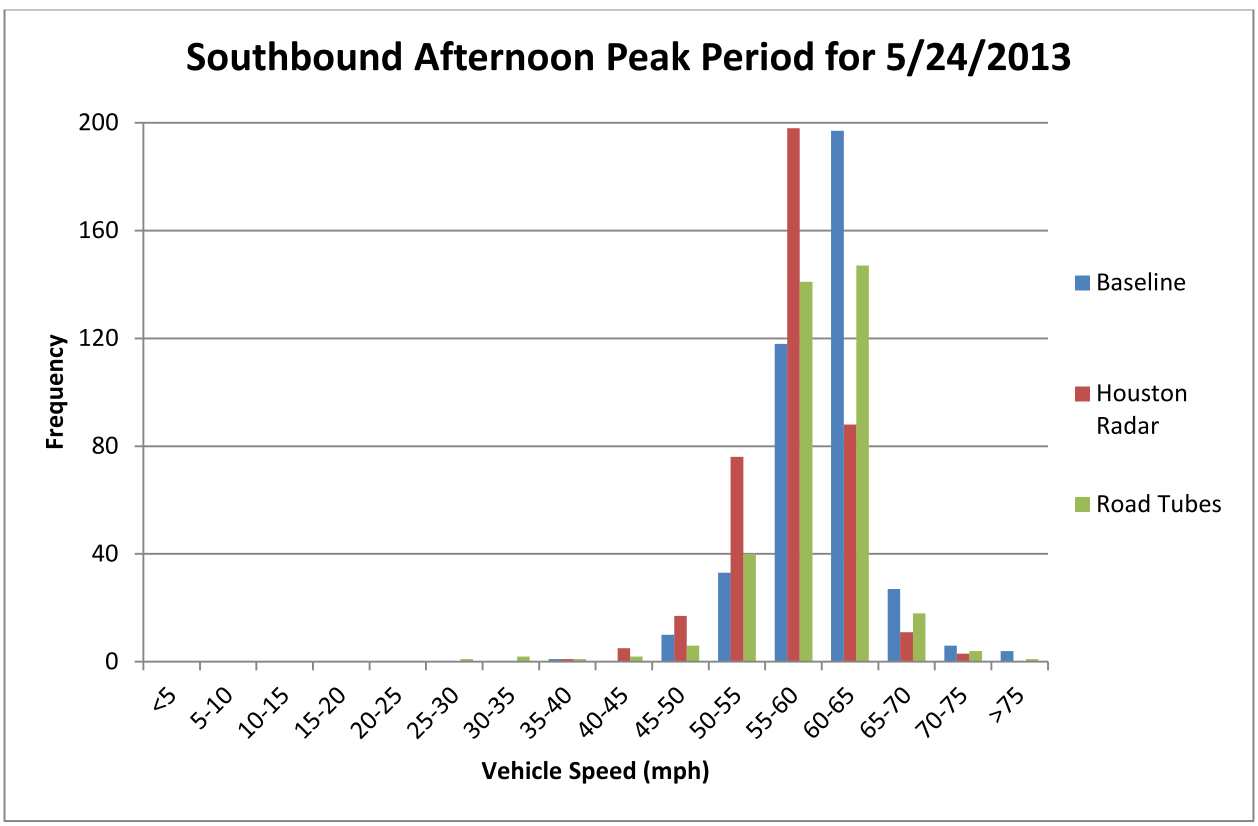


Table B.10 Northbound Speed Comparison - 2:00PM to 8:00PM - 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	0	No Data	0
5-10	0					0		0
10-15	0					0		0
15-20	0					0		0
20-25	0					0		0
25-30	0					0		0
30-35	0					1		0
35-40	0					0		0
40-45	0					0		2
45-50	2					7		2
50-55	4					29		25
55-60	29					144		96
60-65	133					92		118
65-70	105					15		18
70-75	20					7		10
>75	8					1		1
Percent Error	**N/A**					**-0.8%**		**-6.6%**

* This device does not record speeds

Figure B.10 - Northbound Speed Comparison - 2:00PM to 8:00PM - 5/24/2013

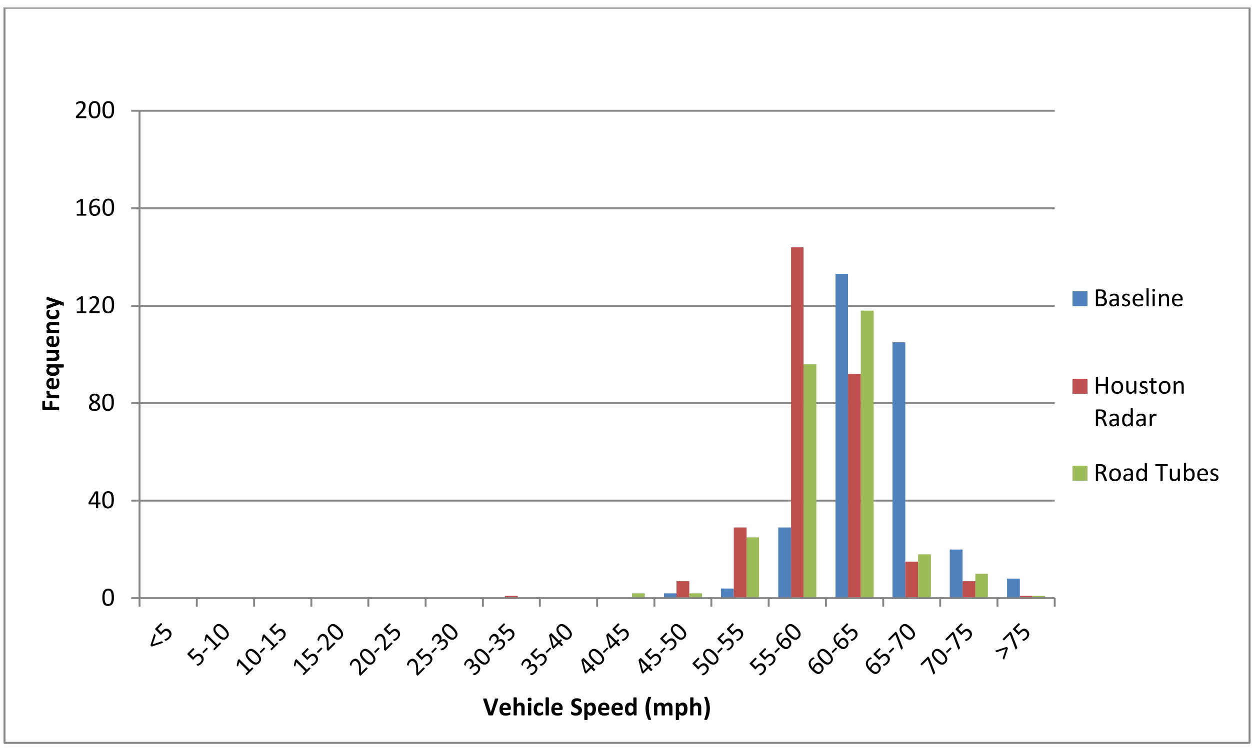


Table B.11 Southbound Speed Comparison - 2:00PM to 8:00PM - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	0		
10-15	1				0	0		
15-20	0				0	0		
20-25	1				0	2		
25-30	1				1	0		
30-35	0				1	1		
35-40	0				1	0		
40-45	2				2	2		
45-50	2				8	4		
50-55	29				36	33		
55-60	106				119	120		
60-65	94				64	62		
65-70	14				6	11		
70-75	2				3	2		
>75	4				2	1		
Percent Error	**N/A**				**-2.0%**	**-3.4%**		

* This device does not record speeds

Figure B.11 - Southbound Speed Comparison - 2:00PM to 8:00PM - 6/11/2013

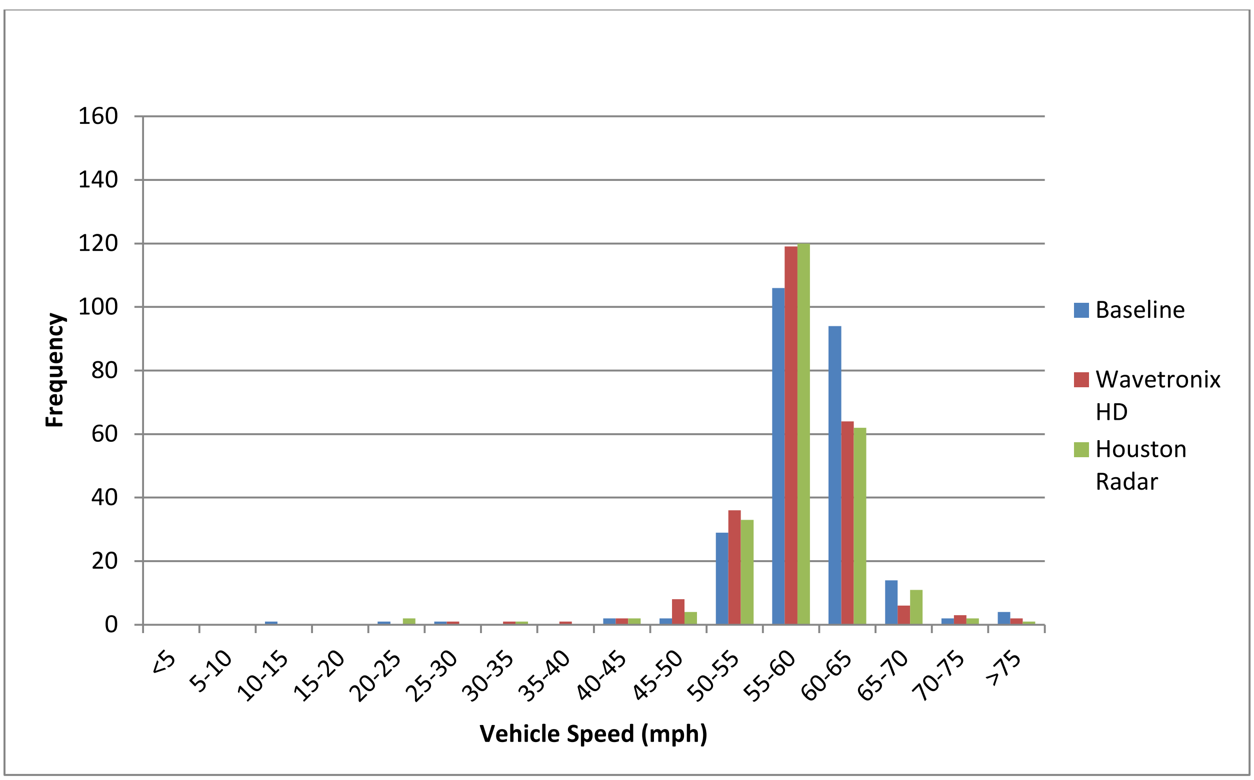


Table B.12 Northbound Speed Comparison - 2:00PM to 8:00PM - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	0		
10-15	0				0	0		
15-20	1				0	0		
20-25	0				0	0		
25-30	0				0	0		
30-35	1				1	1		
35-40	3				3	3		
40-45	2				3	5		
45-50	4				7	8		
50-55	24				40	50		
55-60	126				96	150		
60-65	92				95	41		
65-70	24				17	13		
70-75	9				2	1		
>75	1				0	1		
Percent Error	**N/A**				**-1.4%**	**-2.0%**		

* This device does not record speeds

Figure B.12 - Northbound Speed Comparison - 2:00PM to 8:00PM - 6/11/2013

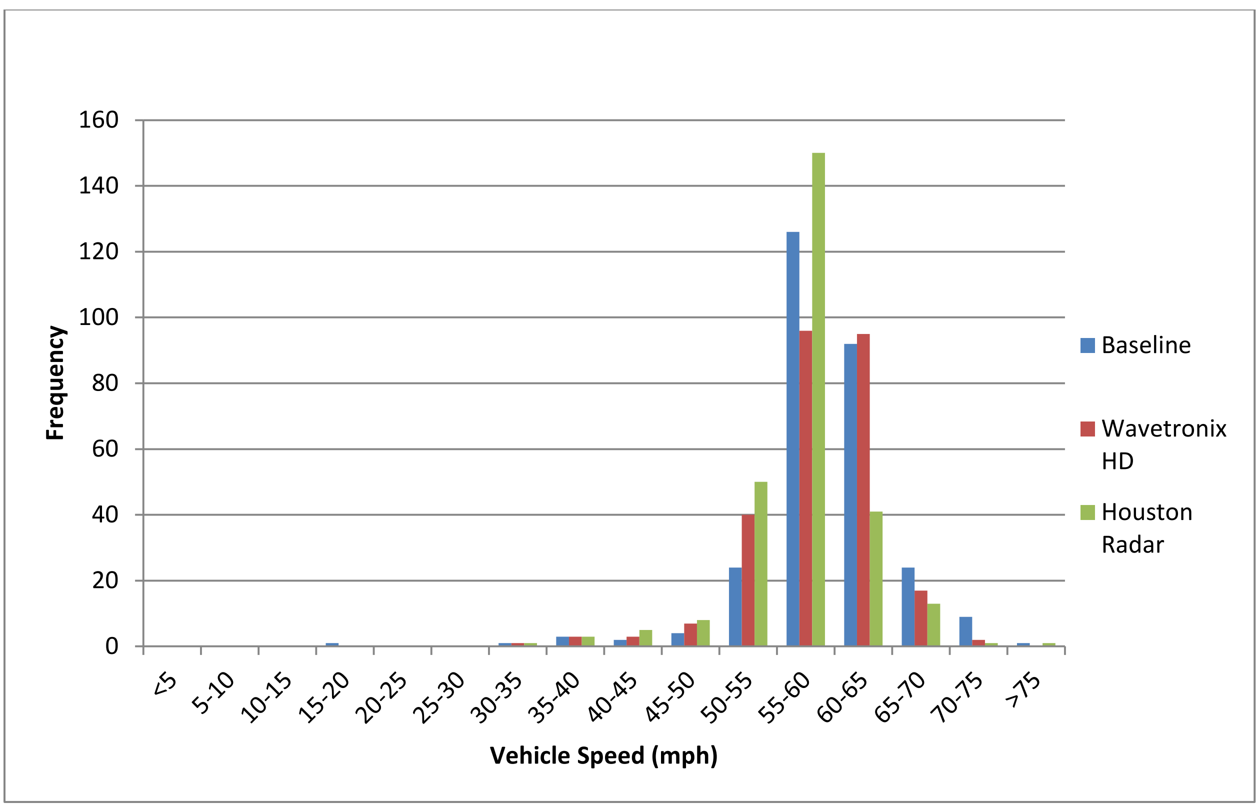


Table B.13 Southbound Speed Comparison – Full Day – 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	1			1	0		1	
15-20	0			0	0		1	
20-25	2			1	0		3	
25-30	2			3	0		3	
30-35	2			3	8		2	
35-40	18			15	18		20	
40-45	22			29	27		25	
45-50	33			34	38		40	
50-55	71			89	98		81	
55-60	174			178	171		179	
60-65	117			96	88		61	
65-70	24			20	18		18	
70-75	4			1	2		1	
>75	0			0	0		0	
Percent Error	**N/A**			**-1.3%**	**-1.8%**		**-8.9%**	

* This device does not record speeds

Figure B.13 Southbound Speed Comparison – Full Day – 1/29/2013

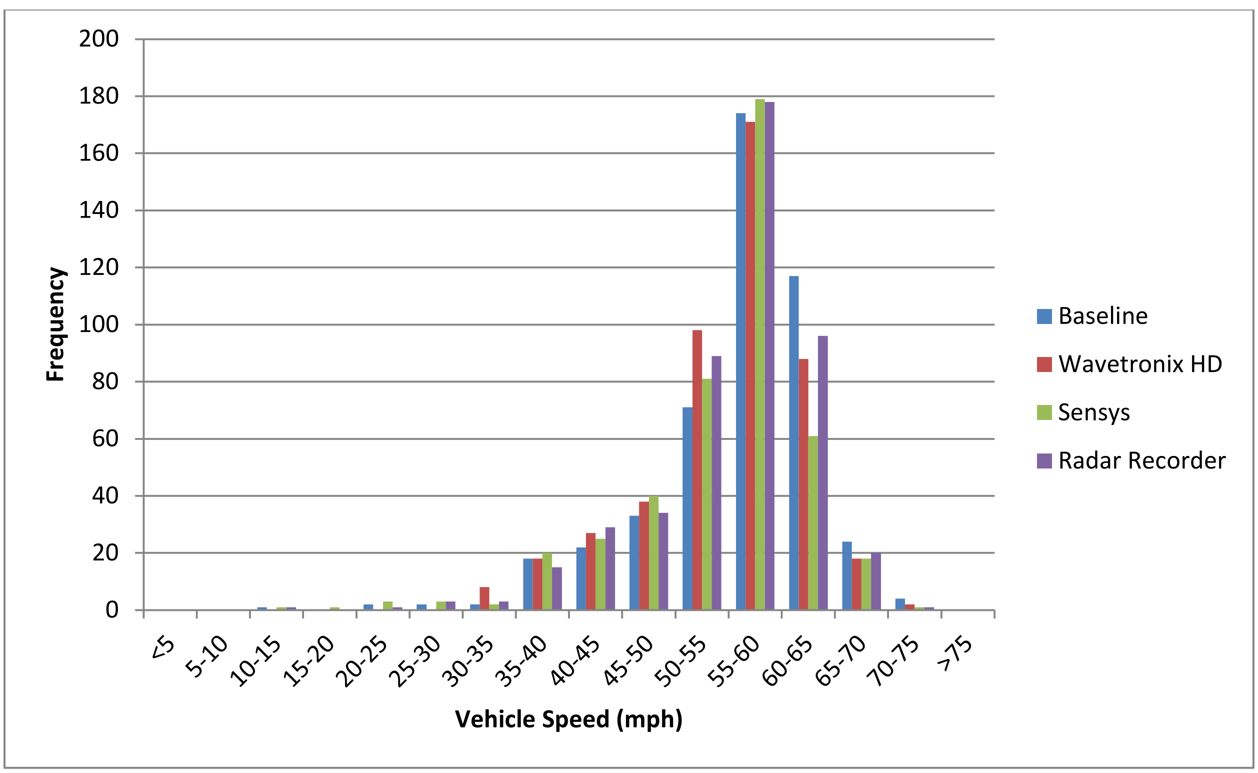


Table B.14 Northbound Speed Comparison - Full Day – 1/29/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	0	0	No Data	0	No Data
5-10	0			0	0		0	
10-15	0			0	0		0	
15-20	0			0	0		0	
20-25	0			0	0		0	
25-30	1			2	0		2	
30-35	5			7	6		4	
35-40	8			9	11		5	
40-45	12			8	11		7	
45-50	23			26	21		27	
50-55	66			72	74		54	
55-60	166			188	156		146	
60-65	159			139	155		143	
65-70	26			18	22		38	
70-75	6			7	12		8	
>75	0			0	1		5	
Percent Error	**N/A**			**-1.0%**	**0.0%**		**-2.9%**	

* This device does not record speeds

Figure B. 14 - Northbound Speed Comparison - Full Day – 1/29/2013

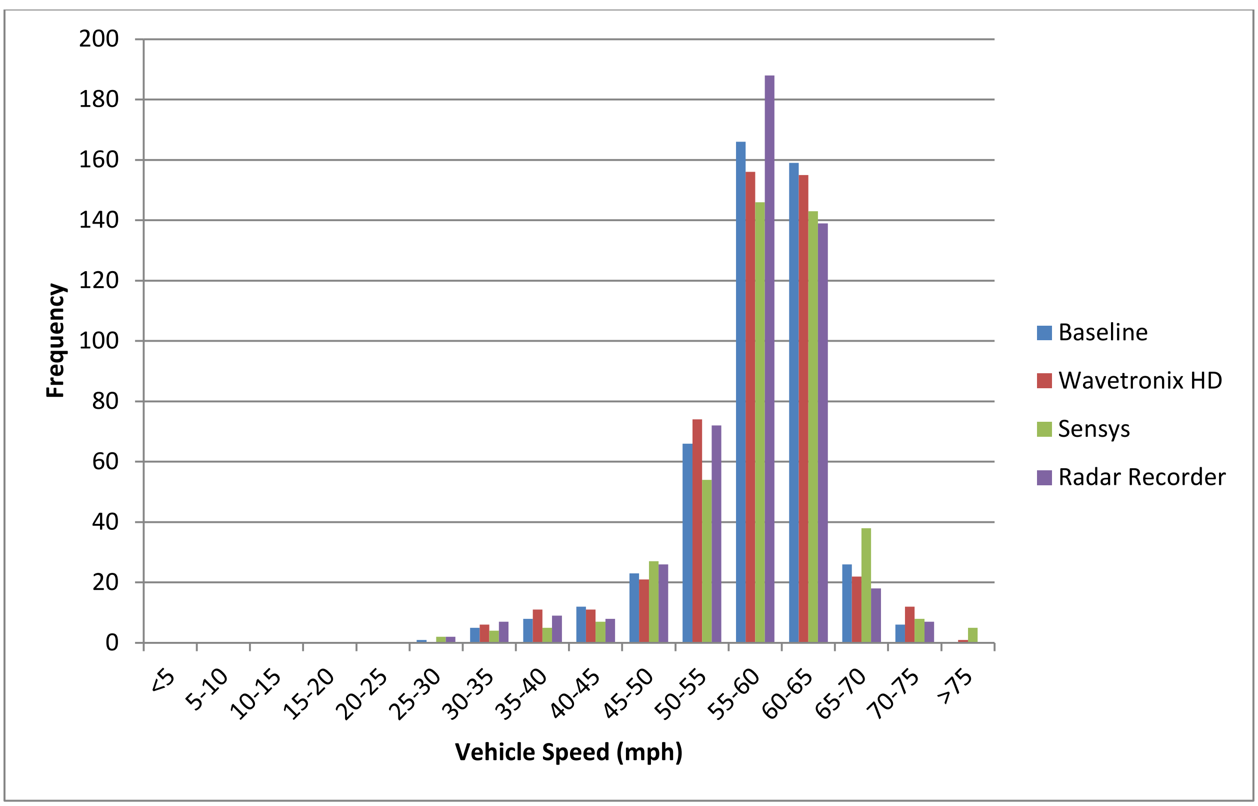


Table B.15 Southbound Speed Comparison - Full Day – 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	4	No Data	0
5-10	0					5		0
10-15	1					2		0
15-20	1					2		1
20-25	1					0		1
25-30	1					0		1
30-35	0					0		4
35-40	2					4		2
40-45	2					6		4
45-50	19					38		16
50-55	54					153		64
55-60	276					454		311
60-65	416					191		323
65-70	80					35		60
70-75	11					4		8
>75	10					5		6
Percent Error	**N/A**					**-1.2%**		**-1.4%**

* This device does not record speeds

Figure B.15 - Southbound Speed Comparison - Full Day – 5/24/2013

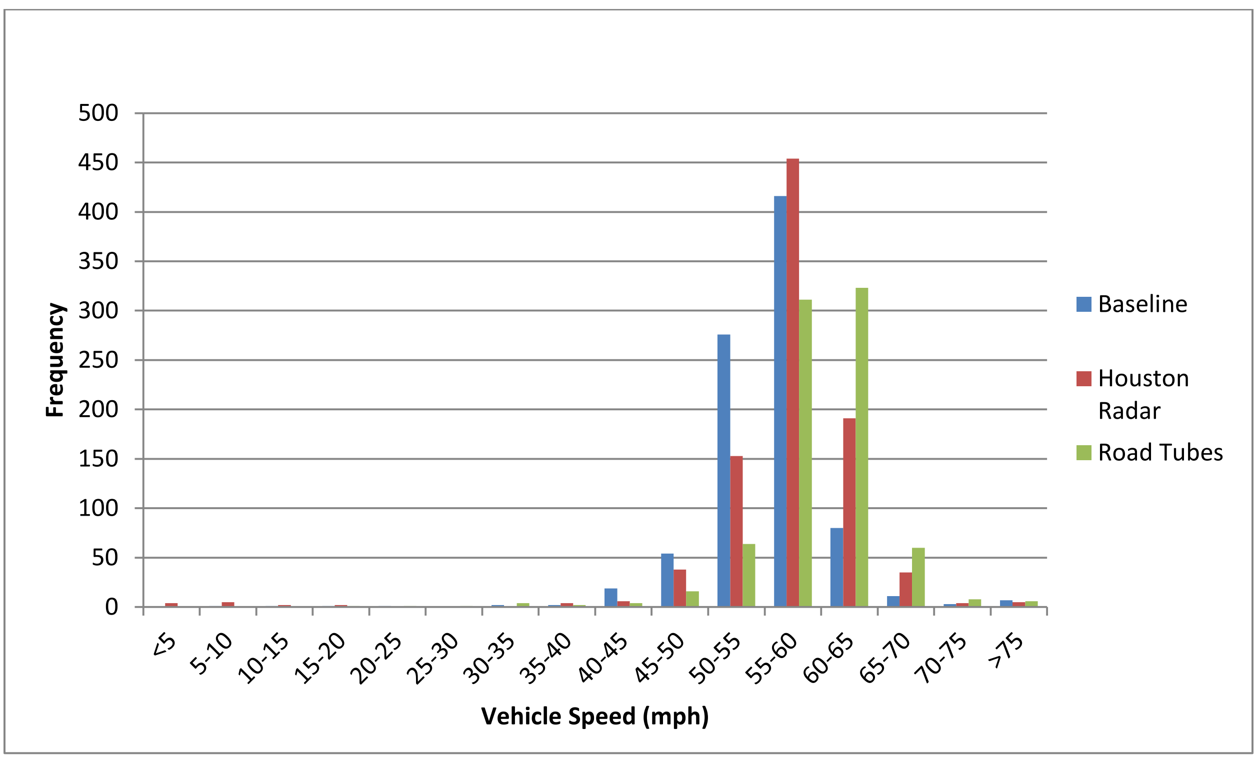


Table B.16 Northbound Speed Comparison - Full Day – 5/24/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	No Data	0	No Data	0
5-10	0					0		0
10-15	0					0		1
15-20	0					0		0
20-25	0					0		0
25-30	0					0		0
30-35	0					1		3
35-40	0					1		2
40-45	1					5		5
45-50	4					25		12
50-55	14					65		52
55-60	61					310		203
60-65	289					193		274
65-70	244					43		48
70-75	48					9		19
>75	17					4		5
Percent Error	**N/A**					**-5.7%**		**-7.0%**

* This device does not record speeds

Figure B.16 - Northbound Speed Comparison - Full Day – 5/24/2013

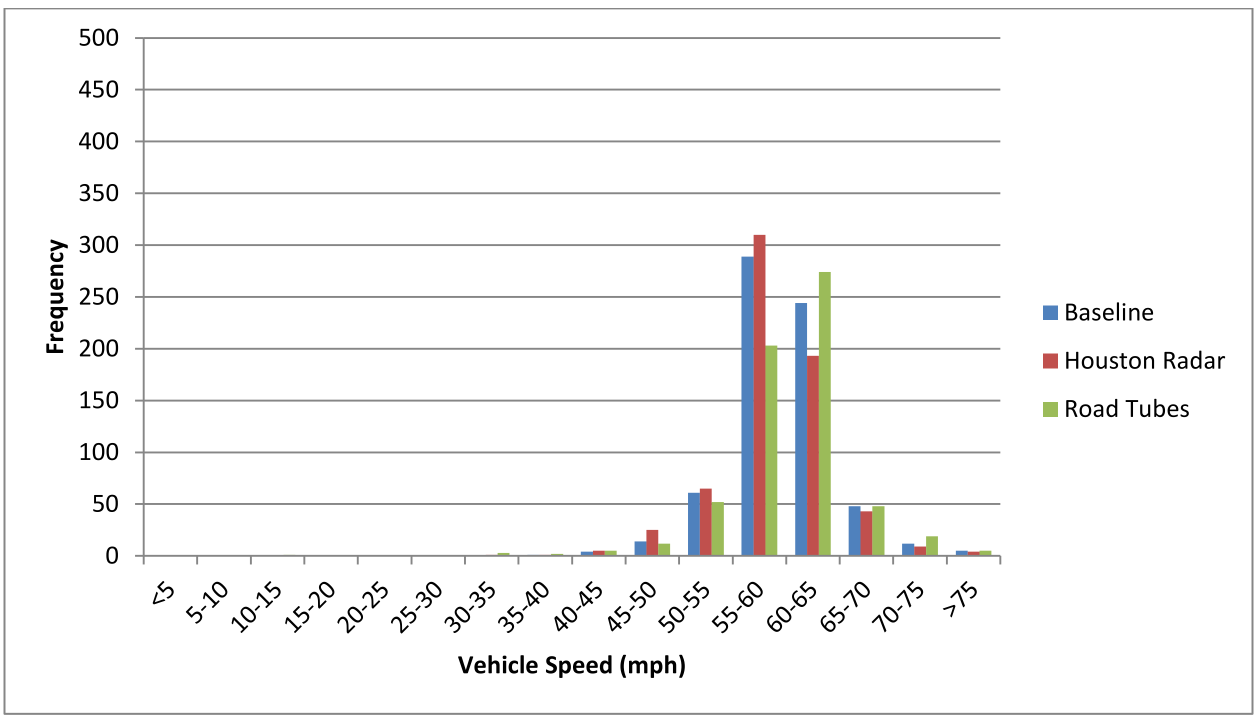


Table B.17 Southbound Speed Comparison - Full Day - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	0		
10-15	1				0	0		
15-20	0				0	0		
20-25	1				0	2		
25-30	1				1	0		
30-35	0				2	2		
35-40	1				2	1		
40-45	3				4	3		
45-50	9				13	10		
50-55	59				86	70		
55-60	225				269	261		
60-65	244				172	174		
65-70	45				23	35		
70-75	10				11	8		
>75	9				5	5		
Percent Error	**N/A**				**-2.2%**	**-1.5%**		

* This device does not record speeds

Figure B.17 - Southbound Speed Comparison - Full Day - 6/11/2013

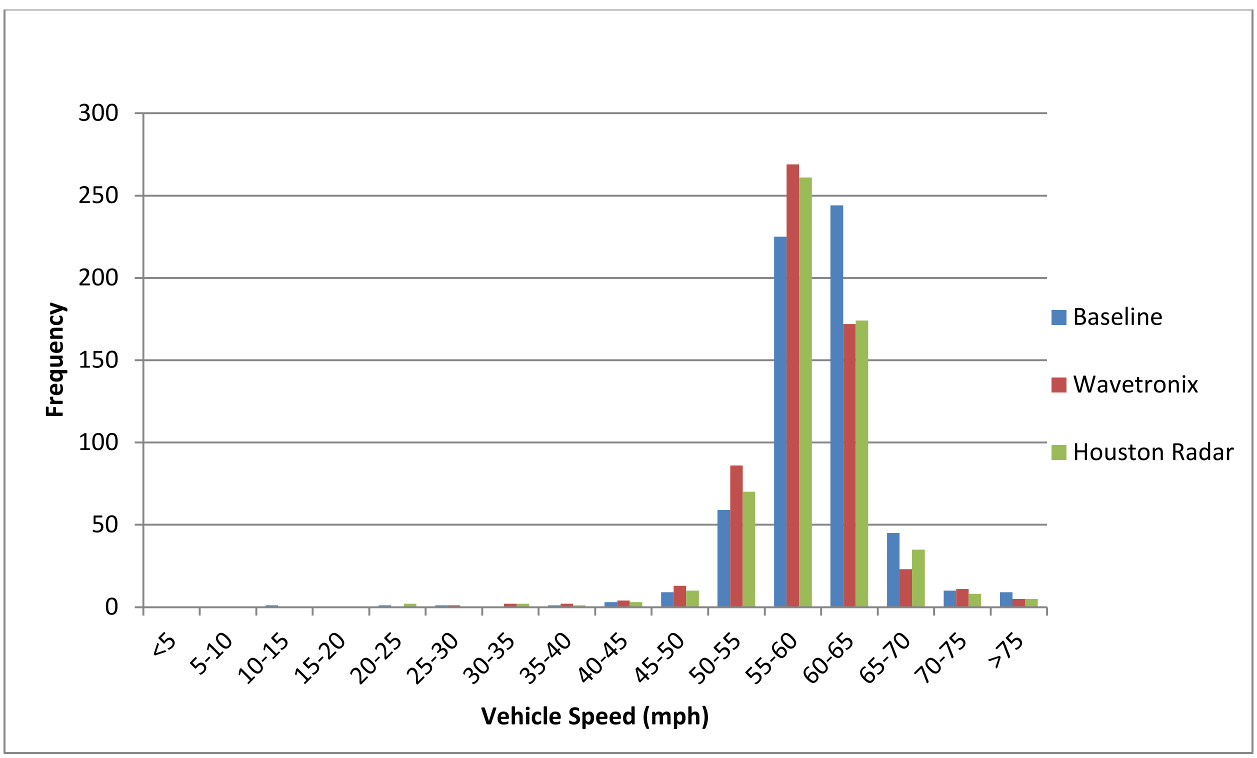
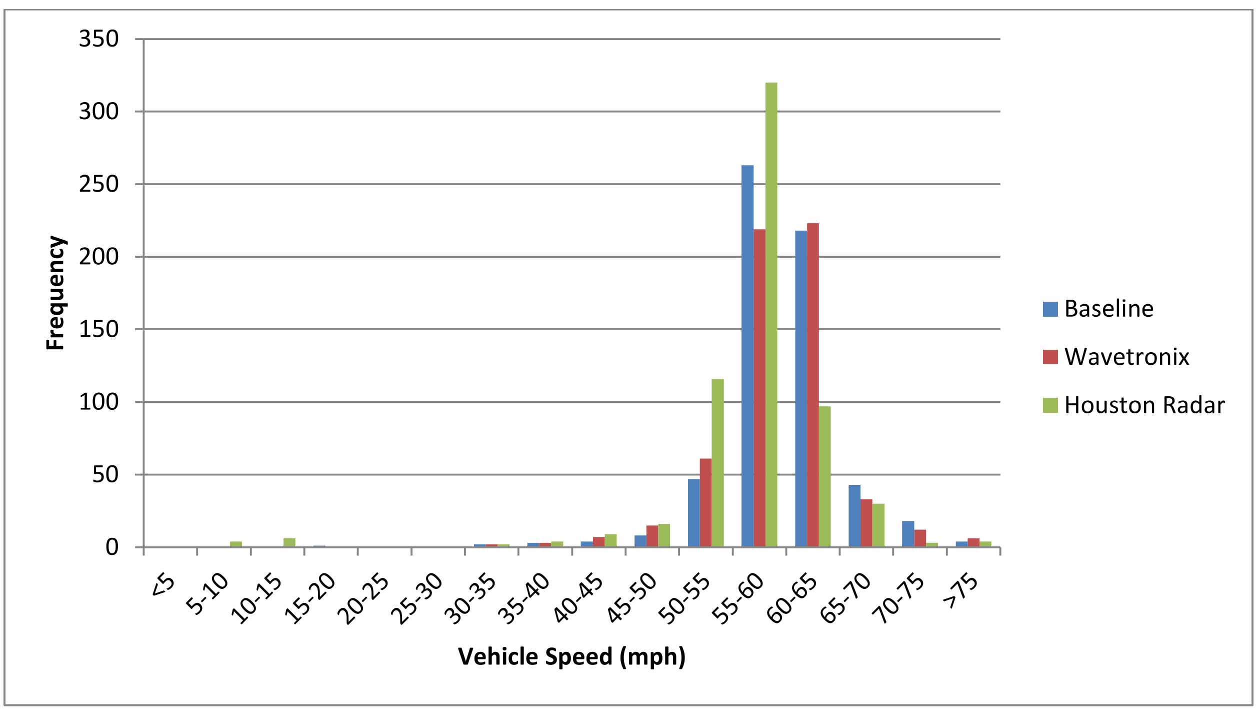


Table B.18 Northbound Speed Comparison - Full Day - 6/11/2013

Speed Bin (mph)	Baseline	COUNT cam	Scout	Radar Recorder	Wavetronix HD	Houston Radar	Sensys	Road Tubes
<5	0	N/A*	N/A*	No Data	0	0	No Data	No Data
5-10	0				0	4		
10-15	0				0	6		
15-20	1				0	0		
20-25	0				0	0		
25-30	0				0	0		
30-35	2				2	2		
35-40	3				3	4		
40-45	4				7	9		
45-50	8				15	16		
50-55	47				61	116		
55-60	263				219	320		
60-65	218				223	97		
65-70	43				33	30		
70-75	18				12	3		
>75	4				6	4		
Percent Error	**N/A**				**-0.6%**	**-5.4%**		

* This device does not record speeds

Figure B.18 - Northbound Speed Comparison - Full Day - 6/11/2013



Appendix C: Classification Data Analysis Tables

This section presents classification tables. The data was standardized into four length-based classification bins (motorcycle, MC; small, S; medium, M; large, L). The tables show the correlation between baseline classification and the sensor classification. To read the table, start on the left side and follow a given row to the right (for example, "S" for small vehicles). Then each column shows how the sensor classified those vehicles (MC/S/M/L). The cells that are shaded gray indicate agreement between the baseline and sensor.

The sum of vehicles that the sensor did not record, but the baseline did record are shown in the "Extra Baseline" column. If this number is negative, this indicates that the baseline recorded fewer vehicles than the sensor.

Classification Tables

Table C. 1 Scout Classification Comparison - AM Peak - 1/29/2013

Southbound

Baseline	Scout: MC	S	M	L	Extra Baseline
MC	0				-16
S		244	1	6	
M			8		
L				12	

Northbound

Baseline	Scout: MC	S	M	L	Extra Baseline
MC	0	0	0	0	31
S	0	251	0	0	
M	0	8	7	4	
L	0	0	0	13	

Table C.2 COUNTCam Classification Comparison - AM Peak - 5/24/2013

Southbound

Baseline \ COUNTCam	MC	S	M	L	Extra Baseline
MC	2	0	0	0	-14
S	0	174	6	0	
M	0	0	11	0	
L	0	0	6	20	

Northbound

Baseline \ COUNTCam	MC	S	M	L	Extra Baseline
MC	4	0	0	0	0
S	0	136	8	0	
M	0	0	7	0	
L	0	0	1	22	

Table C.3 Houston Radar Classification Comparison - AM Peak - 5/24/2013

Southbound

Baseline \ Houston Radar	MC	S	M and L	Extra Baseline
MC	0	2	0	-12
S	0	194	0	
M	0	11	0	
L	0	13	13	

Northbound

Baseline \ Houston Radar	MC	S	M and L	Extra Baseline
MC	0	4	0	7
S	0	131	0	
M	0	7	0	
L	0	6	23	

Table C.4 Road Tubes Classification Comparison - AM Peak - 5/24/2013

Southbound

Baseline \ Road Tubes	MC	S	M	L	Extra Baseline
MC	2	0	0	0	12
S	2	170	10	0	
M	0	0	11	0	
L	0	0	7	19	

Northbound

Baseline \ Road Tubes	MC	S	M	L	Extra Baseline
MC	4	0	0	0	7
S	1	117	19	0	
M	0	0	7	0	
L	0	0	4	19	

Table C.5 Wavetronix HD Classification Comparison - AM Peak - 6/11/2013

Southbound

Baseline \ Wavetronix HD	MC	S	M	L	Extra Baseline
MC	1	0	0	0	4
S	0	178	0	0	
M	0	0	7	0	
L	0	0	7	0	

Northbound

Baseline \ Wavetronix HD	MC	S	M	L	Extra Baseline
MC	0	0	0	0	2
S	0	136	0	0	
M	0	0	11	0	
L	0	5	5	0	

Table C.6 Houston Radar Classification Comparison - AM Peak - 6/11/2013

Southbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	0	0	7
S	0	171	3	
M	0	7	0	
L	0	0	9	

Northbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	2	0	-9
S	0	136	0	
M	0	11	0	
L	0	0	10	

Table C.7 Wavetronix HD Classification Comparison - PM Peak - 6/11/2013

Southbound

Baseline	Wavetronix HD: MC	S	M	L	Extra Baseline
MC	1	0	0	0	13
S	2	208	0	0	
M	0	0	16	0	
L	0	0	16	0	

Northbound

Baseline	Wavetronix HD: MC	S	M	L	Extra Baseline
MC	1	0	4	0	23
S	0	243	5	0	
M	0	0	11	0	
L	0	0	0	0	

Table C.8 Houston Radar Classification Comparison - PM Peak - 6/11/2013

Southbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	1	0	18
S	0	185	8	
M	0	16	0	
L	0	0	28	

Northbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	5	0	14
S	0	243	0	
M	0	11	0	
L	0	4	10	

Table C.9 Radar Recorder Classification Comparison - 24-Hour - 1/29/2013

Southbound

Baseline	Radar Recorder: MC	S	M	L	Extra Baseline
MC	0	0	0	0	0
S	0	389	33	0	
M	0	0	21	0	
L	0	0	13	14	

Northbound

Baseline	Radar Recorder: MC	S	M	L	Extra Baseline
MC	0	0	0	0	-5
S	0	402	21	0	
M	0	0	27	0	
L	0	0	0	21	

Table C.10 Wavetronix HD Classification Comparison - 24-Hour - 1/29/2013

Southbound

Baseline	Wavetronix HD: MC	S	M	L	Extra Baseline
MC	0	0	0	0	2
S	0	403	1	16	
M	0	0	21	0	
L	0	0	0	27	

Northbound

Baseline	Wavetronix HD: MC	S	M	L	Extra Baseline
MC	0	0	0	0	2
S	0	400	7	14	
M	0	0	27	0	
L	0	0	0	21	

Table C.11 Sensys Classification Comparison - 24-Hour - 1/29/2013

Southbound

Baseline	Sensys: MC	S	M	L	Extra Baseline
MC	0	0	0	0	7
S	29	360	26	0	
M	0	0	21	0	
L	0	0	14	13	

Northbound

Baseline	Sensys: MC	S	M	L	Extra Baseline
MC	0	0	0	0	12
S	0	342	47	2	
M	0	0	27	0	
L	0	0	0	21	

* 20 unclassified

Table C.12 COUNTCam Classification Comparison - 24-Hour - 5/24/2013

Southbound

		COUNTCam				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	10	0	0	0	51
	S	0	694	17	0	
	M	0	0	40	0	
	L	0	0	18	44	

Northbound

		COUNTCam				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	10	0	0	0	0
	S	3	577	17	0	
	M	0	0	22	0	
	L	0	0	7	42	

Table C.13 Houston Radar Classification Comparison - 24-Hour - 5/24/2013

Southbound

		Houston Radar				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	0	11	0		29
	S	0	761	0		
	M	0	40	0		
	L	0	31	31		

Northbound

		Houston Radar				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	0	10	0		-22
	S	0	579	18		
	M	0	22	0		
	L	0	0	49		

Table C.14 Road Tubes Classification Comparison - 24-Hour - 5/24/2013

Southbound

		Road Tubes				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	11	0	0	0	73
	S	0	648	40	0	
	M	0	0	40	0	
	L	0	0	6	56	

Northbound

		Road Tubes				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	10	0	0	0	54
	S	0	474	75	0	
	M	0	0	22	0	
	L	0	0	6	43	

Table C.15 Wavetronix HD Classification Comparison - 24-Hour - 6/11/2013

Southbound

		Wavetronix HD				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	8	0	0	0	19
	S	0	516	4	0	
	M	0	0	29	0	
	L	0	0	32	0	

Northbound

		Wavetronix HD				
		MC	**S**	**M**	**L**	**Extra Baseline**
Baseline	**MC**	2	0	7	0	30
	S	0	526	11	0	
	M	0	0	32	0	
	L	0	0	3	0	

Table C.16 Houston Radar Classification Comparison - 24-Hour - 6/11/2013

Southbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	8	0	37
S	0	468	15	
M	0	29	0	
L	0	0	51	

Northbound

Baseline	Houston Radar: MC	S	M and L	Extra Baseline
MC	0	9	0	0
S	0	537	0	
M	0	32	0	
L	0	12	42	