Evaluation of Portable Non-Intrusive Traffic Detection System


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ABSTRACT
The goal of this study is to develop a safe, accurate, simple, and cost-effective method of collecting traffic data by using a Portable Non-Intrusive Traffic Detection System (PNITDS). The system developed for this project provides an alternative to conventional traffic data collection methods, such as inductive loops and road tube counters, by allowing agencies to collect data in high-traffic locations without compromising traffic flow or personnel safety. The selected design consists of a battery-powered, pole-mounted system that serves as a platform for mounting side-fired non-intrusive traffic sensors. Three sensors have been tested under different mounting configurations and traffic levels: the RTMS by EIS, the SAS-1 by SmarTek, and the SmartSensor by Wavetronix. The evaluation focuses on the assessment of traffic sensor performance and the pole-mounted system itself.

Test results show that the system developed is practical for short-term data collection because it can be quickly and safely deployed without interrupting traffic. The system is designed to attach to various existing roadside infrastructure, such as lighting poles and sign poles, providing flexibility in mounting locations. The sensors evaluated can accurately collect volume and speed data from up to eight lanes when optimally mounted and calibrated. Obtaining length-based classification data requires additional time to calibrate the sensor, but when correctly calibrated, the results provide a reasonable measure of the distribution of vehicle lengths within the traffic stream.

I. INTRODUCTION
Traditional traffic data collection methods, such as inductive loops and road tube counters, cause traffic interruption and create safety concerns because personnel are exposed to traffic during installation and maintenance. Consequently, there is a need for the ability to conduct data collection without interrupting traffic, especially for a temporary, short-term data collection. This study seeks to develop a safe, simple, and cost-effective system that can accurately collect traffic data by using a "Portable Non-Intrusive Traffic Detection System" (PNITDS). This system is designed to attach to various types of sign posts along freeways and arterials, and support a traffic sensor to conduct temporary traffic data collection. It provides an alternative to conventional methods by allowing agencies to collect data at high-traffic locations without compromising traffic flow or personnel safety.

The idea of developing and evaluating the PNITDS was conceived at the 2002 North American Travel Monitoring Exhibition & Conference (NATMEC). The Minnesota Department of Transportation (Mn/DOT) was selected to lead the project which was supported by 16 other participating state DOTs through a pooled-fund effort. The prototype system was fabricated in December 2003, and field tests were conducted from February to June 2004. Test results were presented to technical committee members on June 27, 2004 at the NATMEC conference. The final report was expected to complete in July 2004. (As of this printing, the final report is not yet complete.) Refer to the PNITDS project website for further details: http://www.dot.state.mn.us/guidestar/projects/pnitsd.html. A traveling demonstration was scheduled in August and September 2004 to bring the PNITDS to the data collection personnel of participating agencies. The agencies will be able to gain first hand experience with the system's operations.

Because the primary goal of the project is to design, build, and evaluate a pole-mounted PNITDS that is capable of detecting traffic in multiple lanes under various mounting conditions, both the traffic sensors and the portable system were assessed for their ability to perform temporary data collection functions. Specific goals and supporting objectives are listed below:

Goal 1: Assess the Performance of Non-Intrusive Sensors
Objective 1-1: Assess performance in volume, speed, and length-based vehicle classification data collection
Objective 1-2: Assess performance in various traffic levels
Objective 1-3: Assess performance in various mounting configurations
Objective 1-4: Assess performance in various weather conditions

Goal 2: Document System Attributes
Objective 2-1: Document deployment on various signpost types
Objective 2-2: Document calibration issues
Objective 2-3: Document maintenance issues
Objective 2-4: Document system costs

II. PNITDS SYSTEM DESCRIPTION
After researching the existing portable traffic data collection systems, the PNITDS technical committee selected a pole-mounted system for evaluation. The concept of using a tip-up style of pole was originally designed and used by Virginia DOT in 1999. Mn/DOT modified the system and has used it to support RTMS sensors for short-term data collection.

The PNITDS design selected for this project builds on the previous work done in Virginia and Minnesota. The system consists of a battery-powered, pole-mounted system that serves as a platform for mounting side-fired non-intrusive traffic sensors. The pole-mounted system consists of two eight foot poles (one with an angle adjustment unit), a coupler, two sets of base units, and post clamps that can be attached to various types of sign posts (see Figure 1). Other key components include a telescoping pole used to adjust the vertical aiming angle of RTMS sensor via the angle adjustment unit on the top of the pole, a deep cycle marine battery, a traffic sensor, and a laptop that is used to configure the sensor and download archived data. A battery was selected by considering traffic sensor power draw and the length of the traffic study. A 55 amp-hour deep cycle marine battery was selected for this study in order to power any of the sensors for a minimum of three days.

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A battery box is needed to house the battery and deter theft. According to the American Association of State Highway and Transportation Officials (AASHTO) roadway design guidelines, the height of roadway obstructions should be less than four inches when located within a roadway’s clear zone. Larger obstructions should be protected (i.e., guardrail) or moved outside the clear zone. This height requirement specifies that the battery box be 4-inches or less in height. In addition, the crashworthiness of the poles and sensors should be evaluated if the system is deployed within the clear zone.

Three sensors were selected for the evaluation: the RTMS by EIS, the SAS-1 by SmarTek, and the SmartSensor by Wavetronix. Refer to Figure 2 for images of the sensors mounted in the field. Both the SmartSensor and RTMS sensors use radar technologies, while the SmarTek SAS-1 is a passive acoustic sensor. All three sensors have similar capabilities that facilitate the PNITDS data collection: sidefire installation, multiple lanes detected, volume, speed, length-based vehicle class, and auto configuration.

### III. TEST SITE

The PNITDS tests were conducted at the Mn/DOT Non-Intrusive Technology (NIT) test site at Interstate Highway 394 and Penn Avenue in Minneapolis, Minnesota. A data collection shelter located on the southeast corner of the interchange was designed and built in 2000 for the NIT project (http://projects.dot.state.mn.us/nit/) and for future studies.

Several features of this site make it a good location for the PNITDS test. First, the site includes an eight-lane freeway with three lanes in each direction and two reversible HOV lanes in between. This configuration provides an opportunity to fully assess traffic sensor detection capabilities. Second, a round-shaped light pole and two U-channel freeway signposts on the north and south side of I-394 provide mounting options that facilitate the evaluation of system mounting flexibility. Third, in-place inductive loops in the three eastbound lanes are wired into an Automated Data Recorder (ADR) installed inside the existing NIT data collection shelter. These loops provide baseline data for the three eastbound lanes in the test. In addition, a camera, monitor, VCR, and other communication equipment available in the shelter provide a video record of traffic for all eight lanes. Not only can the videotaped traffic records be counted manually to verify baseline loop data, but they can also provide baseline data for those lanes that do not have loops installed. Additionally, the security fence and the alarm system inside the shelter increase security for the testing equipment. See Figure 3 for a photo of the test site.

![Figure 1: Pole-mounted System](image1)

![Figure 2: Traffic Sensors](image2)

![Figure 3: PNITDS Test Site](image3)

### IV. TEST METHODOLOGY

The evaluation includes two focuses: sensor performance and system deployment issues. Different evaluation measurements and approaches were used to accomplish the separate evaluation goals in order to provide comprehensive and practical results.

Sensor performance was assessed by verifying sensor data against the baseline data for various traffic parameters. The baseline data includes both loop and manual counts because the loops were only installed in three eastbound lanes. Traffic at the lanes without loops was videotaped. One peak hour and one off-peak hour traffic were manually counted after the data collection period and used as the baseline. Because the two HOV lanes are usually closed during the

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offpeak hours, two hours traffic during peak periods were counted as the baseline in order to get enough samples. Traffic parameters selected for the evaluation included volume, speed, and length-based vehicle classification. Volume is defined as the total number of vehicles counted during each 15 minute interval. Speed is defined as the average speed that is aggregated from all vehicle speeds detected within each 15 minute interval. Vehicle classification is defined as the total number of vehicles counted for each predefined vehicle length group within each 15 minute interval. Absolute percent difference was chosen as the performance measurement to identify the actual differences between the sensor data and the baseline data. The absolute value avoids error compensation caused by over and undercounting (positive and negative errors) canceling each other out.

**Baseline Volume Data** - Inductive loop volume and speed data was collected by the ADR. By collecting the loop emulation relay outputs into a single database, the ADR processes volume into 15-minute intervals. The baseline volume obtained from the loops was carefully verified by comparing it to manual observations for two peak hours and two off-peak hours. The results showed that the baseline volume detection error ranges from 1.3% to 3%.

**Baseline Speed Data** - Loop detectors configured in a speed trap configuration were used as a baseline for vehicle speed evaluation. The ADR collected per-vehicle speed records that can be compared to manual observations. The speed observations were conducted with a probe vehicle driven through the detection zone at different predetermined speeds. A total of seven sample speed detections were collected for each lane. The baseline speed error ranges from 1.9% to 3.8%.

**Baseline Vehicle Class Data** - Baseline vehicle class data was collected by manual observations. Three length-based vehicle classes were defined for this study (see Table 1). The small vehicle group includes most passenger cars, sports/utility vehicles and vans. The medium vehicle group covers single unit trucks, commercial vehicles, large utility vehicles and typical transit buses. The large vehicle group includes combination trucks, large transit buses and typical semi-trailer trucks.

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Vehicles</td>
<td>0 – 25 ft</td>
</tr>
<tr>
<td>Medium Vehicles</td>
<td>25 – 45 ft</td>
</tr>
<tr>
<td>Large Vehicles</td>
<td>45 – 120 ft</td>
</tr>
</tbody>
</table>

Three reference lines (0, 25 and 45 feet) were measured and painted on the shoulder of the freeway for the vehicle class study (see Figure 4). Traffic passing through the painted area was videotaped from the side of the freeway. The recorded traffic video was reviewed and served as the baseline data for evaluating sensor class detection. The vehicle class was identified by manual observation using the painted marks as a scale. The video camera put a time stamp on the screen and the camera timer was synchronized with the sensor timer, thereby assuring that the traffic detected by the sensor was consistent with the traffic recorded by the camera.

Each sensor was mounted under various offsets and heights based on the vendor-recommended mounting configurations in order to evaluate each sensor’s detection range. Three locations at the test site provide the mounting locations for the sensors, refer to Table 2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Pole Type</th>
<th>Offset (Ft)</th>
<th>Height (Ft)</th>
<th>Sensor Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shelter Railing</td>
<td>50</td>
<td>25</td>
<td>Wavetronix, RTMS</td>
</tr>
<tr>
<td>2</td>
<td>Round Light Pole</td>
<td>22</td>
<td>17/25</td>
<td>Wavetronix, RTMS, SmarTek</td>
</tr>
<tr>
<td>3</td>
<td>U-Channel Signpost</td>
<td>20</td>
<td>16/24</td>
<td>Wavetronix</td>
</tr>
</tbody>
</table>

The test site also provides both high-speed free-flow conditions and congested conditions on a recurring basis (i.e., during peak periods). Sensors were evaluated during 24-hour test periods in order to observe performance in varying traffic levels. 24 hour data only was collected for the three eastbound lanes because these three lanes have loop detectors that served as an automated source of baseline data. Two-hour manual counts (one peak and one off peak) were used as baseline for the three westbound lanes and two-hour peak traffic counts were used as the baseline for the two HOV lanes. Weather records were archived to verify sensor performance under different weather conditions.

Both quantifiable and empirical evaluations were done to assess the system’s deployment and operation characteristics. Deployment time was recorded to quantify the ease of system installation; including pole assembly, sensor deployment, and system attachment. The ease of sensor calibration and data collection were also recorded. Finally, cost and maintenance issues were examined.

V. TEST RESULTS
The evaluation of all three sensors’ performance is summarized from 24-hour test data under various mounting configurations. In addition, some shorter-term tests were conducted to examine specific test conditions. The deployment assessment is based on experiences recorded in a log file during each test. The following results highlight key features and findings of both the sensors and the portable system itself.

1. The Wavetronix Smart Sensor provided accurate volume and speed results for all 24-hour test periods. The results showed that the sensor can accurately detect traffic in both freeflow and heavy traffic levels. The sensor detected eight lanes of traffic, including the two reversible HOV lanes, in all three test locations. The overall volume detection error was between 1.0% and 5.0%, and the speed detection error was between 3% and 9%. The sensor provided a reasonable measure of the distribution of vehicle
lengths within the traffic stream when optimally calibrated. Concrete barriers on the side of the HOV lanes had a slight impact on the sensors ability to detect the lanes behind them except at location one. Even though the concrete barriers caused a challenging environment for the sensor, sensor performance in detecting these lanes was acceptable. The vendor indicated that performance in these lanes would be improved by further tuning sensor configurations and settings. The weather had no impact on the sensors performance. At speed below 3 MPH, some over-counting of vehicles was observed in stop-and-go traffic.

2. The Wavetronix SmartSensor was easy to calibrate. The interface is user friendly and the auto-configuration feature expedited the calibration process. During free-flow traffic conditions, it took about 5 to 10 minutes to complete the sensor configuration; depending on the number of lanes and the amount of previous calibration experience. The total amount of time it takes to complete sensor count verification also depends on the number of lanes and the traffic levels. For example, a multiple lane facility with little traffic would take the longest to calibrate because detection records must be observed on a lane-by-lane basis. This finding is true for the other sensors as well. Sensor speed and vehicle class detection requires additional time to calibrate. Calibration can be done by adjusting the emulated loop scale factors (size and space) for each lane. Increasing scale factors will increase sensor detected speed and vehicle length, and vice versa. The interface allows users to specify three vehicle length-based classifications. Both speed and vehicle length calibration is an iterative process, which takes time to finalize the optimal settings.

3. The EIS RTMS sensor provided accurate volume and speed results for all 24-hour test periods. The results showed that the sensor can accurately detect traffic for free flow and heavy traffic levels when installed in vendor-recommended mounting configurations. Of the three locations tested, the sensor detected all eight lanes at location one (a height of 25 feet and an offset of 50 feet). At the other locations, concrete barriers on the side of the HOV lanes had an impact on the sensors ability to detect the lanes behind them. It is important to note that the concrete barriers present a challenging data collection location for the sensor. The barrier impact can be minimized by mounting at a location with a larger offset, or using two sensors, one on each side of the roadway. Also, note that location two is outside the vendor-recommended mounting range. The overall volume detection error was between 2.4% and 8.6%, and the speed detection error was between 4.4% and 9.0%. The sensor provided a reasonable measure of the distribution of vehicle lengths within the traffic stream when optimally calibrated. Weather had no impact on sensor performance. At speed below 5 MPH, undercounting of vehicles was observed in stop-and-go traffic.

4. The RTMS sensor was easy to calibrate. The auto-configuration feature provides a good starting point for the calibration process. Under free flow traffic conditions, it took 10 to 15 minutes to complete lane configuration by using auto-configuration function. The sensor requires additional manual adjustments to finalize calibration depending on the mounting configuration, the number of lanes detected and the traffic levels. In addition, speed and class calibrations are an iterative process which requires additional time. Calibration can be done by adjusting speed factors and vehicle length multipliers for each lane. The sensor provided vehicle types (Small, Medium, Long and Extra Long) which were verified with manual observations.

5. The SmarTek SAS-1 sensor provided accurate speed and volume results at the freeway test site. However, volume performance was not as accurate during heavy traffic levels. The vendor indicated that the sensor should be mounted higher than the 25 feet that our system provided in order to minimize occlusions and improve results during heavy traffic. Based on the vendor recommended mounting configurations, the sensor was only tested for three lanes of detection at a height of 25 feet and an offset of 22 feet even though it was not an ideal mounting configuration. The overall volume error was between 9% and 11.8%. During free flow traffic, the error was typically between 0% and 7%. Errors during congested periods resulted in significant undercounting when vehicle speeds
Greg Pieper from Smartek comments on:

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I attended a PNITDS presentation using three sensors being put into the portable configuration last fall here in Washington, D.C. Prior to the demonstration outside, they gave some results from the study which are very much like the results in section V of this report.

This PNITDS study was an extension of the work that was begun under the Guidestar NIT II testing completed previously. (SAS-1 was one of the only sensors to receive “five stars” in that study). Prior to the study taking place, Guidestar and others had confirmed by moving various sensors into various geometries what the best geometry would be for each particular type of technology. When we were asked if we wanted to participate in the PNITDS, it was pointed out that the geometries that were to be explored would not necessarily be those that were favorable to the SAS-1 — namely, in a position lower by at least 10 feet than we suggested was necessary. In fact, this unfavorable geometry had been confirmed by the NIT II testing at the same site. In the interest of expanding the users toolbox, we none-the-less agreed to participate in the portable application, knowing that due to the significantly lower mounting height, our technology would have a less accurate count than would be normal because “some vehicles would be run together” at low speeds during stop and go conditions. Those vehicles that were detected properly would still have an accurate speed attributed to them, but the actual count error would be greater than the 3-4% normally seen when mounted at the proper height. This is exactly what happened.

The performance results for SAS-1 aside, safety is the major concern for operations of our roadways. The point is that Guidestar wanted a simple approach for mounting non-intrusive sensors that could be fielded quickly. I applaud their approach. It is similar to that of Mr. Richard Bush in his deployment of radar detectors in the State of Virginia. We are of the opinion that any time the traffic manager can get traffic detectors out of the road bed, the better off he will be in terms of lowering life cycle cost and personnel safety.

Unfortunately, not all technologies are meant to be mounted as low as 15-20 feet above the roadway. Both camera based systems and the SAS-1, which are video and acoustic image based detection systems, are line of sight devices that must clearly “see” the vehicle being detected, so they like to be mounted higher so they can more easily differentiate one vehicle from another across multi-lane highways. Others have successfully used portable mounting schemes that put SAS-1 higher in the air and are getting very accurate results, even in heavy urban traffic. These schemes cost a bit more to implement, and cost is always a consideration, but they are very effective in preventing tampering with the device and are very quickly deployed and retrieved in the presence of heavy traffic. Safety is the primary motivator for all when deploying traffic detection devices. Again, any means of keeping work crews out of the roadway to collect traffic data is a good thing. Different technologies have to be applied differently. This study provides insight into another tool for the data collection manager to safely set up a road side counter for highway usage studies. I would only suggest a different mounting scheme if a SAS-1 is to be deployed. This has been confirmed by the PNITDS geometries.

I have attached a photo of an alternative portable system being used by the State of New York. It was also discussed that the recent NATMEC conferences (2002 and 2004) as a means of more safely gathering count data by using non-intrusive detection. Here, old light trucks have been refurbished (painted), had batteries and/or solar panels attached for quick deployment road side. A much higher height of eye is available with this scheme. Mr. Todd Westhuis at NY DoT has been using it for the past few years in a number of different hard to get to locations where the traditional road tube or loop configuration was both unsafe and inadequate in gathering highway usage statistics. It can be used for all of the sensors discussed in the PNITDS study as well as cameras and other devices. The addition of a radio or wireless modem makes it an ideal platform for work zone monitoring as well. Again, we applaud their efforts to keep their personnel safe while gathering the required data.

The PNITDS application aside, the SAS-1 is a very compelling option for advanced detection on intersection approaches, or in its ITS application of accurately detecting traffic speed, volume and land occupancy when in the proper geometry.

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studies should also evaluate new, non-intrusive sensors as they are introduced to the market. For example, the Infra-Red Traffic Logger (TIRTL) was developed by Control Specialists Company in Florida. The TIRTL claims to count, classify, and determine lane and speeds for multi-lane, bi-directional traffic. It consists of a transmitter and receiver unit on opposite sides of the road, and uses two parallel and two cross beams below axle height to classify vehicles. A future study could evaluate the sensor’s capabilities and its performance.

We have a project web site located at: http://www.dot.state.mn.us/guidestar/projects/pnitds.html Since our product is sponsored by government, there are no patten rights to the pole system we developed. The plans for building the pole system are on the web site and free to all.

IMA