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Non-Intrusive Traffic Detection Comparison Study

Final Report

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BACKGROUND

Obtaining accurate and timely traffic data is essential to successful transportation operations/planning projects. Several methods of collecting traffic data are available, which range from manual counts by field personnel, to using different technologies designed specifically for data collection (such as road tubes, video detection, induction loops, radar, etc.). Traffic detection technologies can generally be classified into two groups: intrusive and non-intrusive. Intrusive detection technologies are installed on/within the roadway. These installations require lane closures, which disrupt traffic flow and increase vehicle-personnel interactions. Using this type of technology is inherently more hazardous and is generally more time consuming, especially for temporary traffic data collection. Non-intrusive traffic detection technologies are deployed adjacent to the roadway and require minimal (if any) interaction with traffic flow. These types of detection technologies do not require any lane closures, which results in a safer environment.

Several studies have been performed comparing different types of non-intrusive technologies. Radar based detection devices have consistently scored the highest in accuracy, cost-effectiveness, and installation/use [1, 2, 3]. The Advanced Traffic Analysis Center (ATAC) has acquired several radar-based traffic detectors and will evaluate their performance for the North Dakota Department of Transportation (NDDOT), specifically for use as temporary data collection devices.

STUDY OBJECTIVES

The main objective of this study is to determine the applicability of using radar-based sensors to support the NDDOT traffic data collection efforts. These sensors would be used primarily as temporary, portable data collection devices, so ideally they would be deployed with minimal resources.

During the study, the sensors will be evaluated for accuracy in providing volumes, speed, and classification using two types of mounting methods. The first method consists of a tripod-based system which was designed and built by ATAC staff. The second method consists of mounting the sensors to an existing sign structure.

This study will also provide documentation on setting up and calibrating each of the sensors to improve accuracy. The configuration and calibration guides for each sensor are located in Appendix A. During the study’s kick-off meeting on June 17, 2008, the format of the sensors’ output files was a concern for the NDDOT. Currently, all of NDDOT’s traffic data are stored as a .PRN file type, which has a much different format than the sensor output files. As a result, this study also will develop an Excel spreadsheet to converts each of the sensor outputs into the .PRN format.

RADAR SENSORS

Radar sensors operate by focusing a radar beam primarily perpendicular to the roadway, and detecting the reflection from vehicles as they pass through the beam. The radar beam tries to emulate an inductive loop by detecting the presence, size, and speed of vehicles. Since the detector only sees the signature of the vehicles passing through its beam, it bases the classification on the length of the vehicle being detected.

Several benefits exist for using radar for traffic detection. Radar sensors are relatively easy to set up and operate, and they have been shown to be among the most accurate non-intrusive vehicle detection technologies. Another benefit of radar sensors is that they can be deployed alongside the roadway, allowing them to be used in a safe environment.

The radar sensors used in this study are among the most commonly used radar-based sensors available (manufactured by Wavetronix and Electronic Integrated Systems (EIS)) and use frequency modulated continuous wave (FMCW) radar technology. Both companies have been in existence for several years, and are continually improving their devices. Some commonalities exist among the different sensors, such as being powered by 12-volt marine deep-cycle batteries, and communicating through a RS-232 serial port. The following sections provide more detail on the sensors that will be used in this study.   Figure 1 shows each of the sensors used in this study, which are mounted using the tripod structures.

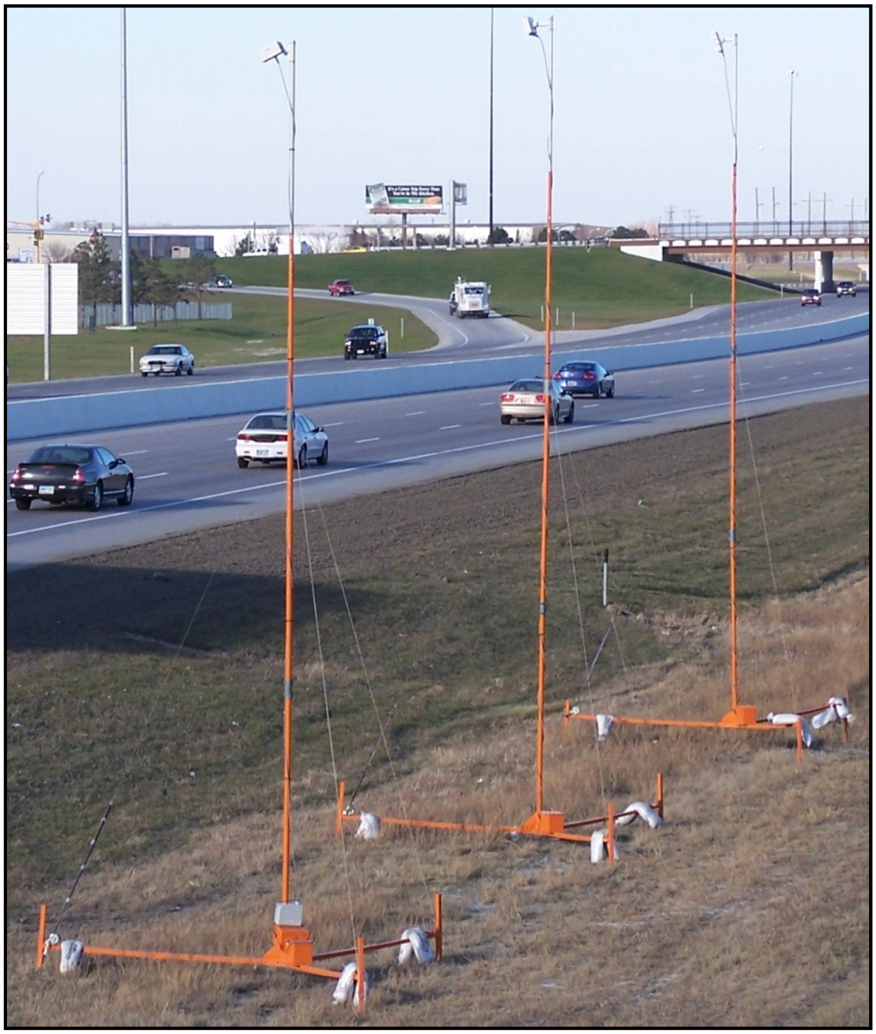

Figure 1. Radar Sensors on the Tripod Mounting System

Wavetronix SmartSensor 105
The SmartSensor 105 is the first-generation radar sensor developed by Wavetronix. The SmartSensor has a range of 200 feet (ft) and collects traffic volume, speed, occupancy, and

classification for up to 8 lanes of traffic. Vehicle classification is user-defined and can be divided into three length-based classes. Speed data collected by the SmartSensor is a running average of 16 vehicles, independent of the time period. The speeds are recorded at the end of each data interval and are stored accordingly. The SmartSensor is capable of collecting data on a lane-by-lane basis, providing directional volumes, classifications, and speeds.

The SmartSensor can be operated from a side-fire position, which allows for a safe and relatively quick deployment. This sensor has an “auto-calibration,” which detects passing cars and assigns the respective lanes. The SmartSensor has an internal data storage capacity of 2,976 time intervals, with a minimum time interval of five seconds.

Wavetronix SmartSensor HD (125)

The SmartSensor HD is the upgraded version of the SmartSensor 105. It has a range of 250 ft and is capable of detecting up to 10 lanes of traffic. The SmartSensor HD collects traffic volume, individual vehicle speed, average and 85th percentile speed, average headway and gap, occupancy, classification, and presence.

Similar to the SmartSensor 105, the SmartSensor HD can be operated from a side-fired position, and has an “auto-calibration” configuration process. The vehicle classification of the SmartSensor HD is capable of 8 length-based classes which are user-defined. All of the power and connection/communication requirements are the same as the SmartSensor 105, which allows existing conditions to be upgraded.

RTMS

The Remote Traffic Microwave Sensor (RTMS) is a data collection device which was developed by Electronic Integrated Systems (EIS). The RTMS is similar to the SmartSensor in that it can be configured to a side-fired mode, and collects data by using a radar beam and detecting the reflections of passing vehicles.

The RTMS is capable of detecting up to 8 lanes of traffic, and has a range of 200 ft. It collects data on vehicle volume, speed, occupancy and classification of 2, 4, or 6 length-based vehicle classes. It has an external memory with a capacity of 4.125 MB, and can store up to 61,000 intervals with time intervals ranging from 10 seconds to 600 seconds.

The main installation requirement of a radar sensor relates to the sensor’s offset from the first lane of travel. The allowable offset (same as clear zone) corresponds to a recommended mounting height. To optimize the accuracy of the sensors, each vendor provides recommended height-offset requirements (Table 1).

Table 1. Sensor Height/Offset Requirements

Offset From First Detection Lane (ft)	Recommended Mounting Height (ft)		
	SS105	SS125	RTMS
5	-	-	17
6	-	16	17
7	-	16	17
8	-	16	17
9	-	16	17
10	12	16	17
11	12	16	17
12	13	17	17
13	13	17	17
14	14	18	17
15	15	20	17
16	15	20	17
17	16	21	17
18	17	22	17
19	17	22	17
20	18	23	17
21	18	23	17.6
22	18	23	18.2
23	19	25	18.8
24	19	25	19.4
25	20	26	20
26	20	26	20.6
27	21	27	21.2
28	21	27	21.8
29	21	27	22.4
30	22	29	23
31	22	29	23.6
32	22	29	24.2
33	23	30	24.8
34	23	30	25.4
35	23	30	26
36	23	30	26.6
37	23	30	27.2
38	24	31	27.8
39	24	31	28.4
40	25	33	29
41	25	33	29.6
42	26	34	30
43	26	34	30
44	27	35	30
45	27	35	30
46	28	36	30
47	28	36	30
48	29	38	30
49	29	38	30
50	30	39	30

Note: Shaded area represents the recommended height/offset

RADAR MOUNTING SYSTEMS

ATAC constructed five tripod towers for temporary data collection. Each tower includes a built-in storage compartment for the power supply (12-volt marine deep-cycle battery). The entire structure can be set up and taken down in approximately 15 minutes, and all of the components are small enough to be stored in a 6 ft (width) by 10 ft (length) cargo trailer. The approximate cost of each tower is $2,000, which will vary depending on the price/availability of materials and the time required for construction. The maximum height of this mounting system is approximately 39 feet.

The second mounting method evaluated was a sign-mount system. This method provides a cheaper and simpler method for using the radar sensors. The sign-mount system consists of poles that are banded to existing sign structures. The approximate cost for this system is $600 each, which will provide a mounting height of approximately 39 feet.

METHODOLOGY

Temporary traffic data collection is difficult to obtain for freeway facilities. Therefore, this study will focus on a freeway segment. In addition, the case study location has to be a high-traffic area so sufficient data can be used for the study.

After a suitable location is selected, the sensors will be set up according to their respective user manuals. Once the sensors have gone through their ‘auto-calibration’ process, fine-tuning will be done by observing traffic flows and adjusting the detection zones as necessary. Speed data will be calibrated with hand-held radar, and adjustments will be made to the sensors when needed.

It is desired to have the sensor’s speed data within 2-3 mph of the hand-held radar. The measures of effectiveness (MOE) for this study are a comparison of the volume, speed, and classification data for each sensor. The data for each sensor will be compared to manually collected data. This comparison will assess the performance of each sensor in a temporary, remote deployment as an alternative to conventional data collection technologies. Comparisons will be made on a lane, direction, and total roadway cross-section.

After all three sensors are set up and operating, the Traffic Data Collection System (TDCS) will be deployed for the manual verification. The TDCS is a video surveillance trailer consisting of a 6 ft (width) by 10 ft (length) cargo trailer which houses a 42 ft telescopic, pneumatic mast. Two pan-tilt-zoom (PTZ) cameras can be mounted to the top of the mast, and are connected to a video recording system inside the trailer. The location of the TDCS (200 ft behind the sensors) will allow for a clear view of the sensors and the passing vehicles.

Each of the radar sensors had different capabilities related to vehicle classification. Therefore, several vehicle length classes were developed based on research done by various transportation agencies (as shown in Figure 2). Based on this data, the following four vehicle classification bins were used:

1. Motorcycles (0 – 10) ft
2. Passenger Cars (0 – 20) ft
3. Single-Unit Trucks (0 – 55) ft
4. Tractor-Trailer Trucks (> 55) ft

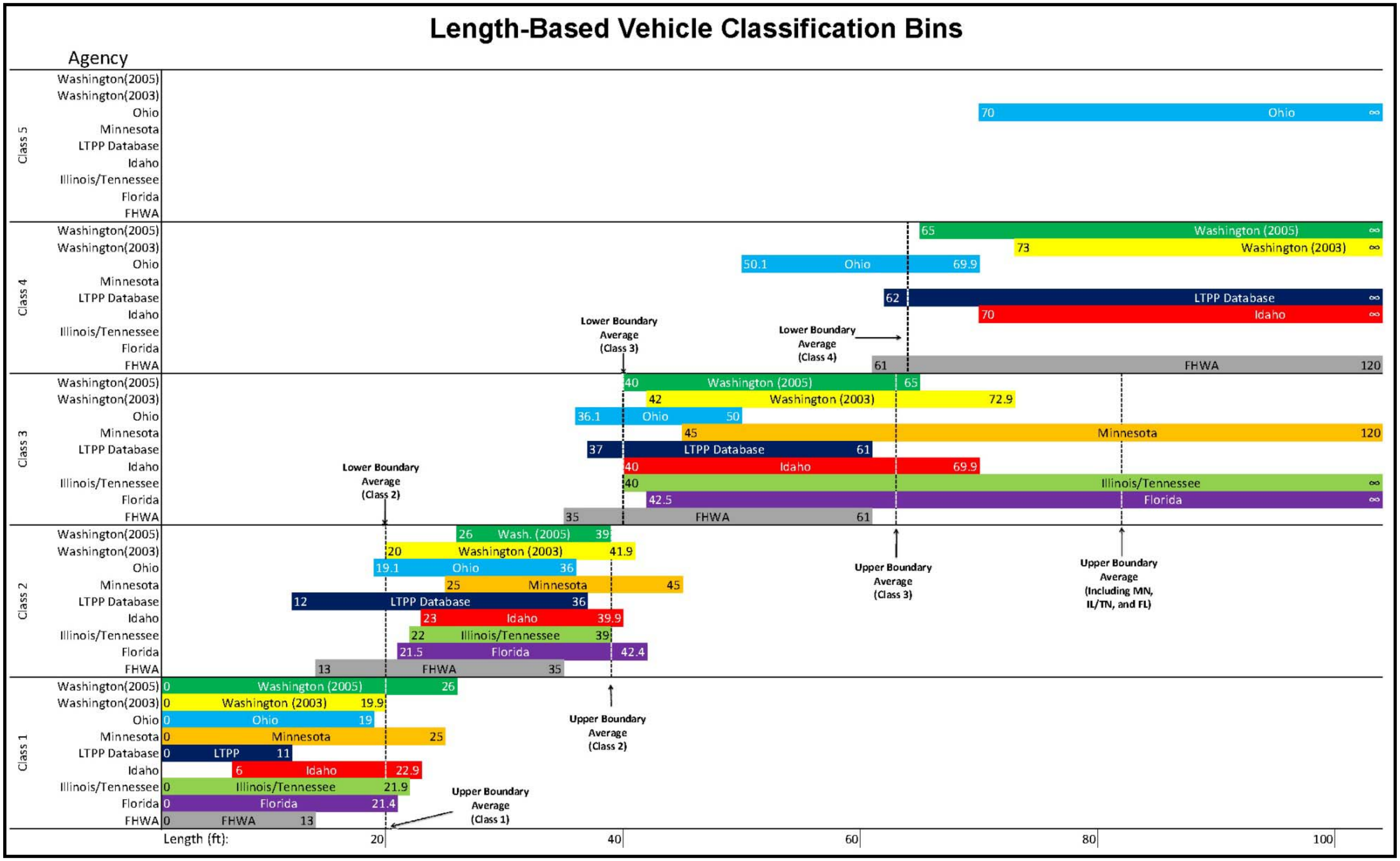

Figure 2. Vehicle Classification Length Ranges (sources 4-9)

The study location also includes an existing Automatic Traffic Recorder (ATR), which uses a series of inductive loops to collect data on volume, speed, and vehicle classification. To provide a comparison to technologies currently being used, the data from the ATR will also be compared with the radar sensor data. It should be noted that the ATR's classification loop in the NB lane 3 was damaged before this study took place. The loop was classifying vehicles by length, rather than by number of axles, which may have had an effect on the accuracy of the data collected in this lane.

CASE STUDY

The location chosen for this study was Interstate-29 (I-29) south of 19th Ave. N. (Fargo, ND), which is shown in Figure 3. This section of freeway consists of six lanes, and has a speed limit of 55 mph. The average daily traffic (ADT) at this location was 26,000 when counted in 2006.

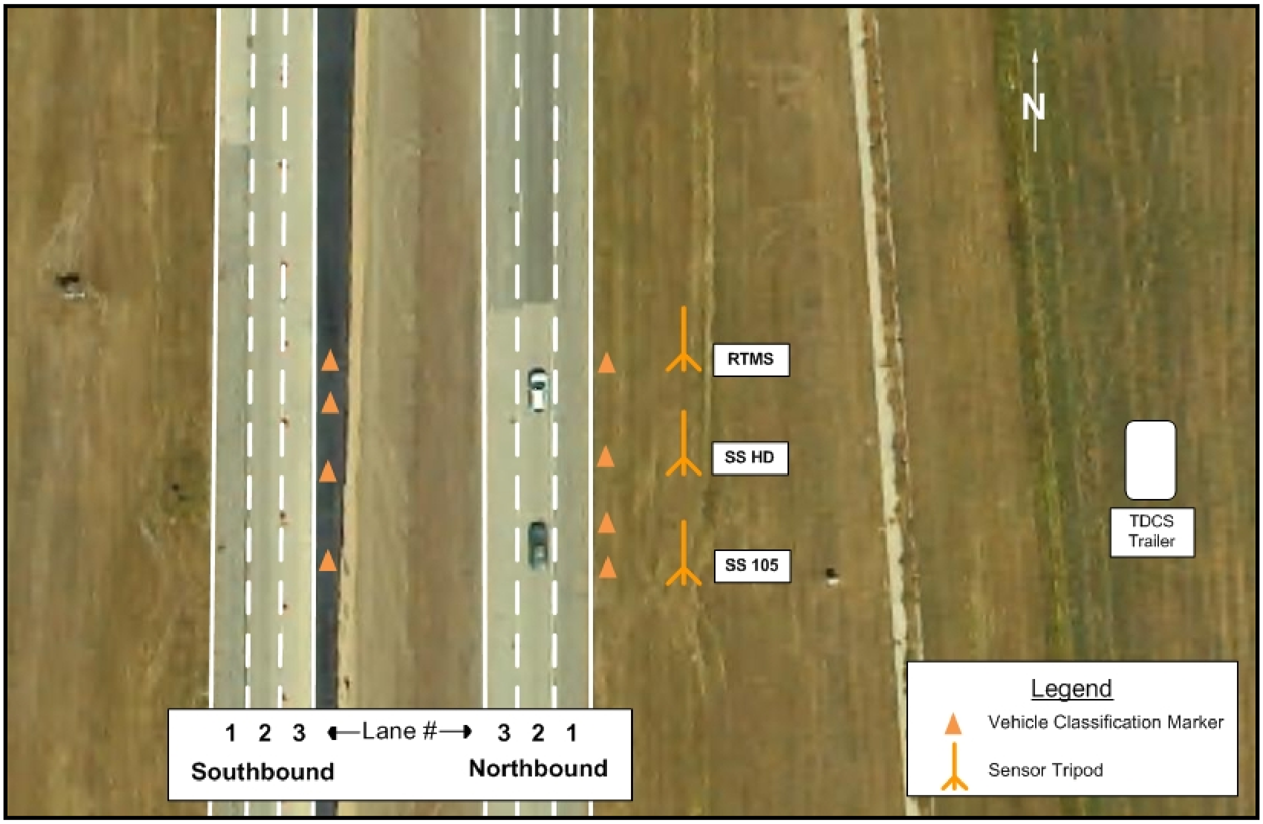

Figure 3. Case Study Location

This location provided easy access to the right-of-way on the east side of the interstate, and was adjacent to a field where the TDCS could be deployed. This site was also the location of an existing ATR data collection system, which was installed during the reconstruction of I-29. In addition, there were several roadway signs in the vicinity, which could be used as sensor mounts. The sensors were set up on July 25, 2008, with a 50 ft offset from the roadway to maintain a safe clear zone.

Sensor Calibration

Most of the sensors allow users to perform speed calibration. The calibration procedures varied greatly among the three sensors, with the SmartSensor 105 being the most time-consuming. The speed calibration for the SmartSensor 105 required taking speed readings for each lane and adjusting the sensor's value up or down depending on the speed error. This was an iterative process and required several attempts to produce accurate vehicle detection (Figure 4).

The initial lane speed sensor values (default of 1.0) produced higher than desired speeds, which required the sensor values to be adjusted. All of the sensor speed values had to be lowered, and overall the southbound speed values were higher than the northbound values with the exception of the northbound lane 2. The calibrated parameters produced speeds that were within 3-4 mph per lane. It should be noted that the actual calibration process depends heavily on the amount of traffic present.

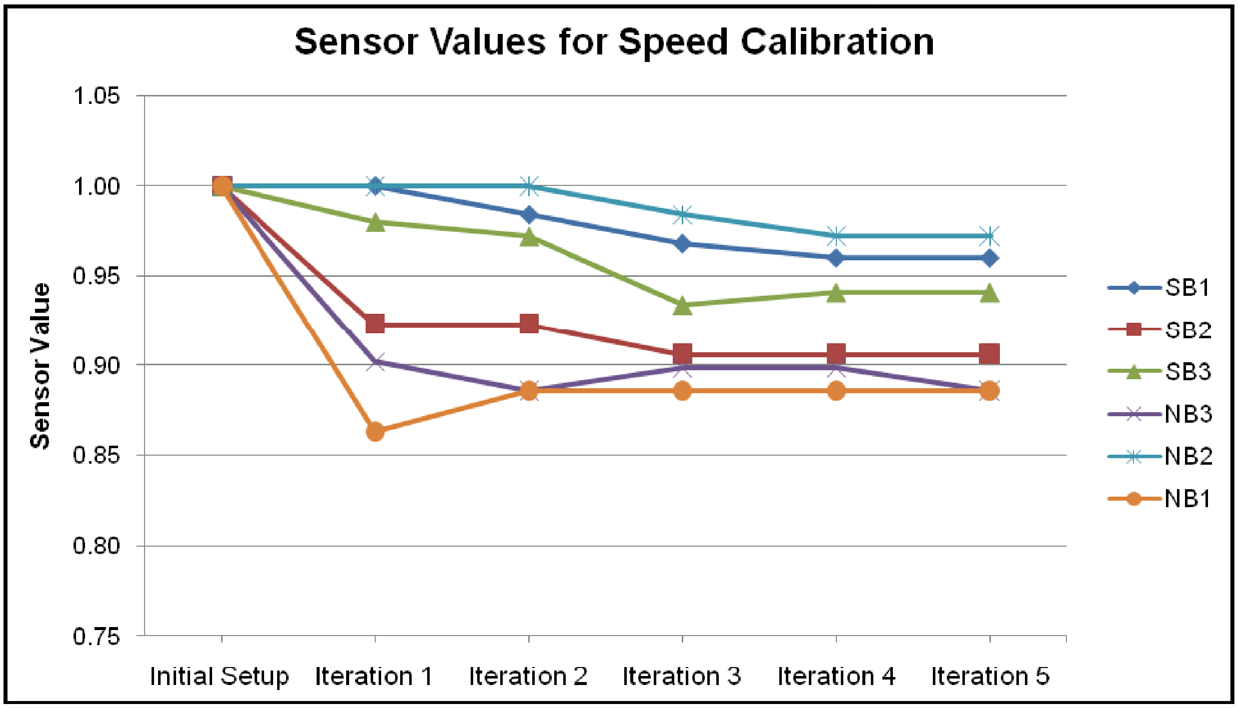

Figure 4. SmartSensor 105 Speed Calibration

Detection Comparison Procedures

To assist in the vehicle classification evaluation, cones were set up alongside each direction of the interstate to serve as visual aids for the manual vehicle length classification. The cones were initially set at (0, 10, 18, and 55 ft). Upon analysis, it was apparent that an adjustment needed to be made to the passenger car vehicle lengths, and it was changed to 20 ft. This was due to under-counting passenger cars and over-counting single-unit trucks. It was observed that several large passenger vehicles are longer than 18 ft.

The duration of each comparison study was approximately one hour. This was done to keep the amount of data at a manageable level while maintaining a sufficient sample size of vehicles. Once the data was downloaded from the sensors, it was compared with the post-processed video data. Data from the ATR during the same time period was also collected to illustrate the comparison between the sensors and inductive loops.

The second phase of this study evaluated sensor accuracy using a sign-mounted method. This was done by using the pole from a tripod and fixing it to the sign structure with metal banding (Figure 5). The offset from the roadway was the same, so no adjustments had to be made to the height. This method of mounting is fairly straightforward, and easy to set up.

Figure 5. Sign-Mounted Sensors

RESULTS

Several different comparisons were conducted for this study, which include volume, speed, and vehicle classification. In addition to the comparison among the three sensors, comparisons were also done using data from the ATR, and from the alternative sign mounting of both SmartSensors. The following section describes the results of the study.

Traffic Volume

The volume data from each comparison was organized into lane volume, directional volume, and total volume (combined NB and SB). Overall, the SmartSensor HD was the most accurate for vehicle volumes, and had comparable results to the ATR. However, there was one instance that the sensor appeared to be malfunctioning, which can be seen in the over-counted volumes for October 14, 2008. After this was noticed, the sensor was restarted and it functioned normally. For the remainder of this study, the results of the SmartSensor HD will not include this day, but are shown in the summary tables. It should be noted that with the exception of a few instances, all of the volume discrepancies were a result of the sensors over-counting the vehicles.

The SmartSensor HD lane volume differed from the manual counts with a range of -3% to 5% (Table 2). The sign-mounted SmartSensor HD accuracy was slightly worse, having differences ranging from -9% to 15% when compared to the manual count. The RTMS showed differences ranging from -10% to 26%. The SmartSensor 105 was the least accurate, with differences ranging from -8% to 31%. The sign-mounted SmartSensor 105 had differences of -12% to 26%, which was a similar range to the tripod-mounted sensor.

Table 2. Lane Volume Comparison

Lanes	Date	Manual Count	SS 105		SS HD		RTMS		ATR		SS HD S.M.		SS 105 S.M.	
			Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.
NB1	9/5	516	516	0%	521	1%	515	0%	-	-	-	-	-	-
	9/18	409	406	-1%	408	0%	407	0%	-	-	-	-	-	-
	10/1	404	402	0%	404	0%	402	-1%	405	0%	-	-	-	-
	10/14	462	471	2%	701	52%	-	-	-	-	-	-	471	2%
	10/16	452	468	4%	-	-	438	-3%	-	-	478	6%	-	-
NB2	9/5	526	525	0%	513	-2%	509	-3%	-	-	-	-	-	-
	9/18	309	327	6%	313	1%	312	1%	-	-	-	-	-	-
	10/1	328	355	8%	330	1%	331	0%	330	1%	-	-	-	-
	10/14	429	442	3%	631	47%	-	-	-	-	-	-	496	16%
	10/16	353	368	4%	-	-	349	-1%	-	-	350	-1%	-	-
NB3	9/5	220	228	4%	220	0%	235	7%	-	-	-	-	-	-
	9/18	88	115	31%	92	5%	111	26%	-	-	-	-	-	-
	10/1	104	130	25%	108	4%	126	17%	108	4%	-	-	-	-
	10/14	145	171	18%	247	70%	-	-	-	-	-	-	141	-3%
	10/16	117	129	10%	-	-	123	5%	-	-	106	-9%	-	-
SB1	9/5	415	403	-3%	407	-2%	429	3%	-	-	-	-	-	-
	9/18	269	270	0%	263	-2%	296	10%	-	-	-	-	-	-
	10/1	316	322	2%	318	1%	329	2%	322	2%	-	-	-	-
	10/14	401	377	-6%	447	11%	-	-	-	-	-	-	494	23%
	10/16	294	295	0%	-	-	289	-2%	-	-	338	15%	-	-
SB2	9/5	643	661	3%	645	0%	629	-2%	-	-	-	-	-	-
	9/18	414	423	2%	415	0%	371	-10%	-	-	-	-	-	-
	10/1	430	434	1%	419	-3%	398	-6%	425	-1%	-	-	-	-
	10/14	489	523	7%	635	30%	-	-	-	-	-	-	615	26%
	10/16	448	463	3%	-	-	440	-2%	-	-	434	-3%	-	-
SB3	9/5	247	249	1%	253	2%	252	2%	-	-	-	-	-	-
	9/18	115	114	-1%	117	2%	120	4%	-	-	-	-	-	-
	10/1	114	117	3%	119	4%	123	6%	116	2%	-	-	-	-
	10/14	153	140	-8%	219	43%	-	-	-	-	-	-	134	-12%
	10/16	114	120	5%	-	-	124	9%	-	-	106	-7%	-	-

Notes: S.M. refers to the sign-mounted configuration
The highlighted cells represent a difference of more than 5%

When the sensor volumes are aggregated by direction, the overall accuracy improved due to the balancing of the under- and over-counted vehicles. Similar to the lane comparisons, the SmartSensor HD had the best overall accuracy for the directional comparisons followed by the RTMS and SmartSensor 105. Compared to manual counts, the inaccuracies of the SmartSensor HD, RTMS, and SmartSensor 105 ranged from -1% to 1%, -1% to 3%, and 0% to 6%, respectively (Table 3).

Table 3. Directional Sensor Volume Comparison

Lanes	Date	Manual Count	SS 105		SS HD		RTMS		ATR		SS HD S.M.		SS 105 S.M.	
			Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.	Vol.	Diff.
NB	9/5	1,262	1,269	1%	1,254	-1%	1,259	0%	-	-	-	-	-	-
	9/18	806	848	5%	813	1%	830	3%	-	-	-	-	-	-
	10/1	836	887	6%	842	1%	859	3%	843	1%	-	-	-	-
	10/14	1,036	1,084	5%	1,579	52%	-	-	-	-	-	-	1,108	7%
	10/16	922	965	5%	-	-	910	-1%	-	-	934	1%	-	-
SB	9/5	1,305	1,313	1%	1,305	0%	1,310	0%	-	-	-	-	-	-
	9/18	798	807	1%	795	0%	787	-1%	-	-	-	-	-	-
	10/1	860	873	2%	856	0%	850	-1%	863	0%	-	-	-	-
	10/14	1,043	1,040	0%	1,301	25%	-	-	-	-	-	-	1,243	19%
	10/16	856	878	3%	-	-	853	0%	-	-	878	3%	-	-

Notes: S.M. refers to the sign-mounted configuration
The highlighted cells represent a difference of more than 5%

A comparison of the total sensor volumes shows the SmartSensor HD to be the most accurate of the three sensors, followed by the RTMS and the SmartSensor 105. Compared to manual counts, the total volume inaccuracies of the SmartSensor HD, RTMS, and SmartSensor 105 ranged from 0%, -1% to 1%, and 1% to 4%, respectively (Table 4).

Table 4. Total Volume Comparison

Lanes	Date	Manual Count	SS 105		SS HD		RTMS		ATR		SS HD S.M.		SS 105 S.M.	
			Vol.	**Diff.**	**Vol.**	**Diff.**	**Vol.**	**Diff.**	**Vol.**	**Diff.**	**Vol.**	**Diff.**	**Vol.**	**Diff.**
Total	9/5	2,567	2,582	1%	2,559	0%	2,569	0%	-	-	-	-	-	-
	9/18	1,604	1,655	3%	1,608	0%	1,617	1%	-	-	-	-	-	-
	10/1	1,696	1,760	4%	1,698	0%	1,709	1%	1,706	1%	-	-	-	-
	10/14	2,079	2,124	2%	2,880	39%	-	-	-	-	-	-	2,351	13%
	10/16	1,778	1,843	4%	-	-	1,763	-1%	-	-	1,812	2%	-	-

Notes: S.M. refers to the sign-mounted configuration
The highlighted cells represent a difference of more than 5%

Traffic Speed

Speed data were recorded during each comparison study to illustrate the variation among the sensors as previously discussed. It was difficult to calibrate the SmartSensor 105 to the hand-held radar. Although the sensor speed values remained constant during some test days, differences between the devices were 5 mph high on one day and 5 mph low on a different day. Eventually the sensor was calibrated to within 3-4 mph for all lanes.

The SmartSensor HD has no parameters for calibrating speed data; however, speed calibration was not needed. On every speed check comparison between the SmartSensor HD and the hand-held radar, all lane's speeds were within 2-3 mph. The RTMS speed calibration was an easy process which required the user to manually enter the speeds taken from the hand-held radar. The RTMS then adjusted the speed detection based on the observed values. Although the speeds were initially calibrated to the hand-held radar, an issue was observed with the

RTMS speed data. The two SmartSensors' speed data are similar and realistic, but the RTMS data was significantly different, which was high for close lanes and low for lanes further away (Table 5).

Table 5. Sensor Speed Data (mph)

Date	Lane	SS 105	SS HD	RTMS	SS HD S.M.	SS 105 S.M.
9/5/2008	NB 1	62	58	72	-	-
	NB 2	63	60	54	-	-
	NB 3	65	64	57	-	-
	SB 1	65	60	40	-	-
	SB 2	63	61	43	-	-
	SB 3	65	65	45	-	-
9/18/2008	NB 1	62	59	73	-	-
	NB 2	57	61	58	-	-
	NB 3	61	65	57	-	-
	SB 1	62	59	42	-	-
	SB 2	60	60	44	-	-
	SB 3	64	66	46	-	-
10/1/2008	NB 1	62	58	71	-	-
	NB 2	58	60	56	-	-
	NB 3	60	64	57	-	-
	SB 1	64	60	41	-	-
	SB 2	60	61	45	-	-
	SB 3	63	65	46	-	-
10/16/2008	NB 1	62	-	72	61	-
	NB 2	60	-	55	61	-
	NB 3	64	-	53	65	-
	SB 1	62	-	40	60	-
	SB 2	60	-	42	60	-
	SB 3	64	-	45	64	-
10/14/2008	NB 1	63	-	-	-	65
	NB 2	62	-	-	-	61
	NB 3	63	-	-	-	60
	SB 1	63	-	-	-	62
	SB 2	61	-	-	-	61
	SB 3	65	-	-	-	61

Note: S.M. refers to the sign-mounted configuration

Vehicle Classification

Since each sensor had different classification capabilities, and the SmartSensor 105 only had the capability to classify 3 classes of vehicles, it was decided to group the classification into 3 major length bins: small (0-20 ft), medium (0-55 ft), and large (>55 ft). The classification aspect of the data collection is the major limitation of each radar-based sensor. The SmartSensor 105, was by far the least accurate of the three sensors. The SmartSensor 105 under-counted the small vehicles and over-counted the medium and large vehicles (Table 6). The SmartSensor HD slightly under-counted the small vehicles and slightly over-counted the large vehicles, while over-counting the medium vehicles. The RTMS undercounted the small vehicles and over-counted both the medium and large vehicles. The SmartSensor HD was consistently more accurate than the other two, especially in classifying small vehicles.

Table 6. Vehicle Length Classification Comparison

Small Vehicles							
	Volumes				**Difference**		
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**SS 105**	**SS HD**	**RTMS**
NB 1	895	527	866	811	-41%	-3%	-9%
NB 2	599	271	579	485	-55%	-3%	-19%
NB 3	272	153	267	253	-44%	-2%	-7%
NB Total	1,766	950	1,712	1,549	-46%	-3%	-12%
SB 3	337	105	325	353	-69%	-4%	5%
SB 2	910	253	889	678	-72%	-2%	-25%
SB 1	584	175	562	651	-70%	-4%	11%
SB Total	1,831	532	1,776	1,682	-71%	-3%	-8%
Medium Vehicles							
	Volumes				**Difference**		
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**SS 105**	**SS HD**	**RTMS**
NB 1	27	384	58	102	1,321%	115%	278%
NB 2	95	431	105	182	353%	11%	92%
NB 3	14	167	20	71	1,092%	43%	407%
NB Total	136	981	183	355	621%	35%	161%
SB 3	13	242	32	10	1,761%	146%	-23%
SB 2	65	727	86	291	1,018%	32%	348%
SB 1	46	439	58	54	854%	26%	17%
SB Total	124	1,407	176	355	1,035%	42%	186%
Large Vehicles							
	Volumes				**Difference**		
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**SS 105**	**SS HD**	**RTMS**
NB 1	3	11	5	9	260%	67%	200%
NB 2	141	150	142	140	6%	1%	-1%
NB 3	22	23	25	22	4%	14%	0%
NB Total	166	183	172	171	10%	4%	3%
SB 3	12	16	13	33	32%	8%	175%
SB 2	82	103	85	67	26%	4%	-18%
SB 1	54	59	50	20	9%	-7%	-63%
SB Total	148	178	148	120	20%	0%	-19%
Total	4,171	4,232	4,167	4,232	1%	0%	1%

Note: Data from 3:30 – 4:30 PM on 9/5/08 and 10:30 – 11:30 AM on 9/18/08

A second classification comparison was conducted among the three radar sensors and the ATR. The data from the ATR was provided by the NDDOT, and the classification performed by the ATR is based on the Federal Highway Administration (FHWA) 15-vehicle classification scheme. Because of this, the 15-vehicle classes were grouped into 3 classes for comparison with the sensors: small (Class 1-4), medium (Class 5-7), large (Class 8-15).

The ATR had similar accuracy to the SmartSensor HD, however, the SmartSensor HD was slightly better overall (Table 7). This may be due to the grouping of classification bins, but there didn’t seem to be any consistency with the ATR’s data. The ATR over-counted some of the lanes, and under-counted others in both the medium and large bins.

Table 7. Vehicle Length Classification Comparison 10/1/08

Small Vehicles									
	Volumes					Difference			
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**ATR**	**SS 105**	**SS HD**	**RTMS**	**ATR**
NB 1	384	166	344	315	383	-57%	-10%	-18%	0%
NB 2	207	81	197	155	213	-61%	-5%	-25%	3%
NB 3	81	55	80	70	86	-32%	-1%	-14%	6%
NB Total	672	302	621	540	682	-55%	-8%	-20%	1%
SB 3	97	24	97	109	102	-75%	0%	12%	5%
SB 2	325	42	309	177	330	-87%	-5%	-46%	2%
SB 1	264	36	260	288	270	-86%	-2%	9%	2%
SB Total	686	102	666	574	702	-85%	-3%	-16%	2%
Medium Vehicles									
	Volumes					**Difference**			
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**ATR**	**SS 105**	**SS HD**	**RTMS**	**ATR**
NB 1	18	232	59	80	19	1,188%	228%	344%	6%
NB 2	63	195	62	104	31	209%	-2%	65%	-51%
NB 3	14	61	13	45	19	335%	-7%	221%	36%
NB Total	95	488	134	229	69	413%	41%	141%	-27%
SB 3	12	82	16	9	4	583%	33%	-25%	-67%
SB 2	53	329	54	169	34	520%	2%	219%	-36%
SB 1	35	255	39	36	25	628%	11%	3%	-29%
SB Total	100	666	109	214	63	566%	9%	114%	-37%
Large Vehicles									
	Volumes					**% Difference**			
Lane	**Manual**	**SS 105**	**SS HD**	**RTMS**	**ATR**	**SS 105**	**SS HD**	**RTMS**	**ATR**
NB 1	2	4	1	7	3	98%	-50%	250%	50%
NB 2	61	79	71	72	86	29%	16%	18%	41%
NB 3	10	14	15	11	3	40%	50%	10%	-70%
NB Total	73	97	87	90	92	33%	19%	23%	26%
SB 3	5	11	6	5	10	120%	20%	0%	100%
SB 2	52	63	56	52	61	21%	8%	0%	17%
SB 1	17	31	19	5	27	82%	12%	-71%	59%
SB Total	74	105	81	62	98	41%	9%	-16%	32%
Total	1,700	1,758	1,698	1,709	1,706	3%	0%	1%	0%

Sensor Mount Results

This study evaluated the use of sign-mounted sensors as an alternative to a dedicated mounting system. This was done to determine if one type of mounting system was superior in terms of volume accuracy. Both the SmartSensor 105 and SmartSensor HD were mounted on the sign, and in both cases the accuracy of the sign-mounted configuration was slightly worse compared to the tripod mounting system.

Compared to manual counts on the same day, total volume inaccuracies of SmartSensor 105 using the tripod and sign-mount sytems were 2% and 13%, respectively. The accuracy of the sign-mounted SmartSensor HD was better than the SmartSensor 105, but slightly less acurate than the tripod-based SmartSensor HD. When compared to the manual volumes, total volume inaccuracies of SmartSensor HD using the tripod and sign-mount sytems were 0% and 2%, respectively.

The discrepancies between the two mounting systems could be attributed to the mounting support. Since the sign post was the same offset at the tripod-bases, the mounting height of the sensors remained the same. However, the height of the sign post was lower than the guy-wires on the tripod bases, so there was slightly less stability for the sensors and an increased possibility for sensor movement. Depending on the sign location and required height of the sensor, this lack of support may not be an issue in all cases.

SUMMARY

This study evaluated three different radar-based sensors to determine their accuracy in collecting vehicle volume, speed, and classification data. It also evaluated two types of sensor mounting configurations to determine if they have a significant influence on sensor accuracy. In addition, set up guides for the SmartSensor 105, SmartSensor HD, and RTMS are provided in the appendices.

For the volume comparison, the SmartSensor HD showed a consistently higher accuracy over the SmartSensor 105 and RTMS, except for the test when the sensor malfunctioned. The SmartSensor HD had lane volume accuracies greater than 95%, directional volume accuracy of at least 97%, and a minimum total volume accuracy of 98%. The accuracy of the SmartSensor 105 was within 69% for lane volumes, 81% for directional volumes, and 87% for total volumes. The RTMS accuracy was within 74% for lane volumes, 97% for directional volumes, and 99% for total volumes. The volume data from the ATR was also used in the comparison and produced similar results as the SmartSensor HD (within 96% for lane volumes, 99% for directional volumes, and 99% for total volumes).

Speed data compared during this study showed similar readings for both the SmartSensor 105 and SmartSensor HD, and significantly lower speed readings from the RTMS (except for one lane). Although the speed calibration for the SmartSensor 105 was a tedious process, the resulting speeds were relatively close to the manually recorded speeds (within 3-4 mph). The SmartSensor HD did not require any type of speed calibration, and it consistently showed speeds similar to the hand-held radar (within 2-3 mph). The speed calibration process for the RTMS was easier than that of the SmartSensor 105, but the data was still inaccurate after calibration and showed differences of up to 20 mph in some instances.

Vehicle classification seemed to be the most difficult task overall for all of the radar sensors. Based on the data collected, the SmartSensor HD was the most accurate in classifying vehicles and had accuracy ranges of (-2% to -4% for small vehicles, 11% to 115% for medium vehicles, -7% to 67% for large vehicles), followed by the RTMS (-25% to 11% for small vehicles, -23% to 407% for medium vehicles, and -63% to 200% for large vehicles), and the SmartSensor 105 (-72% to -41% for small vehicles, 353% to 1761% for medium vehicles, and 4% to 260% for large vehicles). In addition, the data from the ATR also showed some discrepancies when compared to manually collected data (0% to 6% for small vehicles, -67% to 36% for medium vehicles, and -70% to 100% for large vehicles).

A comparison between the tripod-based mounting system and a sign-mounted configuration was performed for both SmartSensor units. In both cases, the sensor's accuracy on the tripod-mounting system was slightly better. SmartSensor HD accuracy for lane volumes was within 95% (tripod mounted) and 85% (sign mounted); directional volume was 99% (tripod mounted) and 97% (sign mounted); and total volume was 100% (tripod mounted) and 98% (sign mounted). The SmartSensor 105 accuracy for lane volumes was within 69% (tripod mounted) and 74% (sign mounted); directional volume was within 94% (tripod mounted) and 81% (sign mounted); and total volume was within 96% (tripod mounted) configuration, and 87% (sign mounted).

Based on this study, the SmartSensor HD demonstrated the best overall performance, followed by the RTMS. The SmartSensor 105 is a first-generation sensor, which has been replaced by the SmartSensor HD, so its performance is understandably lower than the SmartSensor HD. When compared with the inductive-loop ATR data collection system currently in place, the SmartSensor HD showed comparable results. This illustrates the usefulness of using a radar-based data collection system as a viable alternative to intrusive technologies, and can be especially useful for temporary data collection.

REFERENCES

1. Dudek, Conrad L.; Suennen, Mark D.; A Traffic Detection Toolkit for Traveler Information Systems. Texas A&M University, August, 2000.

2. Evaluation of Non-Intrusive Technologies for Traffic Detection. Minnesota Department of Transportation, SRF Consulting Group, Inc., October, 2001.

3. Middleton, Dan; Parker, Ricky; Vehicle Detector Evaluation. Texas Transportation Institute, Texas Department of Transportation, FHWA/TX-03/2119-1, October, 2002.

4. Evaluation of Portable Non-Intrusive Traffic Detection System, Project Meeting Minutes, Minnesota Department of Transportation, October, 2003.

5. Hao, Bingwen; Minge, Eric; Kotzenmacher, Jerry; Evaluation of Portable Non-Intrusive Traffic Detection System. Minnesota Department of Transportation, February, 2005.

6. Illinois Traffic Monitoring Program, Illinois Department of Transportation, November, 2004.

7. Mauga, Timur; The Development of Florida Length Based Vehicle Classification Scheme Using Support Vector Machines. Florida State University, 2006.

8. Traffic Monitoring Guide, Section 4: “Vehicle Classification Monitoring,” Federal Highway Administration, FHWA-PL-01-021, 2001.

9. Wang, Yinhai; Wei, Heng; Zhang, Guohui; An Artificial Neural Network Method for Length-Based Vehicle Classification Using Single-Loop Outputs. University of Washington, 2005.

APPENDIX A:

SENSOR CONFIGURATION/CALIBRATION GUIDES

SmartSensor 105

Installation and Configuration

I. Connect to sensor
   a. Connect the SmartSensor cable to the battery using the positive and negative battery terminals
   b. Connect serial cable from SmartSensor cable to laptop COM port
   c. Open the SmartSensor Manager 2.2.5 (SSMPC.07.04.27.exe) on the laptop
   d. Connect using the serial connection

II. Modify lane configuration
   a. From the “Edit” menu, select “Lane configuration”
   b. Toggle mode to “Automatic”
   c. Click the “Restart” button: RESTART
   d. Click OK on the warning that follows
   e. Allow at least a few minutes for the SmartSensor to detect vehicles in each lane
      Note: The lighter the traffic, the longer it will take for all of the lanes to be detected.
   f. To make further adjustments, toggle to “Manual” mode
   g. Manual configuration options include:
      - Adjust Lanes – Adjusts existing lanes by moving shoulder, lane divider, or centerline. Make sure centerlines (pink lines) are in the center of each driving lane.
      - Paint Lines –Inserts lane dividers in paved areas
      - Remove Lines – Removes a lane divider
      - Remove Lane – Removes one lane of a road
      - Construct Roads – Inserts a new road consisting of shoulder-center-shoulder
      - Remove Roads – Removes a road, including all lanes
      - Construct Barriers – Constructs a median or barrier
      - Remove Barriers – Removes a median or barrier
      - Reverse Direction – Reverses the direction of the lane. Initially all the lanes are shown in the same direction. To display opposing traffic, reverse lane directions.
      - Edit Lane Names – Labels lane names for later identification of lanes on the Sensor Info screen.

      h. Once all desired lane modifications are made, click Update: UPDATE

III. Modify data collection parameters
   a. From the “Edit” menu, select “Data collection parameters”
   b. “General” tab settings:
      - Sensor (Multi-drop) ID – changes ID number. The default is the last four numbers of the serial number
      - RTMS ID – If the user chooses to communicate with the RTMS protocol, all that is required is the RTMS ID
      - Description – Creates a description of the SmartSensor
      - Orientation – Provides a drop-down menu to specify which direction the SmartSensor is facing. Mainly for benefit of the user
      - Measurement units – Provides a drop-down menu to specify unit of measurement

    - RF Channel – In case there are multiple SmartSensors in close proximity, the user should assign each sensor a different RF Channel. This will reduce the interference of the sensors with one another
  - c. “Communication” tab – Leave all settings on default unless otherwise known
  - d. “Data Collection” tab settings:
    - Interval Data – specifies in seconds the interval time over which traffic date are aggregated. The minimum interval allowed is 5 seconds
    - Vehicle Classification – Specifies the length ranges for vehicle classes
    - Lane Setup – Specify lane name and direction. “Scale Occupancy” and “Scale Speed” columns are used when tuning the sensor. These factors are the ratio of lane occupancy/speed to the default occupancy/speed.
    - Default Loop Size and Spacing – If contact closure cards are being used, the cards will read the Default Loop and Size and Spacing. These values are also used when calculating the occupancy and speed scale factors.

IV. Sensor date & time
  - a. From the “Edit” menu, select “Sensor Date & Time”
  - b. Displays date and time of the sensor’s internal clock. Allows the user to manually change the date and time or synchronize the sensor’s clock to PC clock by clicking:

Data Collection and Download

- If the sensor will be deployed for an extended duration, change the battery prior to downloading data.
- Connect the SmartSensor cable to the battery using the positive and negative battery terminals
- Connect serial cable from SmartSensor cable to the laptop COM port.
- Open the SmartSensor Manager (SSMPC.07.04.27.exe) on the laptop:
- Connect using the serial connection option.

I. Data Collection Setup
  - a. From the “Data Collection” menu, select “Setup”
  - b. Specify the desired interval (bin size) in seconds
  - c. Click “Start”
  - d. Click “OK” on the warning that all data stored onboard the sensor being erased
  - e. Allow a few moments for the data collection to begin
  - f. Click “OK” on the “View Interval and Buffer Status” window

II. Data Download
  - a. From the “Data Collection” menu, select “Setup”
  - b. Choose a location to save the log file
  - c. Name and open the log file
  - d. Click “Download”

Note: Download may take several minutes.

  - e. In order to continue data collection, you must begin a new study period: see *Data Collection*. This erases the old data and starts collection of the new data.
  - f. From the “File” menu, choose “Close Connection” to end

SmartSensor HD

Installation and Configuration

I. Connect to sensor
   a. Connect the SmartSensor HD cable to the battery using the positive and negative battery terminals
   b. Connect serial cable from SmartSensor HD cable to laptop COM port
   c. Open the SmartSensor HD Manager on the laptop

II. Connect using the serial connection. Ensure proper sensor alignment
   a. On the main screen, click “Lane Setup”
   b. Click “Sensor Alignment”
   c. Adjust the sensor according to the sensor displayed in the “Sensor Alignment” window. A green arrow means the sensor is positioned correctly for optimal performance; a yellow or red arrow means the sensor in NOT correctly aligned with the roadway.

III. Lane configuration
   a. Automatic configuration
      1. From the main screen, select “Lane Setup” → ”Lane Configuration”
      2. Click the “Tools” icon 🛠 and select “Clear Edit Area”
      3. Click the “Tools” icon again and select “Restart Auto Cfg.”

         Note: This step could take several minutes depending on the amount of traffic.

      4. Once the SmartSensor HD has detected vehicles and created lanes, click “OK” and save the changes to the configuration.
      5. To verify that the lanes have been configured properly, close the “Lane Configuration” window and select “Lane Verification” from the “Lane Setup” menu
      6. If the sensor is unable to configure itself to your satisfaction, use manual configuration.
   b. Manual configuration
      1. From the “Lane Setup” menu, select “Lane Configuration”
      2. Click on a lane to change the lane name, lane direction, and lane activity
      3. Uncheck the ‘Activity’ box to de-activate the lane
         - ➢ Lanes can be adjusted by clicking anywhere inside the lane and using the adjustment tools
      4. Side bars on either side of the ‘Lane Configuration’ window have several different modes. A list of the modes can be seen by holding down the sidebar button
         - ➢ Auto Cfg. – shows the lanes that were automatically configured by the sensor
         - ➢ Saved Cfg. – shows the lanes that are saved on the sensor
         - ➢ Scale – shows the distance in feet from the SmartSensor HD to each lane
         - ➢ Peaks – shows the relative occurrence of events
         - ➢ Tracks – shows the vehicle paths for low-traffic lanes
      5. Lanes can be added by clicking any area where a lane is desired and selecting “Add Lane” from the options in the pop-up box
      6. Deleting lanes can be done by clicking anywhere inside the lane and selecting “Delete Lane” from the options that appear.

IV. Lane verification
  1. From the “Lane Setup” menu, select “Lane Verification”
  2. Side bars on either side of the “Lane Verification” window have several different modes. A list of the modes can be seen by holding down the sidebar button
    i. Presence – displays buttons to the side of each lane that will light up after each vehicle is detected
    ii. Volume – displays the number of events in each lane
    iii. Speed – shows the speed of each individual car in their respective lanes

    iv.-vii. Class – shows vehicle classification, which can be created using the ‘Class Definitions’ feature located in the ‘Data Setup & Collection’ window

Data Collection and Download

a. If the sensor will be deployed for an extended duration, change the battery prior to data download
b. Connect the SmartSensor cable to the battery using the positive and negative battery terminals
c. Connect serial cable from SmartSensor to the laptop COM port
d. Open the SSM HD v.1.3 program on the laptop

e. Connect to the sensor on the main screen by clicking: ⚡
f. On the main screen, select “Data Setup and Collection”
g. Click “Data Collection & Download”→”Data Download”
  i. Choose a location to save the log file
  ii. Name the log file and open it
  iii. After the download is finished, close the “Data Download” window
  iv. Click “Storage Settings”
  v. Click the eraser button to erase all the previous information
  Note: Be sure that the data collection switch is turned to ‘ON’
  vi. Close all windows to disconnect

RTMS

Installation and Configuration

- I. Connect to sensor
  - a. Connect the RTMS cable to the battery using the positive and negative battery terminals
  - b. Disconnect cable at the RTMS port that leads from the RTC Utility (Figure 1)
  - c. Connect RTMS cable from laptop COM port to RTMS data port in the RTC housing unit (Figure 1)

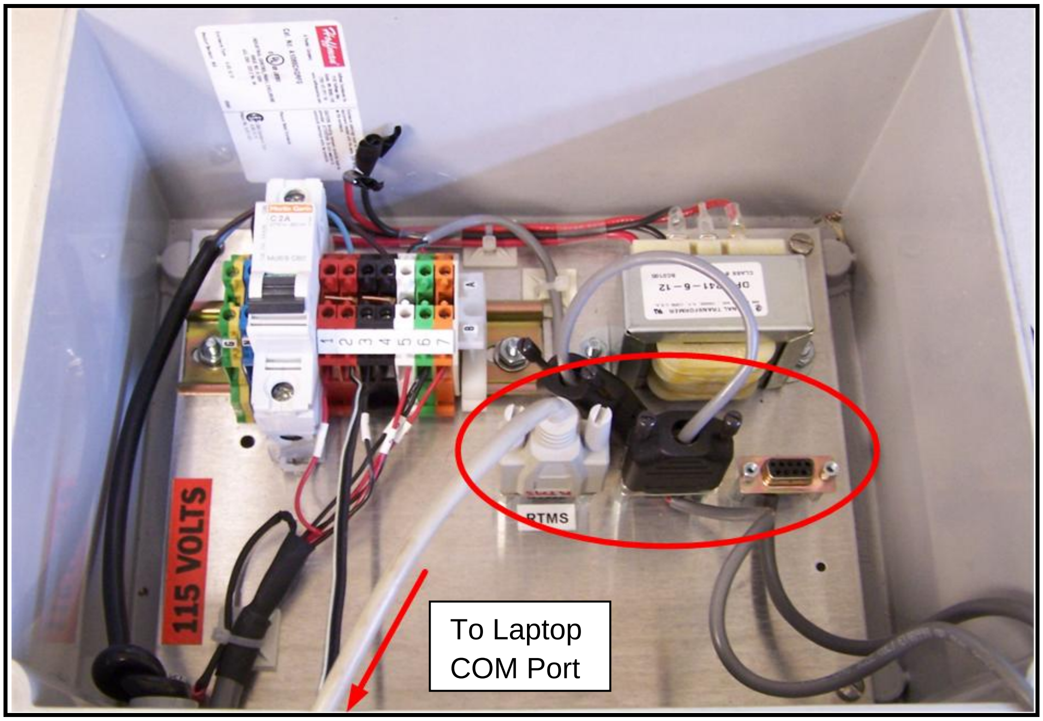

Figure 1. RTMS COM Port Setup

- II. Open the WinRtms program on the laptop

- III. Click the Setup Wizard for step-by-step setup
  - a. Specify RTMS mode of operation
  - b. Click OK
  - c. The Wizard will proceed to set sensitivity and initial zone setup
  - d. Resulting zone setup is presented for approval
  - e. Visually verify, using vehicle blips, whether zones were placed in all lanes of interest.
    - ➢ If they are, click SKIP
    - ➢ If not, click OK to manually change the number of zones and their location

- IV. Click the SENSITIVITY button
  - a. Use up and down arrows to adjust sensitivity
  - b. Typical median value is 7
  - c. Set a value of 5 if only a few close lanes are being monitored
  - d. Increase sensitivity if needed to detect smaller vehicles in middle lanes of interest

e. Do not increase sensitivity to compensate for improper alignment
f. Click OK when finished

V. If vehicles are inaccurately detected as a result of large trucks (splashing), click FINETUNE
  a. If first and last zones are well defined, the Auto fine tuning can be used
  b. For manual fine tuning, set the initial value to 0, then use the up and down arrows to visually verify that a decrease in splashing effect is taking place
    - A splash occurring nearer to the sensor is corrected by increasing the fine tune value
    - A splash occurring farther from the sensor is corrected by decreasing the fine tune value
  c. Click OK

VI. Click PERIOD to set the length of data collection interval, in seconds
  a. Use up and down arrows to adjust the message period (interval) length
  b. Click OK

VII. Verify the accuracy of the vehicle detection
  a. Select PERIOD and set to 30 seconds
  b. Select VERIFY from the main screen
  c. When the left-side window appears, tap the spacebar to checkmark the CLEAR TOTAL COUNTERS ON NEXT MESSAGE INTERVAL box and get ready to start counting
  d. At the end of the current message period, the background window blinks and the program emits a beep, signaling to start the manual count
  e. Count vehicles in the selected lanes as they cross the RTMS beam
  f. At the end of the message period the RTMS updates the detected vehicle counts for that period
  g. Tap the space bar and this will checkmark the STOP COUNTING box and freeze the RTMS count
    - Enter the manual count to display the absolute difference and the percent deviation between the manual and RTMS counts
    - Deviation beyond approximately ±5% may require fine tuning or sensitivity correction
  h. Click SAVE to save results of verification as a text file
  i. Click OK

VIII. Click SPEED CALIB to calibrate the vehicle speeds
  a. Click automatic speed calibration
  b. Input reference speed for all lanes
    - Reference speed for each lane is the average speed and should be determined using radar speed detection
    - Insert an X to exclude a lane from calibration
  c. Enter the number of calibration cycles when OFF is highlighted by using the up and down arrows. CALIBRATION IN PROCESS will flash

     Hint: It is better to reduce the period to 30 seconds so there are more cycles. 7 cycles of 30 seconds is recommended.

  d. The setup utility adjusts all active zone coefficients to converge the reference speeds
  e. If traffic flow changes during calibration , adjust the reference speeds as appropriate
  f. When finished, set the number of calibration cycles to OFF
  g. Click QUIT

IX. Click the SENSOR ID to specify a sensor ID number

X. Click DATA MODE to specify data parameters
  a. Select MESSAGE COMPOSITION to open the RTMS Statistical message window

    - High resolution occupancy provides occupancy measurements with 0.1% resolution instead of the default 1% resolution
    - 6 foot emulation adjusts occupancy measurements to be equivalent to the 6 foot loop data
    - The number of vehicle classes can be specified to be 2, 4, or 6
    - Toggle the REAL TIME CLOCK button to sync data collection with computer clock.
    - Click OK

XI. Advanced parameters can be specified by clicking ADVANCED
  a. EXTENSION DELAY allows the user to change the Mode default
  b. DETECTION THRESHOLD allows the user to change the threshold from default
  c. KM/H – MPH allows the user to convert recorded speeds from the default km/h to mph
  d. LONG VEH/HEADWAY allows users to select either Long Vehicles or Headway as required
  e. SPEED BINS specifies ranges of speed for data collection
    - Specify bin’s upper speed limit
    - Upper limit of a bin automatically defines the lower limit of the next bin
  f. POWER MANAGEMENT allows RTMS powered by battery to be operated in cycles to conserve battery power
    - “Number of cycles on” defines the number of message periods the sensor operates
    - “Standby in minutes” defines the number of minutes the sensor is in standby and draws minimum power. Max time is 4 hours, 14 minutes
  g. CLASSIFICATION allows the user to set the lower limit of the vehicle classes

XII. Click Exit to exit the RTMS

XIII. Disconnect the RTMS cable between the laptop and RTMS data port and reconnect cable from the RTC to the RTMS.

Data Collection and Download

I. If the sensor will be deployed for an extended duration, change the battery prior to data download

II. Connect serial cable from laptop to the available port in RTC housing unit (Figure 2)

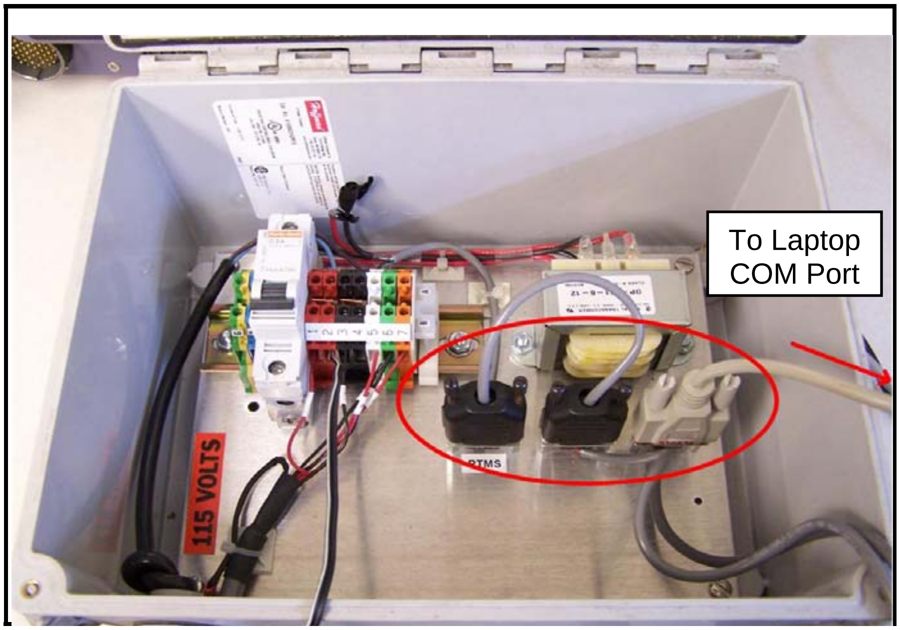

Figure 2. RTMS Data Download

III. Open the RTC Utility program on the laptop

IV. Click DOWNLOAD

V. Choose a location to save the log file

VI. Name the file and click SAVE

VII. After download is complete, click CLEAR RTC MEMORY to erase all data

VIII. Close RTC Utility