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The Economy of Multi-Station Highway Monitoring Using SAS-1 in a Wireless Multi-Point Network

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Introduction

The SmarTek Systems Acoustic Sensor - Version 1 (SAS-1) is an effective multi-lane traffic monitoring system based on detecting the acoustic signals motor vehicles create and radiate during operation. The SAS-1 is a non-contact, passive acoustic (listen only) sensor and is mounted on existing overhead or roadside structures such as light poles, sign bridges, and overpasses It is completely non-intrusive to the highway or to the travelers using the highway. The SAS-1 is very compact and lightweight and is designed to be quickly and easily installed on existing highway structures. No lane closures are needed for a typical installation on a roadside structure. Reliability for the adverse highway environment is designed in to minimize or eliminate any periodic maintenance requirements.

SmarTek Acoustic Sensor (SAS-1)

Since the SAS-1 is a passive sensor (does not radiate any signal) it requires very little power to operate. This coupled with a wireless “home run” option (transceiver and antenna surge protector are inside SAS-1) makes the SAS-1 very suitable for completely autonomous installation and operation using a small solar panel to keep an associated battery charged. The need (and cost) for a hard wired “home run” cable, associated conduit, and installation labor is thus eliminated. Using the SAS-1 with solar power and wireless communication also minimizes weather related project schedule perturbation since there is no need to dig or trench the ground for cables or to cut pavement for loops.

The SAS-1 utilizes advanced signal and spatial processing to provide adaptive interference cancellation and high resolution multi-lane or multi-zone traffic monitoring including shoulder activity. This advanced processing minimizes or eliminates false vehicle detections caused by out of lane or off road noise. The SAS-1 “acoustically images” the highway traffic, thereby providing the end user with significant flexibility to electronically position each detection zone and set each detection zone’s size. This capability eliminates the necessity of precise mechanical “pointing” of the sensor to a detection zone position during install. Electronic detection zone positioning and repositioning (if lanes are moved) is accomplished using SmarTek Systems provided Windows based SAS-1 setup software. The easy to use “SAS Monitor and Setup” software displays the position of every vehicle in real time as the vehicle passes the sensor station. With point and click controls, the end user electronically sets each detection zone position after the sensor has been permanently “locked down”.

Highway Monitoring Requirements

In many urban and for that matter rural areas, there are requirements to provide highway traffic monitoring to facilitate effective congestion management, incident detection, and highway use data collection. Even without incidents to cause significant perturbations, traffic flow is highly time varying, nonlinear, and transient in nature. Sampling the highway system at one spatial point (sensor station) at a given time generally will not provide timely situation information relative to another spatial point in the system unless the points are very close together . For systems as complex and dynamic as highways, an approach of sparse spatial sampling and use of elaborate models to provide (predict) timely situation information does not appear to be appropriate. For accurate and timely highway situation information and incident detection to be possible, traffic monitoring sensors must be spaced reasonably close together. Depending on the area (urban or rural) and the highway, desired sensor station spacing varies from 1/4 mile to several miles. Sensor station spacing of 1/3 to 1/2 mile seems to be common in many urban areas.

Deploying a high density of traffic monitoring sensor stations presents both financial and logistical problems for DOTs and municipalities. The following areas require significant consideration:

1) Hardware Procurement Costs and Life Cycle Costs,
2) Installation and Maintenance Labor Costs and Scheduling,
3) Lane Closure Impact to the Motoring Public,
4) Availability of Site Services (power and communication),
5) Intrusion into Existing Services (power, communications, and structures),
5) End User Operational Considerations (TOC data interfaces, processing, and display capability).

Ideally, the desired system of traffic monitoring sensors would address all of the above issues. Today's sensor, processing, and communication technologies provide the means to effectively deal with many if not all of these issues. The **purpose of this application note** is to present an approach for economically deploying a high density of traffic monitoring stations using the SmarTek Acoustic Sensor Version 1 (SAS-1) for Multi-Lane, Real Time traffic flow monitoring, a Solar Panel/Battery for power, and Wireless (2.4 GHZ) Spread Spectrum radio for communication (up to 1 mile) back to a T-BOX based Information/Data Concentrator. **This application note also provides** an estimated procurement cost comparison with a deployment using traditional loops detector stations.

Multiple Sensor Stations

A multiple sensor station example is considered where sensors are deployed at 1/4 mile to 1/2 mile spacing in both directions on a multi-lane interstate highway (Figure 1). Per lane traffic flow data (such as vehicle volume, lane occupancy, and average speed) is required at real time reporting intervals (20 sec to 2 min are common) to meet traffic management requirements.

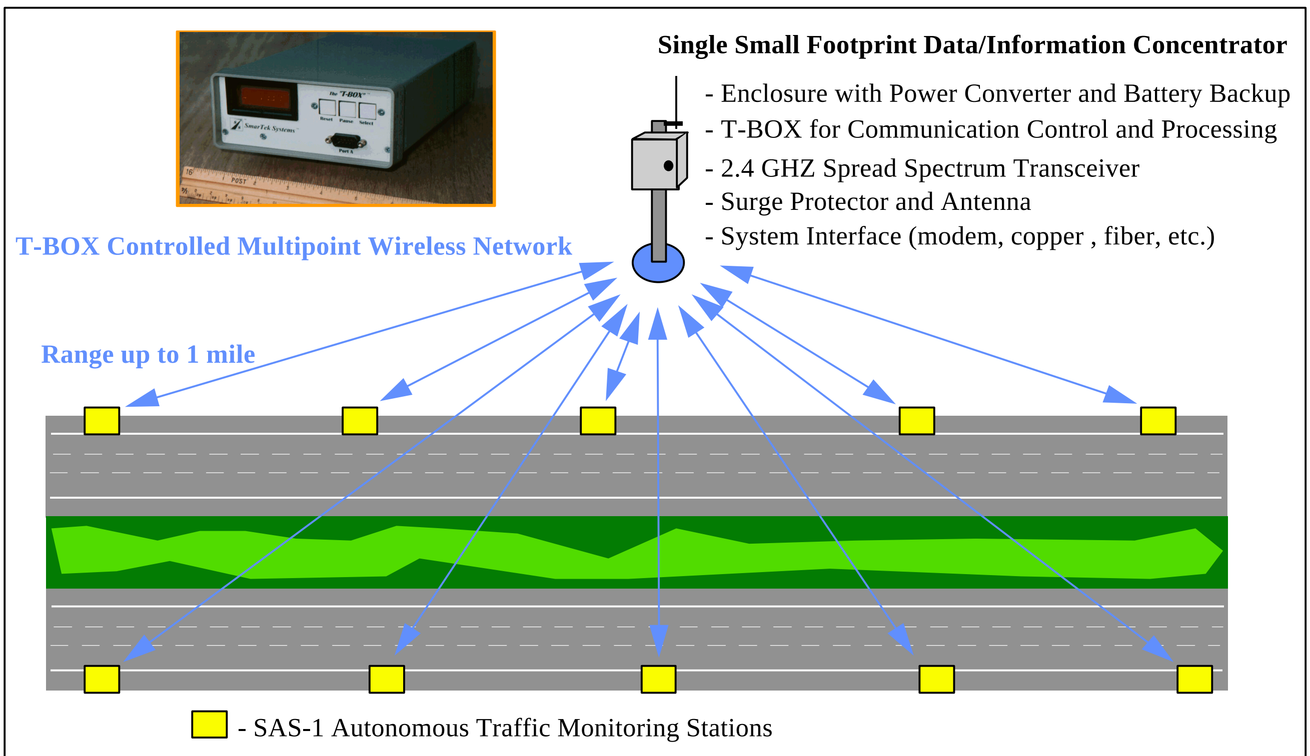

Figure 1 Small Footprint Data/Information Concentrator Using T-BOX

The deployment architecture centers around a single, centrally located Data/Information Concentrator (SmarTek Systems' T-BOX) which gathers traffic flow data from each remote sensor station. The T-BOX controls the multi-point wireless network by functioning as a base station which polls each remote for its traffic data packets according to a specified reporting interval (i.e. 20 sec, 30 sec, 1 min, etc.). The geometry in Figure 1 shows 10 remote sensor stations. The number of remote sensor stations is only limited by the wireless link ranges and the desired reporting period (short reporting periods (1 or 2 seconds) will limit the number of sensors which can be reliably polled due to communication link overhead). **We have demonstrated reliable operation in adverse RF environments for link ranges up to 1 mile and polling intervals as short as 1 second**. Depending on the RF environment and geometry greater link ranges can be supported.

The T-BOX as the central Data/Information Concentrator also serves as the interface point (POTS modem, fiber, copper, etc.) to the Traffic Management System and thus eliminates redundant cost (cabinets, controllers, concrete, interfaces, labor, etc) and logistical problems (install and maintenance scheduling and cost) associated with having a system interface (cabinet) for each traffic monitoring station. The cost savings is quantified later in this report. *While not specifically discussed in this report, the use of T-BOX as the Data/Information Concentrator provides built-in capability to perform significant local incident detection processing for automatic alert generation and reporting coupled with integrated color image capture capability for up to eight cameras.*

SAS-1 Autonomous Traffic Monitoring Station (ATMS)

The SAS-1 Autonomous Traffic Monitoring Station (SAS-1 ATMS) (Figure 2) is configured to address all of the deployment issues listed above. The enabling technologies embodied by the SAS-1 ATMS include the following:

1) a multi-lane, non-contact, passive acoustic sensor (no pavement or motorist intrusion) installed on existing structures over the shoulder (no lane closures) or over the lanes,
2) Small lightweight components which are installed using Band-It (no structure intrusion),
3) Very low power consumption to facilitate battery power with a solar panel for charging, thus eliminating system intrusion (no need to tap into electrical service),
4) Wireless Spread Spectrum (2.4 GHZ) communication (affordable and reliable) to eliminate cost, labor, and schedule issues associated with the installation of home run cables and conduit,
5) Built in sensor addressing, processing and communication capability to facilitate the use of a single centrally located data concentrator and system interface for a large number of sensors,
6) System Integration know-how and multi-point communication software resulting in easy, rapid installation (30 minutes to 1 hour per site depending on conditions).

The SAS-1 ATMS includes four basic subsystems which arrive at each site ready to install:
1) a SAS-1 (with a 2.4 GHZ Spread Spectrum transceiver and antenna surge protector installed inside) for multilane traffic monitoring mounted on an existing structure over the shoulder (no lane closure) or over lanes if desired (3 to 5 lanes of coverage depending on mounting geometry),
2) a whip or yagi antenna to be positioned on the existing structure for optimum performance,
3) a small NEMA strap on enclosure which houses the solar charger and battery,
4) and a solar panel rated for 20, 30, or 40 watts (or more) depending on site location and desired days of operation in the absence of solar charging (heavy overcast, snow, rain, etc.).

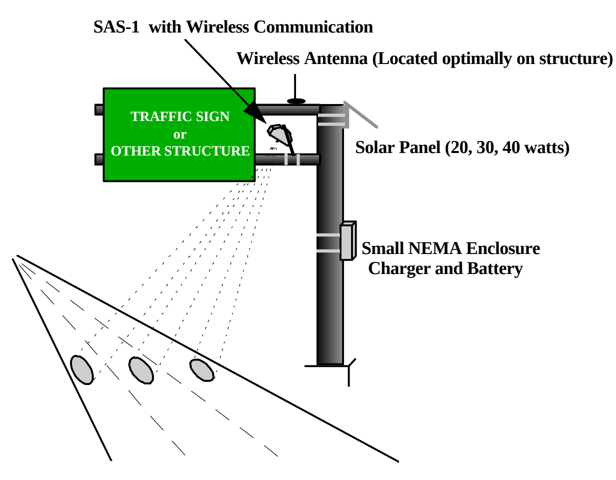

Figure 2 SAS-1 Autonomous Traffic Monitoring Station

Comparison of Procurement Cost for SAS-1 ATMS Traditional Loop Detector Stations

For the multiple sensor station example being considered, each loop detector station would consist of the following components or subsystems:

1) Loop detector cabinet, controller, cardfile, etc.	$5400.00 to $5900.00
2) Loop detectors for three lanes (includes harnesses)	$350.00 to $500.00
3) Site preparation -concrete pad, pull boxes, conduit, etc.	$3000.00 to $5000.00
4) System interface - POTS modem, fiber modem, etc.	$300.00 to $500.00
Total Estimated Cost Per Site (low to high)	$9050.00 to $11900.00

For N traffic monitoring sites the total estimated procurement cost is N*$9050.00 (low side) and N*$11900.00 (high side). Figure 3 shows the comparison of estimated procurement cost as a function of the number of sites.

Note that there is approximately 30% difference between the estimate on the low side and the estimate on the high side. Also note that the above estimate does not include a significant labor component involved in loop detector installation support such as traffic management labor for lane closures, labor supporting pavement cuts, loop wire install into the cuts, and sealing of the pavement cuts. Considering these variations in cost and significant variation in quality and capability of loop detector installers, points to an important consideration during system procurement. Installation of loop detectors or other "in-pavement" detector technologies are typically dominated by significant and highly variable labor components. This component also suffers from continuing upward price pressures (labor rates don't typically go down). Therefore, even if hardware costs go down, the dominant component, labor will probably go up. While the above estimates are used for comparison, evidence and experience has shown that actual per site costs could be much higher than the ones used here.

Another factor considered paramount when installing traffic monitoring stations is the installation time relative to lane closures. In most urban areas, there is no good time to close a lane. Almost always, closing lanes lead to severe congestion which leads to significant safety concerns. For any traffic monitoring technology, the goal should be to not only minimize or eliminate the necessity of lane closures but to minimize the total install time required at each site. **Experience has shown that typical install times for loops on major highways is measured in terms of at least several hours for each site.**

For the multiple sensor station example being considered, each SAS-1 ATMS would consist of the following components or subsystems:

1) SAS-1 for multi-lane monitoring (3 to 5 lanes)	$3500.00
2) Solar Power subsystem (30 watts) including panel, NEMA enclosure, battery, charger	$850.00
3) Spread Spectrum wireless subsystem including transceiver, surge protector, antenna	$800.00
Total Estimated Cost Per Site	$5150.00

For the multiple sensor station example being considered, the centrally located Data/Information Concentrator would consist of the following components or subsystems:

1) Small strap-on NEMA enclosure, power converter, and battery	$450.00
2) T-BOX processor	$2500.00
3) Spread Spectrum wireless subsystem including transceiver, surge protector, and antenna	$800.00
4) System interface - POTS modem, fiber modem, etc.	$500.00
Total Estimated Cost	$4250.00

For N traffic monitoring sites the total estimated procurement cost includes one central Data/Information Concentrator subsystem ($4250.00) + N-SAS-1 ATMS (N*$5150.00). Figure 3 shows the comparison of estimated procurement cost as a function of the number of sites. Note that the cost estimates above are approximate and for comparison purposes only. These estimates do not represent a quote.

The SAS-1 ATMS components will arrive at the each site ready to be installed on existing structures using Band-It. Therefore, install time is minimized and correspondingly install labor is minimized. Required lane closures are eliminated. Typical install times should be no more than 1 hour and could be as low as 30 minutes per site. The install labor component for SAS-1 ATMS is by design a small contributor to station cost. As compared to loop detector sites, the dominant component for SAS-1 ATMS sites is the procured hardware. This hardware is continually under downward price pressure. It is therefore, reasonable to expect that future costs for SAS-1 ATMS to hold steady or go down. Quantity buying can immediately realize reduced costs.

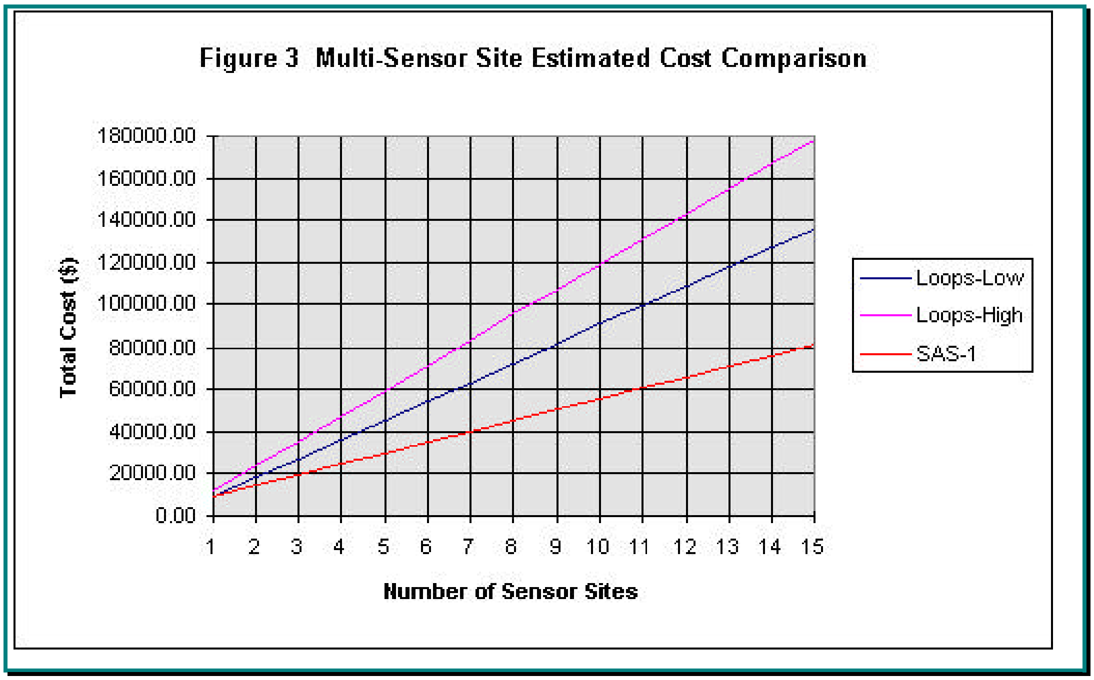

Figure 3 Multi-Sensor Site Estimated Cost Comparison

Summary

The SAS-1 Autonomous Traffic Monitoring Station (ATMS) is a very cost effective approach to meet multiple lane traffic monitoring requirements. The system is by design easy to install with no system intrusion (when using the wireless and solar power options). The SAS-1 is also easy to set up for effective operation. Because of the design, the install and set up labor component is minimized to the point where it is not a primary cost contributor. Therefore, system procurement costs and schedules are well known up front and can be controlled. Additionally, the ease of installation and setup provides for consistent quality of operation and performance. As the comparison plots clearly show, using multiple SAS-1 ATMSs with a central Data/Information Concentrator will result in significant quantifiable savings. For example, implementing a system with 2 SAS-1 ATMSs would result in **cost savings of 20% to 39%** over an implementation using loop detector stations. A system with 6 SAS-1 ATMSs would result in **cost savings of 35% to 50%** and a system with 10 SAS-1 ATMSs would result in **cost savings of 39% to 54%.** In reality the potential for actual savings is even greater since a significant and difficult to control cost component **-** install and set up labor, is minimized when using the SAS-1 ATMS for traffic monitoring.

Signal Interfaces

The SAS-1 provides for several different interfaces depending on the communication link and the cabinet controller interface desired. The standard SAS-1 output message provides traffic flow measurements of vehicle volume, lane occupancy, and average speed for each monitored zone (3 lanes and 2 shoulders) for a specified update period (i.e. 20 sec, 30 sec, 1 min, etc). Vehicle presence relays or a “Wrong Way” asynchronous message can be provided. The vehicle presence relay option requires a SAS-1 Bit Serial to Parallel Interface in the roadside cabinet. The SAS-1 supports the following electrical communication interfaces:

1) RS-485 (full duplex).......................................Hard Wired Home Run (up to 1500 feet)
2) RS-232 (Standard)..Hard Wired Home Run (up to 100 feet)
3) RS-232 (Optional)..Wireless Link (up to 1 mile)

Power

The SAS-1 re-regulates the supply voltage thus compensating for voltage drops and fluctuations caused by long home run cables:

1) Supply Voltage at the Sensor............................12 to 24 VDC
2) Required Power.......................................Less than 2.0 watts

Physical

The SAS-1 is a very compact multi-lane highway monitoring sensor. Superior spatial resolution is achieved by advanced processing rather than physical aperture, thereby resulting in a very small sensor footprint (figure 1):

1) Dimensions...............................12 inches long x 8 inches wide x 5 inches deep
2) Weight......................................Less than 2.5 lbs
3) Material/Finish..........................Aluminum/Enamel/Stainless Steel Fasteners
4) Mounting Approach..................2 inch Diameter Aluminum Tube/Stainless Steel Bands
5) Operating Temperature..............-30 Deg C to 75 Deg C
6) Humidity...................................5% to 100%
7) Shock..NEMA TS2-2.1.10
8)Vibration....................................NEMA TS2-2.1.9

Installation

The SAS-1 provides a great deal of flexibility relative to installation. Its compact size and modest weight make installation easy for a single installer using a bucket truck. Off the shelf, low cost mounting brackets are utilized. Mounting brackets should allow for coarse mechanical positioning so that the sensor face can be oriented to correspond to the operating mode (Multi-Lane monitoring or Wrong Way monitoring) Powering the sensor and using the SAS-1 Monitor and Setup program on a PC Laptop makes the SAS-1 installation and pointing easy and quick. Monitoring the real time display while mechanically orienting the sensor removes any guesswork relative to the SAS-1installation. After the SAS-1 is mechanically oriented and locked down, the position and size of each detection zone (up to 5 in cross road or the up/down road direction) can then be electronically adjusted using the SAS-1 Monitor and Setup program to precisely match the detection zone configuration to the specific traffic flow situation.

1) Height Above Pavement.......................................20 to 40 feet
2) Horizontal Distance to First Detection Zone..........0 to 40 feet (or greater for “Wrong Way” detector)
3) Coarse SAS-1 Orientation...................Mechanical with SAS-1 Monitor and Setup Software
4) Precise Detection Zone Adjustment.......Electronic with SAS-1 Monitor and Setup Software