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# SURVEILLANCE AND DELAY ADVISORY SYSTEM

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## NOTICE

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16. Abstract

This report documents the development and testing of a Surveillance and Delay Advisory System (SDAS) for application in congested rural areas. SDAS included several techniques that could be used on rural highways to give travelers advance information on congestion on the road ahead of them. It is designed to address congestion problems at work zones or at approaches to major attractions. Important considerations for its design are reliability, level of maintenance, and cost. The SDAS employs three different data collection technologies to collect travel time information: weigh-in-motion, video, and radar subsystems. The system gathers data from a test zone, computes travel times, and transmits delay messages to motorists who are headed toward the zone. Important observations were made concerning all subsystems: some methods for detection and operation gave clearly superior results in either accuracy or reliability.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | millimeters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| NOTE: Volumes greater than 1000 l shall be shown in $m^3$. | | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celsius temperature | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.71 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 1.8C + 32 | Fahrenheit temperature | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| fl | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised September 1993)

TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES



## LIST OF ACRONYMS

| | |
|---|---|
| ATIS | Advanced Traveler Information Systems |
| AVI | automatic vehicle identification |
| CCD | Charge-coupled device |
| CMS | Changeable Message Sign |
| COTR | Contracting Officer's Technical Representative |
| FHWA | Federal Highway Administration |
| GUI | graphical user interface |
| HAR | Highway advisory radio |
| IRD | International Road Dynamics |
| ISDN | integrated services digital network |
| ITS | Intelligent Transportation Systems |
| LOS | line of sight |
| MNDOT | Minnesota Department of Transportation |
| NJDOT | New Jersey Department of Transportation |
| RPU | remote processing unit |
| SDAS | Surveillance and Delay Advisory System |
| TMC | traffic management center |
| TOC | Traffic Operations Center |
| WIM | Weigh-in-motion |
| WZTCS | Work Zone Traffic Control System |

# 1. INTRODUCTION

As one of the initial activities under the U.S. Department of Transportation's Rural Intelligent Transportation Systems (ITS) Program, the Federal Highway Administration (FHWA) has initiated a research program to find ways to improve safety, mobility, and services in rural areas. This program is entitled "Rural Applications of Advanced Traveler Information Systems (ATIS)." It was initiated to provide recommended direction for Federal programs with respect to ITS technologies in rural and small urban areas as well as to provide guidelines for ATIS implementation efforts by State and local government agencies in meeting rural traveler needs. The Surveillance and Delay Advisory System (SDAS) was developed and field tested under this program.

Previous initiatives under the Rural Applications of ATIS program have established and prioritized information needs, evaluated the national significance of rural problems, assessed the technological opportunities, and developed and evaluated a series of ATIS concepts for application in rural areas. Based on an evaluation of these concepts, two of the concepts were selected for field testing: evaluating satellite communication systems for mayday applications, and developing SDAS. The evaluation of satellite communication systems for mayday application has been conducted and results of the evaluation have been prepared and documented in a separate report.

The SDAS employed three different data collection technologies to collect travel time information: weigh-in-motion system, video-based detection system, and spot speed measurement system. The data collection technologies gather data from a test zone, compute travel times through the zone, and transmit delay messages, if any significant delay occurred, to motorists traveling through the zone.

The SDAS was prototyped and some initial testing was conducted during the end of the summer of 1997. More conclusive testing was carried out during the summer of 1998. The purpose of these tests was to implement and conduct an evaluation of the application of several technologies for travel time monitoring in rural areas. These tests were conducted under a partnership with FHWA, New Jersey DOT, SAIC/TransCore, International Road Dynamics (IRD), and Nestor Inc. This report describes the SDAS and documents the results of the system tests.

## 1.1 REPORT ORGANIZATION

The purpose of this report is to discuss the development of the SDAS, present the results of testing that was conducted on a rural section of SR 55 in southern New Jersey, and present some lessons learned from the test. The report has been organized into the following chapters:

**Chapter 1:** **INTRODUCTION -** Following some introductory remarks, the remainder of this chapter establishes the need for developing the SDAS and discusses project goals, and presents a summary of the findings.

**Chapter 2:** **PROJECT DESCRIPTION -** This chapter provides an overview of the project and discusses some related work conducted by others. A discussion of space mean speed and spot mean speed is also presented in this chapter, followed by a description of the test site.

**Chapter 3:** **SYSTEM ELEMENTS -** Various system functions, including data collection, communication, data processing, and a motorist advisory interface are discussed in this chapter.

**Chapter 4:** **DATA COLLECTION SYSTEMS -** This chapter presents detailed information regarding various data collection systems used in the SDAS and the results of the preliminary testing of these systems.

**Chapter 5:** **PROJECT COST -** Project costs associated with deploying and testing the SDAS are presented in this chapter.

**Chapter 6:** **LESSONS LEARNED -** In this chapter, lessons learned from developing and testing the SDAS are presented.

**Chapter 7:** **FUTURE ACTIVITIES -** This chapter discusses recommendations for future actions based on the knowledge gained from developing and testing the SDAS.

## 1.2 NEED FOR A SURVEILLANCE AND DELAY ADVISORY SYSTEM

Travelers in rural areas are often faced with traffic congestion and excessive delays when traveling through construction areas or at approaches to rural attractions. Due to lack of alternate routes, the impact of traffic congestion in rural areas can be more severe than in urban areas. This can create costly and frustrating delays. These types of delays arise in the thousands of miles of construction and maintenance zones that occur every year and near rural attractions that draw large seasonal or cyclical traffic volume such as national parks, seashores, ski areas, approaches to beaches, and other similar vacation and recreation sites. Rural roadways often are the most convenient access to these attractions. Many of these attractions generate heavy traffic, resulting in excessive delays, especially on approach and exit roadways. In these situations, rural travelers usually have no idea of the extent of the delay until they are a part of the congested traffic flow.

When dealing with congestion in these areas, agencies usually incorporate static signs upstream of the congested area displaying a continuous message advising of traffic congestion and to "EXPECT DELAY." There is no active determination or measurement of delay in most cases, therefore, the static signs are left in place throughout the expected duration of the delay, regardless of whether or not delays actually exist. Travelers see and may hear, via highway advisory radio, the same message, yet they may experience no delay or widely varying amounts of delay. Drivers lose respect for these types of messages, ignore them, and then experience unexpected inconvenience and frustration. On the other hand, travelers may be convinced to avoid construction or maintenance areas because of expected delays, even when there are none. Travelers are, therefore, interested in travel time information that reflects current conditions through these congested areas. Travel time information is valuable to traffic managers as well, as it enables them to monitor and manage traffic through these areas.

## 1.3 WHY A RURAL SDAS?

Recognizing that traffic congestion does occur within rural areas, a surveillance and delay advisory system could be an important tool in addressing the public's rural travel information needs while continuing the development of the Rural ITS Program. Although the SDAS could be adapted for urban areas, a rural setting is a more appropriate first-time application of this concept. The rationale for this approach follows:

- **Regional Unfamiliarity -** With a high percentage of motorists in rural areas being unfamiliar with the area, a traveler information system could provide timely, accurate, work zone/seasonal peak traveler delay advisories to meet some of a motorist's en-route information needs. These en-route travel advisories could provide motorists with an active indication that delays exist at the approach into the recreational attraction or at the work zone. In addition, some SDAS systems may indicate alternative route information in addition to a real time estimate of the amount of delay.

- **Extensive Delays -** Traffic delays can be extensive in rural work zones, especially if they are on two lane roadways that necessitate the total stoppage of travel in one direction, severely restricting traffic flow. Work on a four-lane rural highway usually necessitates “paring down” to one lane of travel in each direction; these lane crossovers may contain reduced lane widths, causing an additional reduction in capacity, which may lead to delays. This effect is amplified when commercial vehicle traffic is heavy.

- **Lack of Warning -** In rural settings, travelers usually have little warning that delays will be incurred until they are caught in the midst of the congestion. Rural areas are less likely to contain a method for communicating en-route travel advisories. Traffic delay bulletins via radio or TV broadcasts, newspaper notices, or even word-of-mouth exchanges do not usually reach those that reside outside of the area. As such, these travelers have little knowledge of the impact of construction or maintenance activities in rural settings.

- **Lack of Alternate Routes -** In most rural settings, the number of alternate routes is limited, and required services (fuel and rest areas) are not as available. The need for upstream delay advisory signs located at strategic diversion points could enhance the mitigation of congestion and delay, and thus reduce driver frustration.

- **Urban Applications -** Although rural applications of the SDAS are being considered first, transfer of this technology to urban applications would be a natural transition. The nature of the SDAS should lend itself to many urban construction or maintenance situations where permanent detection systems are not likely to be implemented.

- **Other Applications -** The application of an SDAS would be useful to DOTs not only in addressing weekend peak congestion at seasonal attractions, but also in addressing congestion caused by construction activities and at special events.

## 1.4 PROJECT GOALS

The SDAS was prototyped and tested to evaluate the application of several travel monitoring systems in rural areas. The following were primary goals of this project:

- Determine the accuracy of spot speed conversion to travel times using different algorithms.

- Compare the travel times computed from spot mean speed versus space mean speed.

- Determine the effectiveness of automatic vehicle identification (AVI) in determining travel times.

- Determine the percentage of AVI vehicle matches necessary to compute reliable travel times.

- Determine the capability of transmitting and displaying travel delay information to rural travelers.

- Prototype and test a cost-effective surveillance and delay advisory system that can operate in rural environments.

## 1.5 SUMMARY OF FINDINGS

The original prototyping and initial testing of the SDAS in 1997 helped achieve the above goals to some degree. The work during the summer of 1998 gave answers to each of the remaining questions. In general, the test provided valuable insight regarding applications of several technologies for travel time monitoring in rural areas. The results should prove useful in decision-making regarding which technologies are suited for a given application, and what sort of modification should be done to the original SDAS for optimum performance at other locations. The one remaining question, however, is the validity of any of the methods under severely congested conditions, as only light to moderate traffic congestions were ever seen at the New Jersey site.

Following are brief responses to each of the goals outlined in Section 1.4 above.

- Determine the accuracy of spot speed conversion to travel times using different algorithms.

  The three separate speed algorithms described in Section 3.1.2 were compared, and one of them seems to be superior to the others under free flow to moderate congested travel conditions. As mentioned before, no severe congestion was seen at the site during either of the two test periods. Since the travel time monitoring algorithms are easily adjusted at the site, it is recommended that all of them be used with weighting factors that may be adjusted at the site to most accurately reflect local conditions.

- Compare the travel times computed from spot mean speed versus space mean speed.

  Travel times calculated using data from radar detectors were within 5% of space mean speed travel times calculated from the Weigh-in-motion (WIM) Automatic AVI. The WIM-AVI system generally had a higher standard deviation of travel times. This is largely due to a smaller number of data points and the inherent sensitivity of the WIM system to travel times outside the norm.

- Determine the effectiveness of AVI in determining travel times.

  Two separate methods of AVI were used: WIM technology and a video-based system. The WIM system was quite effective in matching vehicles and was reliable for travel time monitoring. However, its cost and portability of the system are problematic. The system is, therefore, recommended for travel time monitoring in areas that require permanent installation. Based on the results of these tests, we believe that further development and testing of the video-based AVI system is required prior to deploying such systems for travel time monitoring in rural areas similar to the test site.

- Determine the percentage of AVI vehicle matches necessary to compute reliable travel times.

  The 1998 results indicate that about 65 percent of the trucks having three axles or more can be matched. A minimum of 19 trucks per hour are needed to achieve 5-minute updates on the WIM travel time system. Assuming 5 percent trucks in the traffic stream, an hourly volume of 380 vehicles in the direction of analysis zone would be necessary to support the WIM matching system.

- Determine the capability of transmitting and displaying travel delay information to rural travelers.

  Data can be automatically gathered by the detection subsystems and transmitted to a Changeable Message Sign (CMS). This capability was not used to provide real time information to travelers during the SDAS tests since there was no significant congestion, and it was deemed more appropriate to have a blank sign. However, on-site testing did show that the system does work and several messages such as “DRIVE SAFELY” and the like were displayed by the system.

- Prototype and test a cost-effective surveillance and delay advisory system that can operate in rural environments.

  The SDAS was tested on a rural section of S.R. 55 in southern New Jersey. Based on the results of these tests, the effectiveness of the SDAS will greatly depend on the specific application of such a system. For an area with recurring congestion, especially where there is a sizeable portion of trucks in the traffic flow, the WIM system may be the most appropriate technology to deploy as the equipment is quite reliable if installed properly. However, the cost of the equipment and especially the set-up would make it more difficult to apply in a mobile system that would be appropriate for construction zones. In this case, the ease of the setup and the lower cost of the spot speed measurement system is clearly advantageous. Video AVI has shown, in this test, to be less reliable. Additional testing should be conducted before this technology can be considered for travel time monitoring in rural environments.

# 2. PROJECT DESCRIPTION

## 2.1 PROJECT OVERVIEW

The SDAS is intended to meet travelers' rural congestion advisory needs by determining the amount of delay through congested areas and automatically broadcasting delay times to travelers approaching and within the area. Determination of travel times for the computation of delays relied on the following technologies. Each is examined in detail later in this report.

- **Data Collection -** Three methods were used to collect data for the SDAS. Two methods, weigh-in-motion and video-based detection, directly measured travel times through the area while a third method, radar detectors, involved converting spot speed measurements into travel times. Data from each method was intended to be used to independently compute the delay time through the desired area.
  - **Passive AVI -** Passive AVI used a vehicle's unique features, such as video signature, weight, axle spacing, and number of axles, to identify a vehicle as it passed each detection station. By using a station upstream and one downstream of the area, a direct travel time was measured. Passive AVI provided a space mean speed, which is discussed in more detail in Section 2.3.
  - **Spot Speed Detection -** Spot speed detection estimated travel times through the area using measured speed at various stations. Data from strategically located stations were transmitted to a data processor to be converted to a travel time. Spot speed detection for travel time computation gave a spot mean speed as explained in Section 3.1.2.
- **Communication -** The communication for the SDAS can be broken down into two types:
  - From the data collection device to the central processor.
  - From the central processor to the dissemination interface.
- A discussion of communication technologies used for the SDAS test is presented in Section 3.2.
  - **Data Processing -** The data processing involved receiving data, performing travel time and delay computations, and formulating and delivering appropriate messages to the traveler interfaces. Details of the data processing system are given in Section 3.3.

– **Motorist Advisory Interface -** A CMS was used to disseminate information to travelers. Highway advisory radio (HAR) was discussed and was the subject of research, but was never tested under this program. Details of the motorist advisory interface are presented in Section 3.4.

## 2.2 RELATED WORK

At the time of this test, two ITS initiatives were being pursued to address congestion in work zones. Maryland has initiated Work Zone Traffic Control System (WZTCS) and Minnesota has developed the Smart Work Zone System.

Maryland's WZTCS project is attempting to reduce the 800 annual accidents in Maryland's construction work zones and to reduce the impact of the major freeway construction projects for the tens of millions of travelers in Maryland. Specific goals of this system include the following:

- Performing two human factors laboratory studies to examine alternative messages to refine the messages given to motorists.
- Alerting workmen of immediate impending danger from an errant vehicle's presence in their work area.
- Forewarning drivers of lane closures.
- Encouraging drivers to use alternate routes.
- Advising drivers of vehicle operating speeds downstream.

WZTCS collects vehicle speed, composition, and volume data using three detector types installed at various stations throughout the work zone. The information from the detectors is sent to a central computer via UHF radio. The computer then performs a series of calculations to determine the queue length, capacity, and queue speed, which in turn is used to determine the delay time. Messages relevant to the delay are sent to CMS and HAR.

The Minnesota DOT initiated the Smart Work Zone project to increase the safety and transportation efficiency in work zones by combining portable ITS components with a permanent infrastructure and a traffic management center (TMC). Several goals of the Minnesota project are to

- Connect the work zone advisory system to an existing TMC.

- Develop a system adaptable to various construction projects.
- Provide the public with real time information.
- Develop public and private partnerships.

The Smart Work Zone system compiles real time traffic data from the work zone and the surrounding roadway system. Video cameras, portable machine vision detectors, and permanent magnetic sensors gather traffic information such as speed, volume, incident detection, and vehicle intrusion into the work zone. This data is transmitted to the Minnesota Department of Transportation (MnDOT) TMC, where it is reviewed by system operators and decisions are made regarding changes necessary to improve traffic through the work zone. The operator determined messages are then transmitted to permanent and portable CMS. Data is transmitted via spread spectrum radio, cellular phone, and integrated services digital network (ISDN) leased lines.

Key differences exist between the two current work zone projects and the SDAS. The Minnesota system and the Maryland system are designed primarily to manage traffic and improve safety in a metropolitan area. Both systems rely on spot speed measurements (see Section 3.2) for data collection and are large and complex, which leads to high start-up and operating expenses. The Minnesota project uses video sensors (Autoscopes), ISDN communication, and an operator at a TMC to make management decisions, such as what messages are appropriate for the motorist advisory interface. Actual delay information is not given to the travelers. The Maryland project relies on speed detectors, queue detectors, intrusion detectors, and a central processor to compute delays based on the queue length, speed, and the system capacity. The system requires a large array of sensors, lane control devices, and portable speed bumps to manage traffic in the work zone.

The SDAS has been designed not to duplicate these efforts but to complement them. SDAS will be more effective in rural settings for several reasons:

- **Data Collection Procedure:** The SDAS is capable of collecting both space mean speed and spot mean speed. In fact, one of the primary goals of the testing of the system is the comparison of the travel times computed using different data collection techniques.
- **Adaptability:** SDAS is adaptable not only to many delay areas but also to many environments. In an area where detour routing is available, results can be broadcast far enough upstream to warn motorists of delays and provide delay information. The system may be adapted to different size delay areas

because of its modular nature. Additional sensors, communication links, and motorist advisory interfaces may be added as necessary.

- **Cost:** Although several different technologies were tested, applications in other areas could consist of a single set of sensors, communication, one processor, and the required interfaces. Many DOTs possess some or all of the equipment necessary to operate the system. Depending on the configuration used, most components may be reused and moved with minimal effort, because the system could be installed with little or no permanent infrastructure.

Although the tests in Minnesota and Maryland are fundamentally different from the SDAS, they also share similarities that may be adapted to the SDAS. All aspects of each system have been closely examined to determine their value and applicability to the SDAS system.

The existing projects could also benefit from the SDAS test. The SDAS test is intended to provide guidelines with respect to delay time computation methods. Also, the SDAS tested several AVI methods that could complement those systems being currently tested.

### 2.3 SPACE MEAN SPEED AND SPOT MEAN SPEED

The focus of the SDAS test was to assess several technologies used for travel time monitoring. Although this test dealt with a temporary configuration of detectors in a rural environment, the results of the investigation may have broad-based application in future travel time monitoring systems. There are basically two different approaches to travel time measurement:

- **Spot Mean Speed -** Speed of individual vehicles measured at one or several locations along a segment.

- **Space Mean Speed -** Harmonic mean of speeds obtained by dividing the total distance traveled by one or more vehicles on a section of roadway by the time required for a vehicle to travel the known segment distance.

To a limited degree, the evaluation was expected to focus on accuracy and effectiveness of travel time computations for the two approaches. Three spot mean speed calculation procedures were tested (see Section 3.1.2). Two AVI technologies were used to measure space mean speed. These AVI technologies were tested to determine which detectors are effective and which technologies are best suited to certain physical settings and conditions. It was anticipated that these two approaches would be evaluated under varying degrees of congestion. However, as will be discussed later in this report, due to lack of congestion during the tests, only limited comparison was made.

### 2.4 TEST SITE

Testing of this system occurred on State Route 55 in New Jersey south of Vineland. Figure 1 shows the layout of the test area and data collection technologies. This limited access road was ideal for carrying out the project, because it is located in rural southern New Jersey where congestion becomes a problem during the summer weekends. Traffic has been reported to backup three to four miles on this road on Friday afternoons and Saturday mornings from the SR 55/SR 47 merge, due to heavy weekend travel to the New Jersey beaches.

The test area was a 4.3-mile southbound section on SR 55, beginning a few hundred feet after SR 49 crosses under SR 55 and ending about 300 feet before the SR 55/SR 47 merge. Between the upstream and downstream sites there was only one exit, with no return entrance, which provided access to a low volume local road. There was only one entrance ramp onto SR 55 throughout the entire test area. This ramp provided access from SR 49 to SR 55 South. It was estimated that the total entering traffic from SR 49 was less than 5 percent of the total traffic on southbound SR 55. Therefore, the percentage of vehicles entering and exiting between the upstream and downstream sites was minimal. The test was conducted on the southbound lanes only. At the upstream end of the site, the road is a four-lane divided highway. The lanes merge together into a single lane about 3000 feet before the downstream end of the segment. Data collection locations, as shown in Figure 1, are numbered P-1 through P-5, with P-1 being the upstream location and P-5 being the downstream and command center for the installation. Radars for spot mean speed detection were located at all sites, while the AVI space mean speed detectors were located at P-1 and P-5 only.

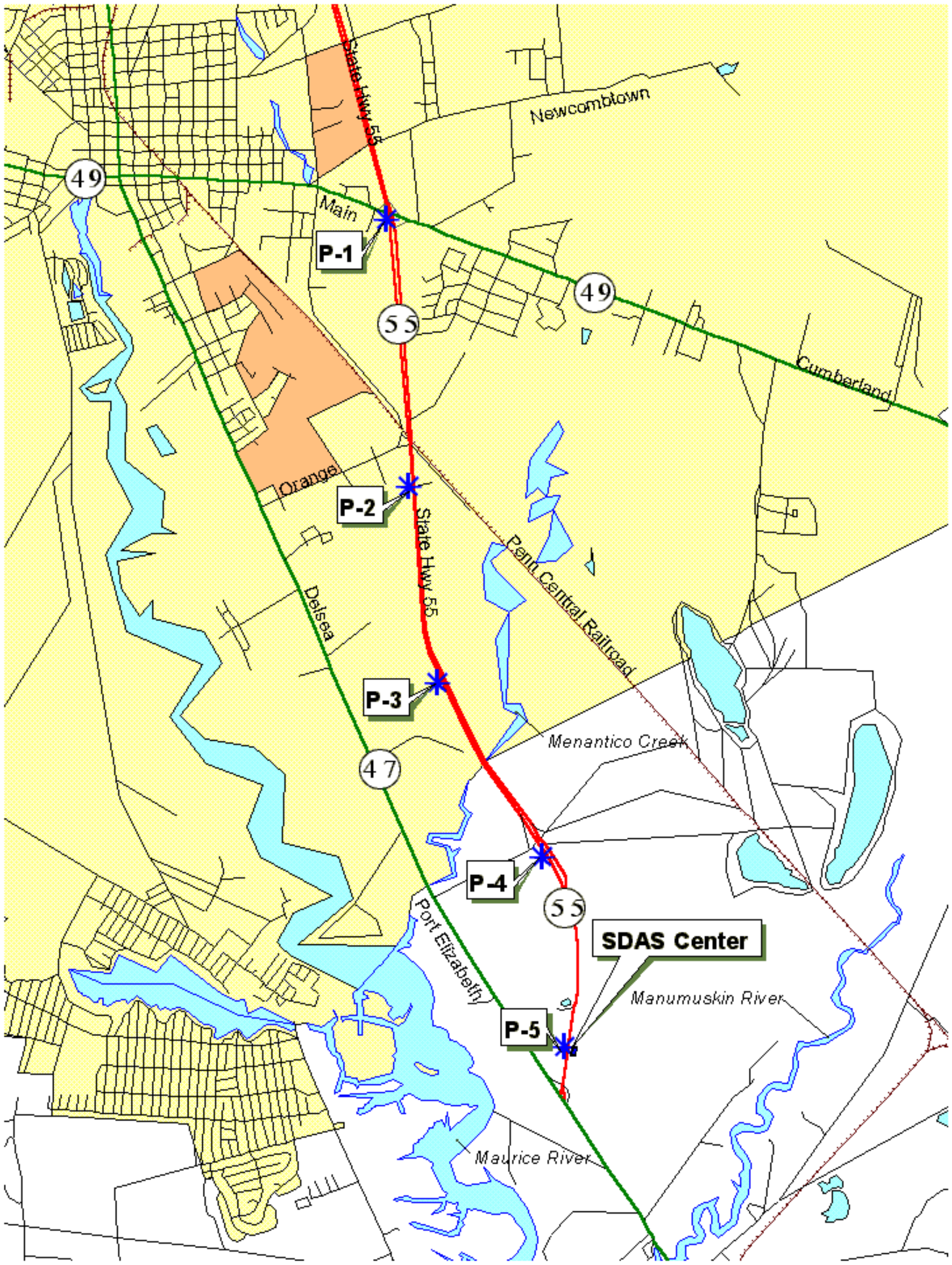



**Figure 1. Test site location**

# 3. SYSTEM ELEMENTS

As discussed in Chapter 2, the system included four major elements: data collection, communication, data processing, and a motorist advisory interface. Figure 2 shows a schematic of the overall arrangement; detailed discussions of these elements are presented on the following pages.

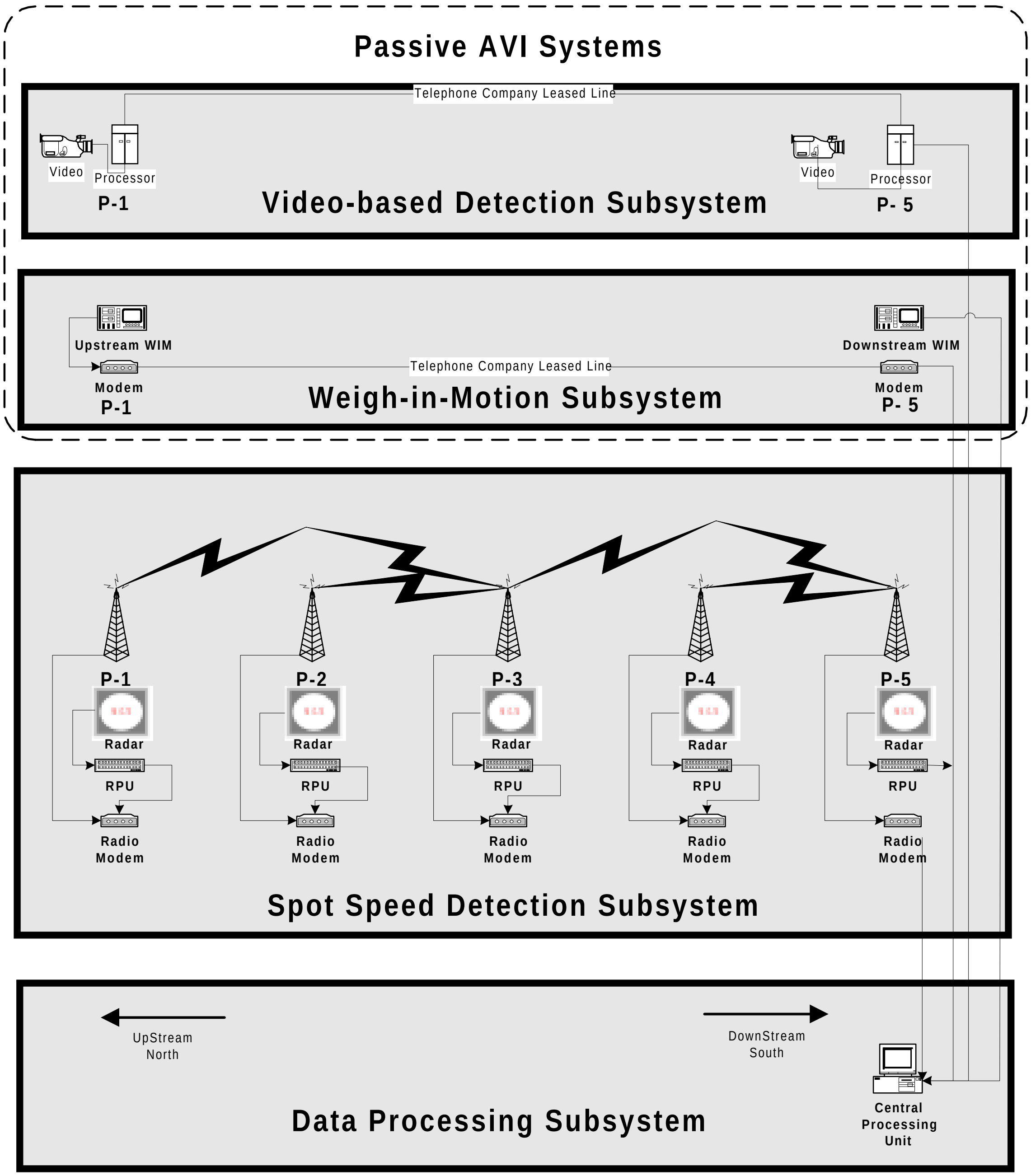



**Figure 2. SDAS equipment layout**

## 3.1 DATA COLLECTION

As discussed earlier, the two data collection methods tested for the SDAS were passive AVI and spot speed measurement. Manual data collection was used for ground truth testing of the other methods.

### 3.1.1 Passive AVI

Passive AVI systems use unique vehicle characteristics to identify vehicles at two or more locations. These systems rely on roadside sensors to identify vehicles, and require no vehicle-based equipment. The two technologies that were tested for passive AVI follow:

- Video-based Detection System
- WIM

Video technology has been used in traffic surveillance and in limited application as “loop emulation” detectors. Recent advances in technologies, from cameras to computing platforms and software, have advanced the state of the art to deliver affordable systems that not only detect activity in an image but recognize and track moving objects. The most advanced systems are capable of producing a rich set of data including counts, speeds, headway, occupancy, lane change counts, stopped vehicle detection, improper direction of travel, unauthorized travel in restricted lanes, and classification of vehicles by vehicle type. Unique characteristics of vehicles can be extracted and used to form a “signature” unique to that vehicle. This signature provides a mechanism for tracking vehicles from site to site using low bandwidth communications.

The WIM technology is most commonly recognized from its use in the commercial vehicle industry. WIM sensors weigh and classify vehicles as they approach a weigh station, allowing agencies to determine if a vehicle should be stopped and weighed on more accurate static scales or if they may bypass the scale facilities. WIM sensors measure the weight, axle spacing, and number of axles.

These technologies can be used to compute travel times between two known stations. As a vehicle passes the passive AVI station upstream of the desired detection zone, a vehicle signature is captured and stored in a database. Another reader downstream from the detection zone captures a signature, sorts through the database, and matches the signature with one taken upstream. The differences between the passage time at each station results in the travel time between the two stations.

### 3.1.2 Spot Speed Measurement

Travel times can be estimated using speed measurements at strategic locations through the detection zone. This procedure can be used to determine the delay and to make traffic management decisions in the detection area of interest. As discussed in Section 2.1, the SDAS test was designed to provide some insight into the accuracy and appropriateness of using spot speed measurements for travel time computation.

The travel time through the detection zone was computed using three algorithms:

- Link travel times are computed by dividing the link length ($D_i$) by the average speed of the stations at either end of the link. Zone travel time is the sum of all link travel times within the zone.

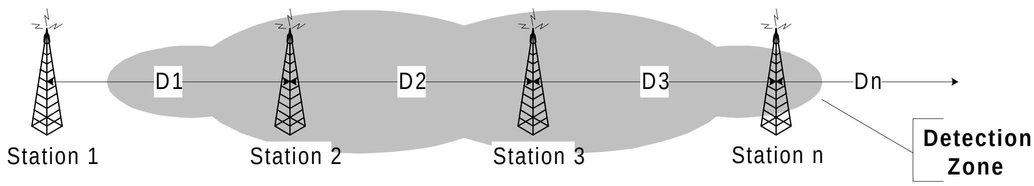
- Link travel times are computed by dividing the average length of the two links adjacent to a speed detection station by the spot speed at that station. Zone travel time is the sum of all link travel times within the zone.

- The total length of the zone is divided by the average speed at all the stations.

Mathematic representation of each of these algorithms is given in Figure 3.

The delay time was computed by subtracting the free flow travel time from the actual travel time within the detection area. This test was set up to evaluate each procedure and to determine the most appropriate algorithm of computing the delay time through a detection zone using spot speed measurements.

For rural applications, it is important that the detectors not only be accurate but also inexpensive, easy to set up and take down, and easy to work with. Radar detectors fit all these criteria and were good candidates for this project. Generally, the radar units are easy to set up and align to obtain speed readings. They have been used in several applications across the nation. The units are relatively inexpensive and are able to communicate with a remote processing unit (RPU). Radar detectors can be roadside-mounted on a 20-foot pole, which could easily be incorporated into a portable station. They can be mounted several feet away from the roadway, too, out of the path of construction.




Where:

$S_i$ = spot speed at Station i

TT = travel time

$D_i$ = distance i

**Algorithm 1**

$$TT_1 \cong \sum_{i=1}^{n} \left( \frac{D_i}{\frac{\left(S_i + S_{(i+1)}\right)}{2}} \right)$$

If i = n, then $S_i$+1 = $S_i$ (i.e., station will be out of work zone, and speed will be free flow)

**Algorithm 2**

$$TT_2 \cong \sum_{i=1}^{n} \left( \frac{\frac{\left(D_{(i-1)} + D_i\right)}{2}}{S_i} \right)$$

If i = 1, then $D_{(i-1)}$ = $D_i$ (i.e., there is no "$D_0$" so it is approximated with "$D_I$") and $D_n$ = $D_{(n-1)}$

**Algorithm 3**

$$TT_3 \cong \sum_{i=1}^{n} \left( \frac{D_i}{\frac{\left(\sum S_i\right)}{n}} \right)$$

and $D_n$ = $D_{(n-1)}$

**Figure 3. Algorithms for approximating travel times using spot speed detection**

For the summer of 1998 testing, more permanent 40-foot poles were used to increase the range of the radios. These poles were mounted on more permanent concrete footings. While this installation improved the performance of the communication system, it did decrease the portability of the equipment.

#### 3.1.3 Manual Data Collection

A manual data collection technique was used to verify travel times through the detection area. Rather than having probe vehicles travel through the zone on a regular basis and record travel times, it was more efficient to collect travel time information manually. Two individuals, one at each end of the test area, were equipped with telephones that were connected to the phone jacks used for the AVI systems, as described in Section 3.2. A more portable setup could just as easily be designed with cellular phones. The person at the upstream site (P-1 as shown in Figure 1) would identify a highly recognizable vehicle, describe it, and note the time that it passed the upstream station. The downstream spotter, stationed in the SDAS center (P-5), used a specially designed spreadsheet on the computer used for data processing. He or she would press a button to record the time and the description given by the upstream spotter. An example of the spreadsheet is shown below in Figure 4. When the downstream spotter saw the vehicle described by the upstream spotter at the downstream location, he or she could press the time button again as it passed. Using the distance between the stations, travel times and overall speeds were instantly calculated. The manual data collection method easily captured one vehicle per minute with a high degree of accuracy. The data gathered thus served as the baseline for evaluation of the travel times computed by the system.

## 3.2 COMMUNICATION

System communication falls into two categories: communication from sensors to the processor and communication from the processor to the motorist advisory interfaces.

#### 3.2.1 Sensor to Processor Communication

The communication needs for the SDAS depended on the means of data transmission. It seemed logical to transmit all of the data on one network rather than having a separate communication system for each data collection system. Concerns with the communication network included the following:

- Bandwidth **-** The passive AVI, especially the video-based system, required high bandwidth and was the critical factor in determining the bandwidth requirements of the system.

- Mobility **-** The communication system needed to be easy to install and maintain by staff.

Corel Quattro Pro - C:\Projects\5541-62 SDAS\DATA\Manual ...\ManCts98-09-01.wb3

A:B42 | white chevy minivan dark windows

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | SAIC | Weather | Raining | Date | 01-Sep-98 |
| 2 | | | 4.3 | Begin Time | 05:27 PM |
| 3 | | | | Observers | McBride / Sykes |
| 4 | **Manual SDAS Counts** | | | | |
| 5 | | | **Observation Times** | | |
| 6 | **Vehicle Number** | **Description** | Up Stream | Down Stream | **Calculated Speed (mph)** |
| 7 | Example | blue pickup | 04:58:50 PM | 05:03:05 PM | 60.7 |
| 40 | 33 | grey voyager dark windows | 06:12:48 PM | 06:16:30 PM | 69.7 |
| 41 | 34 | white suv | 06:13:42 PM | 06:17:38 PM | 65.6 |
| 42 | 35 | white chevy minivan dark windows | 06:15:00 PM | 06:19:02 PM | 64.0 |
| 43 | 36 | bluegreen caravan | 06:15:45 PM | 06:19:48 PM | 63.7 |
| 44 | 37 | red neon | 06:17:20 PM | 06:21:26 PM | 62.9 |
| 45 | 38 | burgundy station wagon PA plates | 06:17:55 PM | missed | |
| 46 | 39 | red plymouth shadow | 06:20:36 PM | 06:24:58 PM | 59.1 |
| 47 | 40 | mercury cougar burgundy | 06:21:58 PM | 06:26:19 PM | 59.3 |
| 48 | 41 | station wagon green woody | 06:23:33 PM | 06:27:25 PM | 66.7 |
| 49 | 42 | 18 wheeler w/ tank | 06:24:13 PM | 06:28:14 PM | 64.2 |
| 50 | 43 | red ford up w/ silver toolbox | 06:25:45 PM | 06:30:11 PM | 58.2 |
| 51 | 44 | white lincoln | 06:26:52 PM | 06:31:00 PM | 62.4 |
| 52 | 45 | yellow 2axle truck | 06:27:32 PM | 06:31:39 PM | 62.7 |
| 53 | 46 | white chevy lumina yellow tags | 06:28:37 PM | 06:32:29 PM | 66.7 |
| 54 | 47 | small white station wagon | 06:30:57 PM | 06:35:14 PM | 60.2 |
| 55 | 48 | bluegreen jaguar | 06:31:34 PM | 06:35:44 PM | 61.9 |
| 56 | 49 | bluegreen 2tone van | 06:32:25 PM | 06:36:19 PM | 66.2 |
| 57 | 50 | dark gray towncar w black ragtop | 06:34:26 PM | 06:39:07 PM | 55.1 |
| 58 | | | | | |
| 59 | | | | Average Speed | 63.42 |

ManualMatch.wb3 | ManCts98-09-01.wb3 | READY

**Figure 4. Manual collection spreadsheet**

- Transmission Range - Transmission range could be an issue in the rural areas. The signal needed to be transmitted over a fairly long distance and over an area without line-of-sight (LOS).
- Interference Problems - The signal could have been subject to noise from other communications in the detection zone environment, including short wave radio.
- Cost - System costs were a major consideration. Communication networks vary in cost. Since one of the goals of SDAS was to prototype and test a cost-effective system, low cost communication systems were preferred.

The optimal method of communication would have been telephone lines, whether leased or dial-up, from all sensor equipment to the central processor. Both the upstream and downstream sites were accessible to telephone. However, for the midpoint sites of the test section telephone lines would be very expensive.

Communication systems that were considered for the midpoint test sites were cellular, microwave, spread spectrum, and low power RF.

- Cellular - Cellular transmission of data has become more popular. Off-the-shelf data modems at 28.8 Kbps have made cellular a viable communication medium for transportation activities. Unfortunately, cellular radio has several downfalls associated with it. Cellular coverage is not available in all areas. Further, the cost associated with a constant cellular connection would be relatively high, given that continual communication was probable (although periodic communication was considered, such as once every five minutes). These issues made cellular communication an unlikely candidate.

- Microwave - Microwave radio is popular because it offers a high bandwidth and is often used in traffic management systems where a fiber optic cable network is not available or practical. However, microwave transmission was a poor candidate for this test because of several reasons. The radios are relatively expensive, they require line of sight for transmission, and an FCC license is required to operate the microwave. Because of the LOS requirement, either large towers or repeaters would have been required at this rural test area.

- Spread Spectrum - Spread spectrum radio was a very promising communication medium. The radios do need LOS, but they are relatively inexpensive (about $3000 for a Cylink) and it is relatively easy to hop the spread spectrum signals using repeaters.

- RF Transmission - There were several types of RF radios that were similar in price and capacity to the spread spectrum radios. These radios are portable, mobile, and were acceptable for the test. A disadvantage with these radios was that they are more likely to be subject to signal interference.

Table 1 describes the characteristics of the communication candidates that were considered for the midpoint sites on this project.

**Table 1: Communication candidates comparison**

| | **Cellular** | **Microwave** | **Spread Spectrum** | **Low power RF** |
|---|---|---|---|---|
| Capacity | Low | Very High | Moderate | Moderate |
| Capital Cost | Low | Very High | Moderate | Moderate |
| Recurrent Cost | High | Low | Low | Low |
| LOS Required* | Low | Yes | Yes | Yes |

* LOS = Line of Sight

After considering various communication alternatives, it was determined that short-wave radio, or RF transmission, was the best option to communicate with the spot speed detectors. Therefore, 47 MHz hand-held voice radios provided by the New Jersey Department of Transportation (NJDOT) were used for communications with the central processor via a radio modem.

Telephone lines were available at both the upstream and downstream sites, it was used with the passive AVI systems. For the weigh-in-motion system, the upstream site communicated over a leased telephone line to the central processor at the downstream site via a US Robotics Courier modem. This leased telephone line basically served as a serial cable between the upstream and downstream sites. The data received at the upstream site was constantly transmitted over the leased line to the downstream central processor. The downstream WIM electronics plugged directly into a digiboard of the central processor. Data received from the downstream sensors to the WIM electronics were routed into the central processor by a standard serial cable.

The upstream video-based equipment communicated over a standard dial-up telephone line. Originally, communication was supposed to occur over a leased line just like the weigh-in-motion system. However, after the setup, the two modems used could not connect with each other using Microsoft's Windows NT operating system. The leased lines were wired into a telephone junction box to convert them into standard dial-up telephone lines. A modem at the downstream site would call the upstream site when data was requested from upstream. Basically, the upstream and downstream sites were always connected throughout daylight hours. Video data from the upstream and downstream sites were stored together on the video equipment's processor, then routed to the system central processor via a standard serial cable.

### 3.2.2 Communication to Motorist Advisory Interfaces

Communication from the central computer to the CMS and HAR was made via cellular service. CMS and HAR are both programmable and accessible remotely via a cellular telephone. Because cellular service was available in the area, it was the practical choice. The number of times a message changes may have been an issue, however. If traffic and delay times fluctuate considerably, then frequent communication would be required to inform motorists of this delay. This could become costly with cellular telephones, because customers are billed according to the time, length, and number of calls made.

The SDAS software provides an option to relay messages to CMS when extensive delays are observed. Next to the CMS message box in the SDAS software, there is an option to turn on or off the CMS message generator. By checking the box "on," the CMS would be called to relay messages to the traveling motorist.

Messages were preprogrammed into the signs by using an assigned number; the SDAS software would relay the message number, thereby displaying the proper message. This would all be achieved using a standard 28.8 Kbps modem connected to the central computer and calling the cellular telephone that was attached to the CMS.

The SDAS software did not include any means of automatically sending messages to the HAR. Verbal updates were provided by the system operator to the NJDOT traffic control center if delays became significant. NJDOT intended to send their own message to the HAR, which was located about 3,000 feet north of the upstream site.

### 3.3 DATA PROCESSING

The processor was the heart of the system. Each data collection system required different software and different amounts of processing power. Some processing could be accomplished on a remote unit while other processing required a database and PC processing capability. Each system was individually examined to determine its computer needs. After each system's computer processing power requirement was determined, the system as a whole was examined to see if the entire test could reside on one central on-site computer or if each data collection method would require a dedicated processing system. In the end, one central system computer was used to collect and compare travel times from the three data collection technologies. Detailed description of each data collection system is provided in the next chapter.

The overall system was integrated at a single Windows NT-based computer. Figure 5 shows the general layout of the graphical user interface (GUI) designed by SAIC/TransCore for this project. In the upper left-hand corner is the Radar Spot Speed subsystem box. The rows are numbered P-1 through P-5 to correspond to the radar stations, which are shown in the map at the right of the GUI. During system operations, the first column of boxes shows the most recently recorded speed at each station.

The second column shows the average speed at each station for the current day (or since the most recent system reset.) The third column shows the number of recordings taken at the station during the current day. The fourth column is a column for the length of the segment between stations. This number is input by the user prior to system operation. Each box shows the length of the segment between the current row and the row below it, thus the last row shows a segment length of "0" as there is no station P-6.

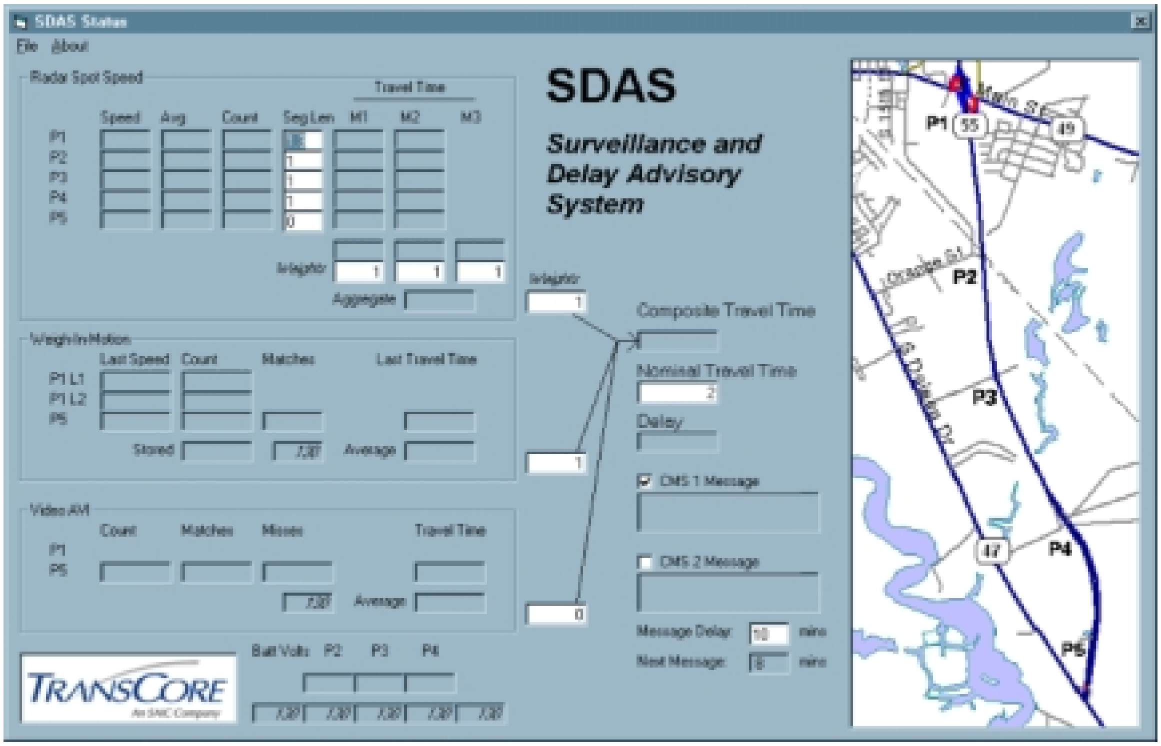


**Figure 5. SDAS user interface**

Columns five and six show the segment travel time according to algorithms M-1 and M-2 described in Section 3.1.2. Algorithm M-3 has no information, since it calculates only the overall section travel time, and not individual link's travel time. At the bottom of these columns is a row for weighting of each of the methods, including a weighting for algorithm M-3. The composite travel time for Methods number 1 through 3 including their respective weights is shown in the Aggregate box on the bottom right of the Radar Spot Speed box.

The box below the Radar Spot Speed box is the Weigh-In-Motion subsystem box. It shows three rows that correspond to the WIM sensors at P-1 and P-5. The first two rows show data from the left and right lanes at station P-1. The third row shows data from the single sensor in the two-lane road at station P-5. Similar to the box above, the columns show the latest recorded speed at each of the stations, while the third column shows the number of vehicles that were counted during the current day. The third column, "Matches" shows the number of vehicle matches that the program was able to make during the current day. "Last Travel Time" shows the travel time based on the most recent match and the average travel time for the day based on the WIM matching system.

Below the WIM box is the Video AVI subsystem box. This box shows the count for the day of the number of video observations, matches, and misses. To the right, it shows the most recent travel time and the average travel time for the day.

To the right of the three boxes is a composite box that allows a weighting factor to be assigned to calculated travel times by each subsystem to create an overall composite travel time and a delay calculation. Beneath this is a control area to send messages to the changeable message sign. The GUI has been designed specifically for testing of SDAS at this location. However, it can easily be tailored for application of SDAS at other locations.

## 3.4 MOTORIST ADVISORY INTERFACE

The final component of the SDAS was the interface used to inform travelers of delay conditions. There were two portable interfaces ready to be used for information dissemination: CMS and highway advisory radio.

### 3.4.1 Changeable Message Signs (CMS)

Several features of portable CMS made them ideal candidates for a motorist advisory interface in the SDAS project:

- **Portability -** Some CMS are trailer-mounted units and are highly mobile, which was ideal for this project.

- **Local Controller -** The portable CMS comes with a local controller, which has all software and hardware necessary to control the sign, program new messages, and store predetermined messages. These functions reduce the requirement of computer power of the CMS. Each system will only need a communication interface and a radio integrated into the system.

- **Low Power Requirements -** Portable CMS could have its own power source, and because of the low power requirements, it can run for a long time on that source. Most signs are flip disk with external lighting, which require considerably less power than an LED or fiber sign. Power can be supplied by a generator powered by a large storage tank or a solar cell.

- **Multiple Vendors -** There are several manufacturers of portable CMS in the marketplace. Because of this, the signs are available in varying degrees of complexity making it easy to find a sign that fits the SDAS application.

- **Common to Agencies -** Most state agencies and some local agencies already have portable CMS. This will reduce the cost for these agencies to implement similar travel information systems.

In the summer of 1997 test, two portable CMSs were used, one located just prior to the upstream site and the other located about 20 miles north of the upstream site. Both were located in areas where motorists could take a detour if they so desired.

Each CMS was equipped with a local controller that had all the software and hardware necessary to control the sign, program new messages, and store predetermined messages. Each used a cellular telephone to receive messages from remote locations. Both were solar powered signs located in a clear, open space to allow sunshine to fully power their batteries. The fiber signs, manufactured by American Signal, were provided by NJDOT. The signs were preprogrammed with special messages by NJDOT staff. For the sign located 20 miles north of the upstream site, there was only one programmed message. The only message that would display explained that 30 minute delays could be expected on SR 55 South from SR 49 to SR 47. Of course, the message would only be displayed if delays exceeded 30 minutes. The sign just north of SR 49, or the upstream site, contained three messages. They read that 5, 15, or 30 minute delays from SR 49 to SR 47 could be expected. The appropriate message would be displayed, as travel times were being computed by the SDAS software, and if delays exceeded at least 5 minutes.

In the 1998 test, only one CMS was located about 5 miles north of the P-1, the upstream site. This CMS was a Solar Message Center manufactured by Precision Solar Controls, and was controlled through the use of an on-board cellular telephone. Connection to the SDAS center was made through the use of a Hayes Accura modem. The sign was programmed with numerous dual messages such as “DELAYS TO ROUTE 47” / “BE PREPARED TO STOP,” “HEAVY DELAYS TO ROUTE 47” / “USE ROUTE 49 TO SHORE.” These sequential messages could be triggered by the SDAS sending a simple code such as “75” for the first message or “76” for the second message.

As previously stated, the delay notifications were never used, and the only message sent was an occasional “DRIVE 55” / “STAY ALIVE.” However, these messages were thought of as distractions to motorists, so the sign simply remained blank for essentially all of the 1998 test.

#### 3.4.2 Highway Advisory Radio (HAR)

Another method of providing information to motorists is through their car radios. The information content can be much greater than that displayed on a CMS and can either use live messages, preselected tape messages, synthesized messages based on information from a database, or messages called in from a remote cellular phone.

HAR was used to complement the CMS if detour information was needed or if delays became excessive. If detouring became applicable for the test, then traveler information beyond the support of a CMS would have been required. The HAR used was located about 3,000 feet north of the upstream site. Also, there was one exit between the HAR and the upstream site. The HAR that was to be used if needed was a portable, standalone device mounted on a trailer with a solar power source. Messages sent out by the HAR were to be determined and delivered by NJDOT.

# 4. DATA COLLECTION SYSTEMS

This chapter presents a detailed description of each of the three data collection systems along with the results of the tests carried out for the project. Figure 2 shows the SDAS prototype layout with the specifics of each data collection technology.

## 4.1 WEIGH-IN-MOTION

The WIM system was based on technology provided by IRD. The system was installed in the southbound lanes on SR 55 as described below.

At the upstream location (P-1) two piezo detectors and two inductive loops were installed in each lane of traffic. In between the detectors, a road temperature sensor was installed to keep the sensors calibrated. Data from these detectors were processed using IRD's roadside electronics, located in a traffic controller cabinet, to determine number of axles, axle spacing, and axle weights. This information was used to assign each vehicle a unique signature, which was then transmitted in formatted data records to the downstream site (P-5). The data were then logged into the database at the system central computer.

The downstream location also consisted of a set of piezos and loops connected to roadside electronics recording the same type of data as the upstream station. This data was used to compile a unique signature for each vehicle passing through the downstream sensors, which was then compared to the upstream data for signature matching. If two like signatures were obtained, travel times could then be computed between the upstream and downstream sites. All equipment was powered by a 120-volt, 20 amp services that the local power company provided.

### 4.1.1 Travel Time Algorithm

The IRD WIM stations collected, formatted, and transmitted data records through a 9.6 Kbps serial port each time a vehicle crossed over the sensors. The data included vehicle speed, weight, number of axles, axle spacings, axle weights, and time and date stamps. Data records from the upstream site were stored in memory and compared with the readings from the downstream site.

To check for a match, the algorithm first compared the number of axles. If the number of axles was the same, then the axle spacings were compared. The WIM sensors in place in the highway pavement can measure axle spacing to an accuracy of about 6 inches. Parameters to vary the tolerances for the matching algorithm can be set in the SDAS Monitor GUI by using the File|Show Debug options in the menu. The tolerance for the axle spacing in inches and the axle weight in percent can be varied to calibrate the WIM sensors at various locations. The tolerance of axle spacing was varied between 2 and 24 inches during this test, while the weight tolerance was varied between 5 and 25 percent. If all the axle spacings matched, then the axle weights were compared. If all the axle weights matched within the specified tolerance, then a match was declared and the stored upstream record was deleted.

Once a match was found, the travel time was computed by subtracting the time stamp of the upstream reading from the time stamp of the downstream reading. For this test, the algorithm used the time that each record was received, instead of the time stamp generated by the WIM computers themselves. For projects involving more WIM sites and slower data collection, it might be important to synchronize the clocks in the WIM computers and use their time stamps directly.

$$TT_{ave(t)} = \alpha \times TT_{(t)} + (1 - \alpha) \times TT_{ave(t - 1)}$$

The following weighted-moving-average model was used to compute the current average travel time:

Where:

| | | |
|---|---|---|
| $TT_{ave(t)}$ | = | Current average travel time |
| $TT_{ave(t-1)}$ | = | Previous average travel time |
| $TT_{(t)}$ | = | Current travel time |
| $\alpha$ | = | Weight factor ($\alpha = 0.25$) |

This model introduces a smoothing filter to the calculation of current average travel time. The smoothing filter specifies the weight given to the most recent travel time value. It is used to lessen the effect of the data from any one vehicle on the calculation of the average travel time for the zone.

The WIM readings were not accurate enough to distinguish between most two axle cars, because many cars have similar axle spacings and weights; therefore, most two-axle vehicles were not considered for signature matching. During this test, the parameters were set to ignore all two-axle vehicles with wheelbases between 50 and 168 inches. This excluded about 98 percent of the two-axle vehicles recorded. It was assumed, and later proven within the scope of the project, that the remaining two-axle vehicles along with all three-plus axle vehicles formed a large enough sample to calculate representative travel times.

#### *4.1.1.1 Axle Weight Normalization*

During the initial phases of the test, it was observed that the axle weight readings were not consistent between the upstream and downstream sites. On one vehicle, the weights might match within 5 percent, but on another vehicle the readings might be different by as much as 50 percent. This may have been due to the level accuracy for the axle weight measurement or because of the poor condition of the pavement at the downstream site, which affected the sensor’s functionality. However, it was found that the ratios of the individual axle weights to the overall weights were much more consistent at both locations. Therefore, all the axle weights were normalized before use in the comparison algorithm. During the test, the normalized axle weights were compared using a 5 percent tolerance.

#### *4.1.1.2 Sliding Time Window*

In order to reduce processing requirements and minimize the number of false matches, the comparison algorithm used a sliding time window. Matches that would indicate a travel time of less than one half of the current average travel time were discarded. During the scan for a match, stored upstream data records older than four times the current average travel time were also deleted. Finally, travel times were validated against a window based on the current average travel time. If a match indicated a travel time of less than half or more than twice the current average travel time, it was discarded.

### 4.1.2 Data Processing

A desktop computer running Windows NT was used for storing and processing the data for signature matching. The computer was equipped with a 133-MHz Pentium processor, 32 megabytes of RAM, a 1-gigabit disk drive, and an 8-port intelligent serial port card. The software to collect the data from the WIM system was written in Microsoft Visual Basic. Because the purpose of data collection was to collect as much information as possible for later analysis, the data files became quite extensive.

Field processors provided by IRD were used at the upstream and downstream sites to collect the raw data from the WIM field sensors. Once the data was processed into axle spacings, number of axles, weights per axle, vehicle speeds, time stamp, and date stamp, it was transmitted and stored in a database on the central computer. The travel time algorithm then looked through the database to tag any similar signatures to determine a travel time. If a match was made, the travel time was calculated for the matched vehicle.

### 4.1.3 Test Results

Data collected in the field were logged to disk files for detailed analysis after the test period. One of the initial steps in this analysis was to conduct a sensitivity analysis to determine a combination of settings for tolerance levels for spacing and axle weight parameters to maximize vehicle matching capabilities of the SDAS. In the original test, the tolerance for spacing was set at 2 inches and the tolerance for the weight measurement was set at 5 percent. These numbers were varied in order to determine the impact on the matching capabilities of the system. Table 2 shows the results of this analysis. Columns 1 and 2 show variation in spacing and weight tolerances, respectively. Column 3 shows the total number of records that were read by the WIM subsystem during the last three days of October 1998. The “Total Records” column shows all records gathered by the two WIM sites at P-1 and P-5 station. Column 4 shows the total number of vehicles that had more than two axles, which were selected for comparisons.

Ideally, all vehicles crossing WIM station P-1 must also cross at P-5 station. However, because of intermittent communications from P-1, the number of records at this station was significantly less than a number of records at P-5. Therefore, the number of records at P-1 was used as the total number of vehicles available for matching. Column 7 then shows the total number of records matched under the given tolerance settings. The percent matched is shown in Column 8.

**Table 2. Sensitivity of percent matched to changes in spacing and weight parameters**

| Spacing (inches) | Weight (percent) | Total Records | Vehicles w/ 2+ Axles | Percent Trucks | P1 Records | Matched | Percent Matched |
|---|---|---|---|---|---|---|---|
| 2 | 5 | 22171 | 1193 | 5.4% | 336 | 40 | 11.9% |
| 5 | 5 | 22171 | 1193 | 5.4% | 336 | 71 | 21.1% |
| 10 | 5 | 22171 | 1193 | 5.4% | 336 | 72 | 21.4% |
| 24 | 5 | 22171 | 1193 | 5.4% | 336 | 88 | 26.2% |
| 2 | 10 | 22171 | 1193 | 5.4% | 336 | 36 | 10.7% |
| 2 | 25 | 22171 | 1193 | 5.4% | 336 | 56 | 16.7% |
| 5 | 15 | 22171 | 1193 | 5.4% | 336 | 218 | 64.9% |

Since the WIM equipment is subject to some error, an axle spacing tolerance of less than about 3 inches is probably too strict. However, selecting an axle spacing of more than 6 inches is probably too large, especially since the percentages go up only marginally after the 5-inch setting. Relatively large increases in the weight tolerance do not seem to help the matching process. This may be due to the fact that the axle weights are normalized as a percentage of the total weight at both WIM sites. Based on the results of the sensitivity test, relaxing both restraints to 5 inches for the axle spacing and 15 percent on the axle weight yielded almost a 65% match rate.

The next step was to check the validity of the 65% match rate. Table 3 shows that the matching results are somewhat erratic as the tolerances are relaxed. However, once the tolerances are set to the 5-inch, 15-percent range, the matching results yield an average travel time of about 4.14 minutes with a standard deviation of only 20 seconds. This means that normal travel times would range between 3.84 and 4.43 minutes. This is compatible with the results achieved through the manual data gathering as well as the radar travel speeds. A number of these matches were also traced manually to further substantiate the validity of the matching rate.

**Table 3. Sensitivity of travel time to changes in spacing and weight parameters**

| Spacing (inches) | Weight (percent) | Avg Travel Time (min) | Standard Deviation (min) | Minimum Normal | Maximum Normal |
|---|---|---|---|---|---|
| 2 | 5 | 4.29 | 0.36 | 3.93 | 4.65 |
| 5 | 5 | 11.90 | 2.89 | 9.01 | 14.79 |
| 10 | 5 | 5.83 | 0.78 | 5.05 | 6.62 |
| 24 | 5 | 6.41 | 0.91 | 5.50 | 7.32 |
| 2 | 10 | 4.22 | 0.36 | 3.86 | 4.58 |
| 2 | 25 | 4.20 | 0.35 | 3.85 | 4.55 |
| 5 | 15 | 4.14 | 0.30 | 3.84 | 4.43 |

The WIM electronics equipment can be set to screen vehicle records by FHWA Vehicle Class as shown in Table 4. For the sensitivity testing done for this report, the WIM electronics was set to store all vehicles for three days of data. SAIC/TransCore developed two programs to screen and post-process the data to simulate the screening and processing, which would normally take place in the field. By design, the SDAS does not match passenger cars (Class 2 vehicles) and since motorcycles are difficult to detect and measure, only Class 3 and above are generally matched for speeds.

Because trucks constitute less than 6 percent of the total traffic at the SDAS site, it was important to match as many of them as possible. The two most obvious screening techniques are first, to match all vehicles of Class 3 and above, or second, to match all vehicles with three or more axles. The first technique could be accomplished in two ways. The first would be to set the WIM electronics to record all vehicles and allow the SDAS Monitor program to screen vehicles on its own. The second way is to set the WIM electronics to screen out Class 1 and 2 vehicles to limit the size of the database. The results of these two methods is essentially the same, with the only difference being the size of the stored database, and will thus be referred to collectively as a single matching technique. The second of the two screening techniques is to set the WIM electronics to screen out Classes 1 through 5 and attempt to match only vehicles with at least three axles.

**Table 4. FHWA classification description**

| Vehicle Class | Vehicle Description |
|---|---|
| 1 | Motorcycles |
| 2 | Passenger cars |
| 3 | Other two-axle, tour-tire single unit vehicles |
| 4 | Buses |
| 5 | Two-axle, six-tire, single unit trucks |
| 6 | Three-axle single unit trucks |
| 7 | Four or more axle single unit trucks |
| 8 | Four or less axle single trailer trucks |
| 9 | Five-axle single trailer trucks |
| 10 | Six or more axle single trailer trucks |
| 11 | Five or less axle multi-trailer trucks |
| 12 | Six-axle multi-trailer trucks |
| 13 | Seven or more axle multi-trailer trucks |

Table 5 shows the same 3-day period with a comparison of matching techniques used. The left set of numbers show matching for all non-passenger cars. The right set of three columns show the results of matching only three-plus axle vehicles. It can be seen that although travel times are very close, the standard deviation is almost always higher when 2-axle vehicles are thrown into the matching database.

**Table 5. Comparison of screening techniques**

| | Technique 1 | | | Technique 2 | | |
|---|---|---|---|---|---|---|
| | Class 3 and Above | | | 3+ Axles | | |
| | Oct 29 | Oct 30 | Oct 31 | Oct 29 | Oct 30 | Oct 31 |
| Max Travel Time | 5.15 | 5.03 | 5.15 | 4.85 | 4.82 | 5.82 |
| Mean Travel Time | 4.04 | 4.09 | 4.16 | 4.05 | 4.12 | 4.23 |
| Min Travel Time | 2.53 | 2.72 | 3.23 | 3.40 | 2.82 | 3.62 |
| Standard Deviation | 0.37 | 0.35 | 0.30 | 0.23 | 0.29 | 0.36 |
| | | | | | | |
| High Normal | 4.41 | 4.44 | 4.46 | 4.29 | 4.40 | 4.59 |
| Low Normal | 3.68 | 3.75 | 3.86 | 3.82 | 3.83 | 3.88 |

Based on the work done in 1997 and 1998, it is believed that it is generally the best practice to set up the WIM electronics to screen out vehicles with fewer than three axles. To achieve optimum performance in the matching algorithm, the SDAS Monitor program should be set up to tolerances of 5 inches and 15 percent for axle spacing and axle weight, respectively.

Since the 1998 results indicate that in nearly 65 percent of the trucks having three axles or more can be matched, we calculated that a minimum of 19 trucks per hour are needed to achieve 5-minute updates on the WIM travel time system. With 5 percent trucks in the traffic flow, this would mean that about 380 vehicles per hour in the direction of the analysis zone are necessary to support the WIM matching system.

## 4.2 SPOT SPEED DETECTION

Radar detectors were used for spot speed measurements. Five radars detectors were used along the test site, which was approximately 4.3 miles long. Site identification was in the order of the upstream site being labeled P1 while the downstream site was P5. The distance between P1 and P2 was 1.3 miles, while the distances between P2 and P3, P3 and P4, and P4 and P5 were about 1 mile each.

Model TDS-40 radar detectors were used, because they are best suited for roadside installation. These detectors can detect vehicles either approaching or departing the station and have a detection range of approximately 300 to 500 feet from the unit. The radar detectors were mounted on steel poles provided and installed by NJDOT. They were placed approximately 16 feet above the road surface and attached to a steel plate which was bolted to the steel pole. Along with each detector, an RPU was installed. The RPU collects the speeds detected by the unit and averages the speeds over a preset time period, which was 1 minute for this project.

The upstream and downstream sites were powered from a 120 volt, 20 amp power drop from the local power company. However, during the 1998 test, three radar detectors in between the upstream and downstream sites were each powered by a combination of solar power collector and 12-volt rechargeable cell. The battery and RPU were housed in a weatherproof steel cabinet affixed to the main pole.

### 4.2.1 Data Processing

Radar detectors have only minimal data processing needs since any computation is trivial and speed was directly measured by the detectors. Thus, an RPU provided sufficient computing power for this test. RPUs are small, portable, and relatively inexpensive. They are powered by 12 VDC or 120 VAC. The RPU is programmed in C, which is easy to program, and most DOTs have computer support readily available and familiar with C. Debugging is fairly easy and field adjustments can be made. The RPU can have up to 512KB of memory and communicates through a standard RS-232 connection.

Data were downloaded from the RPU to the central computer once every minute so that large storage capacity within the RPU was not a problem. The RPU configuration was a dispersed architecture. Each unit was configured to act as a stand alone unit. This created a portable, modular, self-contained station that was well suited for the rural environment. Also, the RPU did not generate heat associated with a PC, making it better adapted to the field.

Once the data reached the central computer, it was stored in a database for analysis. For comparison purposes, three travel time computation algorithms were used for travel time computations. Travel times were then stored in the central computer for computation of delay and comparison with the other data collection systems.

#### 4.2.2 Communication

The simplest way for the RPUs to communicate to the central computer would have been through a standard dial-up telephone line; however, telephone lines were unavailable without major effort and expense. After an evaluation of communication alternatives, it was determined that short-wave radio was the best option of communicating with the spot speed detectors. The 47 MHz radios were portable, mobile, and considered acceptable for the communication requirements of this test.

One of these radios was placed at each of the five radar sites. Each radio had an antenna assembly attached to the steel pole; the ground wire and the antenna cable, which plugged directly into the radio, were attached to the antenna.

Because the range of the radios was limited to two to three miles, a daisy chain technique was used to communicate the data from the radar detectors to the central computer. A radio modem was connected to each radio, which allowed the central processor to interpret the data the radios were sending back to it. The radio modem at the downstream site attached to a digiboard, which was connected to the central processor for data interpretation and travel time computation. The radio modems and radios at P2, P3, and P4 were each powered by the same solar power collector and 12-volt rechargeable cell that powered the radar units and RPUs. At P1 and P5, a standard 120 volt power drop was provided.

#### 4.2.3 Test Results

In the tests performed during the summer of 1997, problems with two of the radar detectors precluded a thorough evaluation. However, the test conducted during the summer of 1998 yielded more encouraging results. The radar detectors worked very well and were adequately powered through the solar power panel / battery combination. The most difficult part of the setup involved the radio connection from the units to the SDAS central computer via the short-wave radios. It must be remembered that a daisy chain form of communication had to be used. This meant that for transmission of data from P5 station to P1 station, data had to be transmitted through at least another site in between the two stations. After solving the initial setup problems, however, throughout the two month testing period, all radar sites communicated satisfactorily to the central computer.

The radar detectors speed readings are exceptionally sensitive to the angle at which the dectector is aimed at the road. Adjustments to the position angle speeds can make a considerable difference in measured speed in comparison with the actual speeds on the road. All detectors were calibrated for proper operation after installation.

Comparisons were made between the travel times computed by the three algorithms discussed previously in Section 3.1.2. Figure 6 shows computed travel times, for an hour of operation on September 1, 1998, based on the three algorithms and their average. Travel times measured manually, for the same period of time, are shown for comparison. As shown on this figure, algorithm 1 consistently overestimates the travel time, while algorithm 2 underestimates the same. Travel times computed using the third algorithm and those computed by the average of all three algorithms were very close to the observed travel times.

It is important to note that comparisons could not be made during various levels of congestion as was desired. Speed readings by 5-minute increment were averaged for all weekdays for the month of September. This resulted in the graph shown in Figure 7. Patterns of the three algorithms and their averages with respect to each other are similar to those shown in Figure 6. Figure 8 shows similar information for an average weekend day. It shows a slight increase in travel time during the mid-day period from about 9:30 A.M. to around 2:00 P.M. as shown in the highlighted area.

Here is the only indication we have of traffic slowing due to congestion. In this mid-day period, algorithm 2 shows higher sensitivity to congestion than the other methods, while algorithms 1 and 3 show much less overall sensitivity to congestion. Although not shown due to lack of data during the weekends in September, other field observations based on manual counts during the weekends still show algorithm 3 to be overall the most accurate of the three.

### 4.3 VIDEO-BASED DETECTION SYSTEM

Nestor, Inc. has developed a real-time image-based detection and tracking system named TrafficVision™. This system uses neural networks to detect and track a vehicle or object while it is within the field of view of the imaging system. This section presents a discussion of system elements as well as the results of some preliminary testing of the system conducted and reported by Nestor.

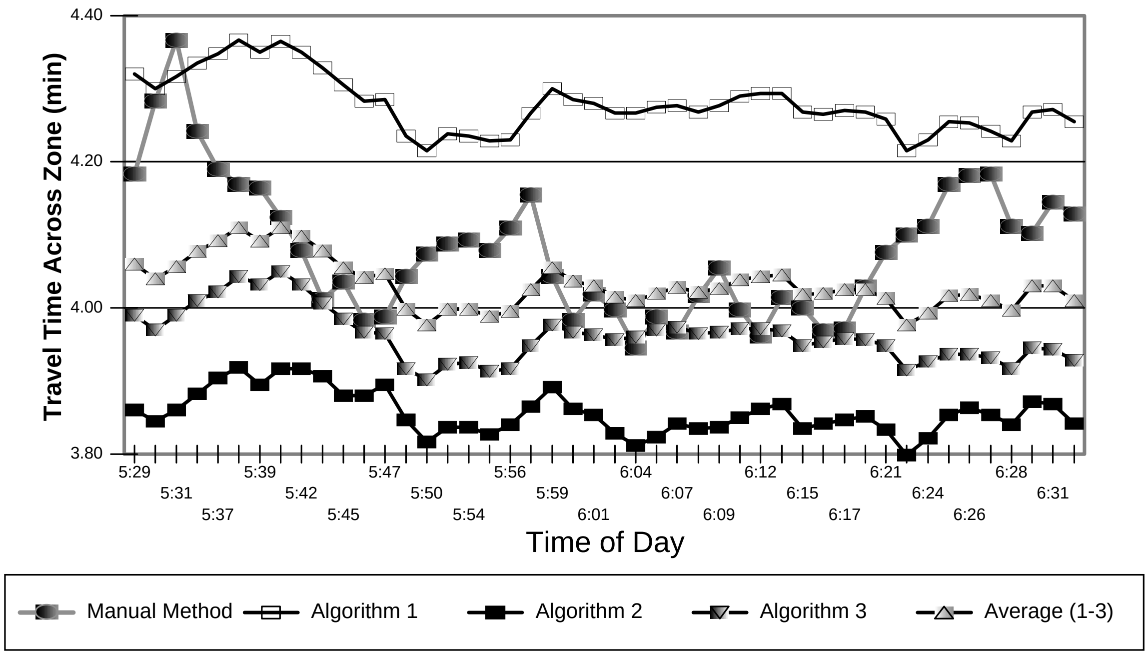



**Figure 6. Comparison of estimated travel times**

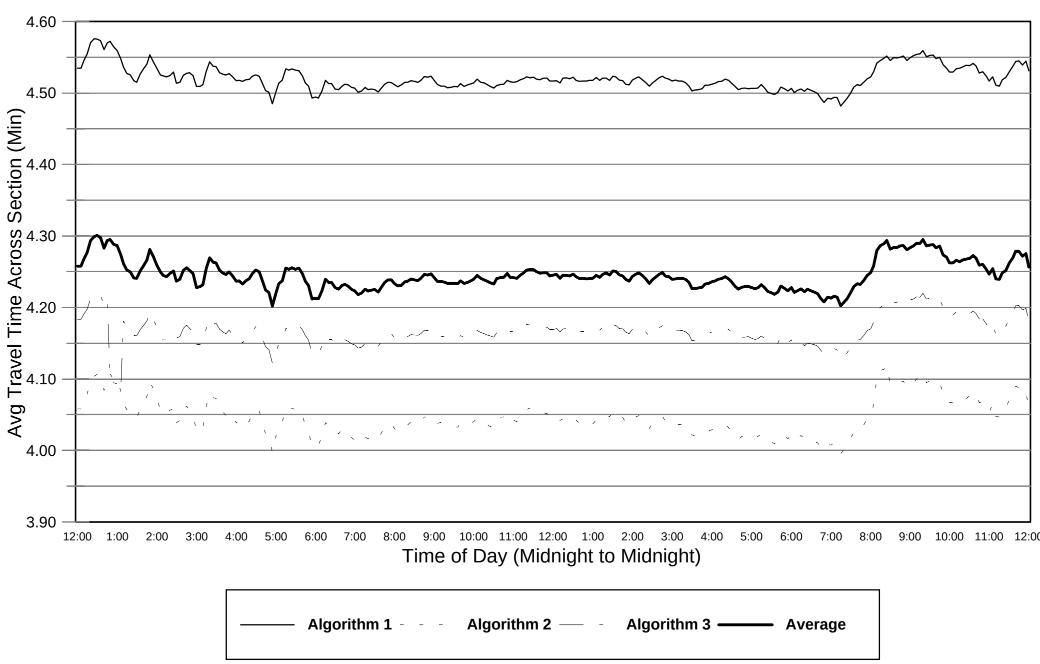



**Figure 7. Average section travel time on weekdays**

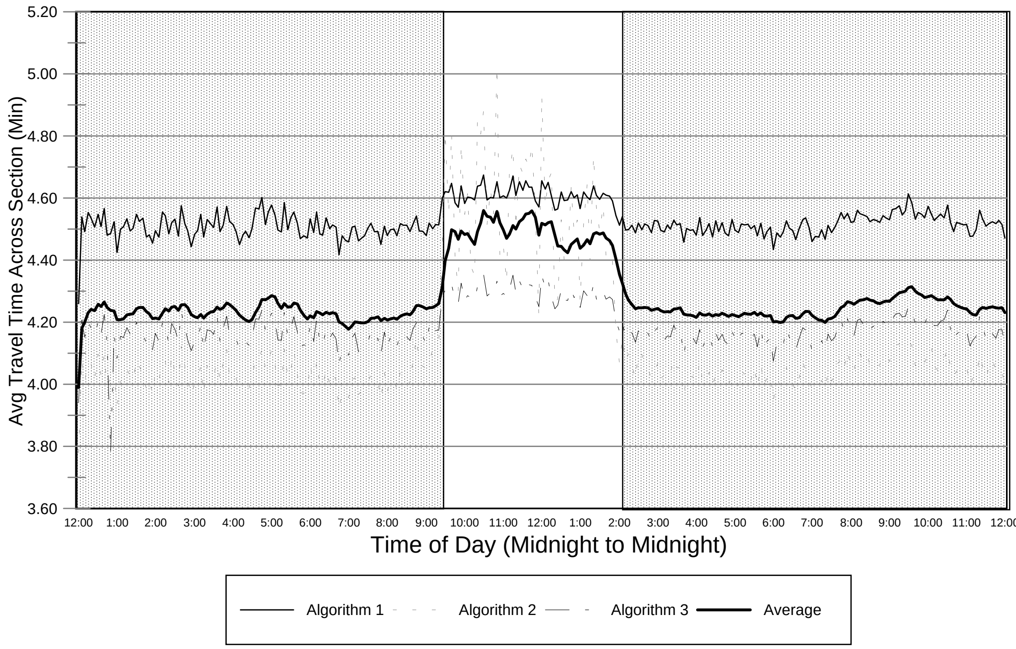



**Figure 8. Average travel time on weekends**

## 4.3.1 Elements

The following system elements are discussed in the next section:

- System configuration
- Communications
- Video sensors
- Processing platforms

### *4.3.1.1 System Configuration*

Video cameras were located at two sites, approximately 4.3 miles apart. At both sites, a local IBM-compatible PC running TrafficVision RoadSide Station™ software processed the video to detect and track vehicles, create vehicle signatures, and communicate with a host PC running TrafficVision ServerNT. This configuration is identical to that which is required in a Traffic Operations Center (TOC) or in remote communications concentrator environments. The downstream trailer on SR 55 served as the TOC.

The upstream system was located in a roadside traffic controller cabinet. Due to the proximity of the TOC trailer to the downstream site, both the downstream sensor system and the server were located inside the TOC trailer.

*4.3.1.2 Communications*

A dial-up modem connection was provided from the upstream site to the server, operating at 33.2 Kbps. The downstream system communicated to the server over Ethernet. Resulting reports were sent from ServerNT to the TransCore's central computer over a 9.6 Kbps serial connection. All communications from the upstream station to the downstream station were routed through ServerNT. No processing of information was performed by the server on data being routed to the downstream station.

In addition to communications among the various system components for normal operation, it was possible to perform various administrative tasks from the server. These tasks included configuring the remote stations, moving files between the server and the remote stations, updating software on the remote stations and performing remote shutdown and re-booting of the remote stations. Remote system administration and diagnostics could also be performed from the server.

*4.3.1.3 Video Sensors*

Charge-coupled device (CCD) cameras from Javelin, provided and installed by NJDOT, were used to provide color images as an analog signal (NTSC composite video). Each camera was mounted approximately 40 feet above the roadway and approximately 20 feet off the edge of the road adjacent to the low speed lane and were aimed upstream to provide a frontal view of approaching traffic. The upstream view covered two approaching lanes and distances ranging from about 90 feet to 275 feet upstream from the camera. The downstream view covered two lanes, one approaching and one receding, ranging from about 80 feet to 320 feet upstream from the camera. Only vehicles in the approaching lane were candidates for matching.

*4.3.1.4 Processing Platforms*

Three IBM-compatible PCs, all 200 MHz Pentium-based machines, were used as computing platforms. The system installed in the upstream traffic controller cabinet was configured in an environmental enclosure that meets NEMA-12 specifications. Two were configured with TrafficVision RoadSideStation software running on Windows95 and equipped with a Matrox Meteor video capture card and a Nestor, Inc. PCI4000 Recognition Accelerator card. The third was configured with TrafficVision ServerNT software running on Windows NT 4.0. In addition, the downstream system was used to run a demonstration program that displayed low resolution images of matched vehicles to permit visual evaluation of performance.

#### *4.3.1.5 Travel Time Algorithm*

For each vehicle tracked at the upstream station, a signature data packet was created and transmitted via the server to the downstream station. There, the signatures were stored as an array of candidate vehicles for matching. A subset of these candidate matches, based on estimated arrival time, were compared to vehicle signatures created for vehicles arriving at the downstream station. A wide estimated arrival time window was used to allow for vehicles traveling excessively fast and for unpredicted delays. This window was adaptive based on measurements of actual traffic characteristics.

Preliminary matches were evaluated for uniqueness prior to accepting them as actual matches. Each match was scored using several criteria. The highest scoring match had to exceed a confidence threshold and had to exceed the score for the next highest scoring candidate by a minimum differential before it was considered to be a correct match. Once a match was considered to be correct, calculation of the travel time was performed using time stamps from both observations. Travel times from all matched vehicles during each 1-minute interval were averaged and reported to the TransCore or central system.

Unlike some travel time systems, no vehicles are excluded from processing. The majority of vehicles observed were passenger cars and the majority of vehicles tracked by the TrafficVision system were passenger cars. In addition, all vehicles visible in a frame are tracked independently and, with proper camera mounting (similar to that used in this test), the presence of large vehicles does not preclude tracking smaller vehicles present at the same time.

### 4.3.2 Test Results

The video-based system was only tested during the 1997 testing period. Even then, due to a variety of startup problems, the system was not operational during the initial tests. This precluded the comparison of the test results with other systems and the data collected manually. Testing began on October 14, 1997, and continued for two days. Three tests were performed, two using live video and one using taped video from the same cameras on August 29, 1997. Table 6 shows the results from the three days of testing. Note that the travel times are displayed in seconds.

**Table 6. Video-based detection results**

| Date | Starting Time | Ending Time | Total Flow | Vehicles Matched | Match % | Travel Time(sec.) | Comments |
|---|---|---|---|---|---|---|---|
| 10/14/97 | 3:53 pm | 5:14 pm | 561 | 69 | 12.3% | 250.5 | Clear |
| 10/14/97 | 5:23 pm | 6:23 pm | 331 | 55 | 16.6% | 243.7 | Clear |
| 10/14/97 | 5:23 pm | 8:18 am | 2237 | 106(1) | 4.7%(1) | 273.3(1) | Overnight(1) |
| | | | | | | | |
| 10/15/97 | 8:23 am | 9:54 am | 464 | 26 | 5.6% | 304.4 | dark, rainy |
| | | | | | | | |
| 10/15/97 | 10:10 am | 1:16 pm | 977 | 64 | 6.6% | 263.8 | Dark, rainy |
| 08/29/97(2) | 1:30 pm | 3:00 pm | 1415 | 84(2) | 6.7%(2) | 260.0(2) | Clear (tape) |

(1) Filtered to remove obviously incorrect matches at night by removing values less than 50% of the median and values greater than twice the median.

(2) Video tape demo. Video tape causes substantial image quality degradation, reducing matching rate. The matching rate was similar to that in the rainy conditions; however, the quality of the matches was better. One erroneous value (over 12 times the median value) was removed. Including it would have increased the travel time to 316.6 seconds.

During the 1-hour run on October 14, 1997, from 5:23 pm to 6:23 pm, the matching display was monitored to evaluate the correctness of the matches. Of the 55 vehicles matched, 53 were correct.

The dark and rainy conditions on the October 15, 1997, test seriously degraded both the matching rate and the quality of the matches. Poor visibility of vehicle features, extraneous image “noise” caused by flooding of the road surface, and headlight reflections caused problems. These conditions had not been present in the data used for developing the algorithms used for vehicle matching. Future work will be done with a variety of weather and lighting conditions when appropriate data (video tape) is available.

The limited data collected during the test period indicates that the video system performed well for travel time measurement. Additional work is necessary to operate under varying weather conditions. In good conditions, such as those on October 14, the results significantly exceeded specifications in both percentage of vehicles tracked and percentage of tracked vehicles that were correctly matched. Additional filtering was shown to be a simple and effective measure to further improve the quality of the results.

Installation of sensors and equipment convenient to the road but away from the pavement proved to be a significant advantage of the video system. The system was installed in the controller cabinet in 10 minutes without disturbing traffic. When resurfacing occurred at the upstream site, the in-pavement sensors were destroyed, but the video system was unaffected. Also, the ability to visually verify the quality of the results at the TOC, either live or through subsequent review of stored images, permits unambiguous verification of performance.

TrafficVision does not require a minimum vehicle speed. This is particularly important for travel time measurements since congested traffic is often the justification for providing travel time sensors. Additionally, the system monitors and matches all vehicle types and is able to match passenger cars in addition to large vehicles. Further, if there are variations in vehicle speed associated with vehicle type, possibly due to lane restrictions, sensors that are able to monitor all types of vehicles and to separate individual vehicle measurements in clusters of vehicles will provide more accurate travel time measurements. Advanced video-based systems, such as TrafficVision, can also be enhanced to provide more detailed reporting such as reports by vehicle class.

## 5. PROJECT COST

This section of the report provides approximate costs for implementing the SDAS. It must be noted that these costs are associated with implementing the SDAS at the site discussed in Section 2.4. Specific site characteristics and their impacts on cost must be taken into account when preparing cost estimates for implementing in other locations. The costs are provided for each of the three data collection systems tested in this project to allow cost comparison of each system. The costs for the WIM system are shown in Table 7. The table lists the elements necessary for proper operation of this type of system.

**Table 7. Weigh-in-motion equipment costs**

| Item | Quantity | Unit price | Total cost |
|---|---|---|---|
| WIM Electronics c/w operating software, interface cards, power supply, and termination panel | 2 | $12,500.00 | $25,000.00 |
| Inductive loops including lead-in and sealant | 6 | $250.00 | $1,500.00 |
| Piezo detectors including lead-in and sealant | 6 | $1,500.00 | $9,000.00 |
| Courier modem | 2 | $215.00 | $430.00 |
| Standard dial-up telephone line (installation fee only) | 4 | $75.00 | $300.00 |
| Power drop (installation fee only) | 2 | $25.00 | $50.00 |
| Meter cabinet, type TL (electrical service cabinet)* | 4 | $1,169.00 | $4,676.00 |
| Multi-conductor cable, 14/10* | 500 | $6.77 | $3,385.00 |
| 2/0 copper wire* | 4800 | $1.20 | $5,760.00 |
| Copper wire, 6 pair telephone* | 2000 | $0.27 | $540.00 |
| Cabinet (upstream)* | 1 | $882.00 | $882.00 |
| Piezo detector installation* | 6 | $3,100.00 | $18,600.00 |
| Loops, 6 @ 6 x 6, 4 turns* | 300 | $8.30 | $2,490.00 |
| Foundation, type P (for upstream cabinet)* | 1 | $300.00 | $300.00 |
| Foundation, type MCF (for electrical cabinet)* | 4 | $300.00 | $1,200.00 |
| Conduit, 3 inch, type cur* | 300 | $32.00 | $9,600.00 |
| 20” junction box* | 1 | $325.00 | $325.00 |
| Trenching* | 2000 | $1.00 | $2,000.00 |
| **TOTAL** | | | $86,038.00 |

* These elements were provided by the NJDOT and the associated costs include materials, equipment, and labor (installed costs).

The costs for the spot speed detection system are shown in Table 8. This table shows the essential elements necessary for implementing a system similar to the system used for this test.

**Table 8. Spot speed detection equipment costs**

| Item | Quantity | Unit price | Total cost |
|---|---|---|---|
| RPU Protocol Switch | 5 | $277.00 | $1,385.00 |
| RPU Enclosure | 5 | $33.00 | $165.00 |
| RPU Switching Power Option | 5 | $33.00 | $165.00 |
| RPU Development Kit | 1 | $329.00 | $329.00 |
| RPU Dynamic Software | 1 | $395.00 | $395.00 |
| Whelan TDS-40 radar | 5 | $1,200.00 | $6,000.00 |
| Power Sonic 12-volt battery | 5 | $132.10 | $660.50 |
| Battery charger | 1 | $196.55 | $196.55 |
| Antenna modem | 5 | $119.00 | $595.00 |
| Antenna adapter | 5 | $8.24 | $41.20 |
| Locks securing coolers | 3 | $5.00 | $15.00 |
| Standard dial-up telephone line (installation fee only) | 2 | $75.00 | $150.00 |
| Power drop (installation fee only) | 1 | $25.00 | $25.00 |
| Traffic Signal Standard, type T | 3 | $410.00 | $1,230.00 |
| Traffic Signal Standard, type L | 2 | $669.00 | $1,338.00 |
| Solar Panels with regulators | 3 | $1,000.00 | $3,000.00 |
| Batteries (2 per location) | 6 | $40.00 | $240.00 |
| Meter cabinet, type TL (electrical service cabinet)* | 2 | $1,169.00 | $2,338.00 |
| Multiconductor cable, 14/10* | 500 | $6.77 | $3,385.00 |
| Copper wire, 6 pair telephone* | 1000 | $0.27 | $270.00 |
| Foundation, type SFT (for steel pole)* | 5 | $700.00 | $3,500.00 |
| Foundation, type MCF (for electrical cabinet)* | 3 | $300.00 | $900.00 |
| Foundation, type P-MC (for electrical cabinet)* | 1 | $1,500.00 | $1,500.00 |
| Conduit, 3 inch, type cur* | 150 | $32.00 | $4,800.00 |
| 20" junction box* | 1 | $325.00 | $325.00 |
| Trenching* | 1000 | $1.00 | $1,000.00 |
| Radio, hand held, lo-band* | 5 | $600.00 | $3,000.00 |
| **TOTAL** | | | $36,948.25 |

* These elements were provided by the NJDOT and the associated costs include materials, equipment, and labor (installed costs).

Table 9 provides the costs associated with the video-based detection system used for this test.

**Table 9. Video-based detection equipment costs**

| Item | Quantity | Unit price | Total cost |
|---|---|---|---|
| Pentium Pro, 200 MHz (min), 48 MB RAM computer | 1 | $6,000.00 | $6,000.00 |
| TV/TOCS (link travel time software) | 1 | $20,000.00 | $20,000.00 |
| TV/FS Basic FW 2 (TrafficVision freeway configuration) | 2 | $11,875.00 | $23,750.00 |
| Standard dial-up telephone line (installation fee only) | 4 | $75.00 | $300.00 |
| Power drop (installation fee only) | 2 | $25.00 | $50.00 |
| Steel pole (40')* | 2 | $760.00 | $1,520.00 |
| Meter cabinet, type TL (electrical service cabinet)* | 4 | $1,169.00 | $4,676.00 |
| Multiconductor cable, 14/10* | 500 | $6.77 | $3,385.00 |
| 2/0 copper wire* | 4800 | $1.20 | $5,760.00 |
| Copper wire, 6 pair telephone* | 2000 | $0.27 | $540.00 |
| Cabinet (upstream)* | 1 | $882.00 | $882.00 |
| Camera assemblies, Javelin* | 2 | $8,000.00 | $16,000.00 |
| Foundation, type SFT (for steel poles)* | 2 | $600.00 | $1,200.00 |
| Foundation, type P (for upstream cabinet)* | 1 | $300.00 | $300.00 |
| Foundation, type MCF (for electrical cabinet)* | 4 | $300.00 | $1,200.00 |
| Conduit, 3 inch, type cur* | 300 | $32.00 | $9,600.00 |
| 20” junction box* | 1 | $325.00 | $325.00 |
| Trenching* | 2000 | $1.00 | $2,000.00 |
| **TOTAL** | | | $97,488.00 |

* These elements were provided by the NJDOT and the associated costs include materials, equipment, and labor.

Operation and maintenance costs of the system are not included. The cost of the SDAS software is not included either because this software has already been developed. Some modification may be required to tailor the software for a different site. Modifications to the SDAS software will depend on the data collection technology used and the site at which the system will be deployed.

Table 10 details the common items necessary for this project. These items are considered common since all three data collection technologies required use of these elements to form a complete traveler information system. Note that some of the equipment, such as the computer and monitor, may be substituted by other comparable equipment. Items listed are those associated with this project only.

**Table 10. Common element equipment costs**

| Item | Quantity | Unit price | Total cost |
|---|---|---|---|
| Pentium 133, 32 MB RAM, 1 GB, Windows NT computer | 1 | $2,000.00 | $2,000.00 |
| 17” SVGA monitor | 1 | $500.00 | $500.00 |
| Digiboard with I/O box | 1 | $472.00 | $472.00 |
| Portable CMS (new) | 2 | $40,000.00 | $80,000.00 |
| US Robotics modem (1 for CMS and 1 for Remotely Possible software for remote access and diagnostics) | 2 | $143.00 | $286.00 |
| Software modification | 1 | $5,000.00 | $5,000.00 |
| Trailer (per month lease) | 1 | $190.00 | $190.00 |
| Cabling and connectors | Lump | $125.00 | $125.00 |
| **TOTAL** | | | $88,573.00 |

Finally, in Table 11 total costs are given per data collection technology. The specific costs are the total costs taken from each technology shown in Tables 7, Table 8, and Table 9. Again, the common costs are the same since the items shown are necessary elements for all three technologies.

**Table 11. Sensor technology total cost**

| Technology | Specific costs | Common costs | Total |
|---|---|---|---|
| Weigh-in-Motion | $86,038.00 | $88,573.00 | $174,611.00 |
| Spot Speed Detection | $36,948.25 | $88,573.00 | $125,521.25 |
| Video-Based AVI | $97,488.00 | $88,573.00 | $186,061.00 |

# 6. LESSONS LEARNED

This chapter presents lessons learned from prototyping and testing of the system and makes several recommendations regarding future actions for further development of the system.

The purpose of this project was to prototype a travel time monitoring system using various technologies and to conduct preliminary testing of the system to evaluate its application in a rural setting. The system was developed to enhance data collection capabilities for travel time monitoring in rural areas. The goals of this project were achieved. Specifically, the testing of the SDAS helped achieve the following goals:

- Spot speed conversion to travel times using three different algorithms was determined to be both accurate and cost effective under a limited range of operating speeds.

- Travel times computed from spot mean speed versus space mean speed were compatible with manual speed calculations under a limited range of operating speed.

- It was determined that, if specific conditions are met (see Section 6.1), AVI applications are effective in travel time monitoring.

- It was determined that AVI can capture over 65 percent of the trucks under free flow speed operating conditions and compute reliable travel times. Worth mentioning is the assumption that trucks travel at the same speed as passenger cars in the traffic flow. This may not be the case in some settings, such as mountainous terrain. However, under congested conditions, speeds should be similar.

- Although the system was designed to be capable of relaying delay information to travelers. This capability was not tested due to lack of extensive delay during the test period.

- The SDAS was cost-effectively prototyped and tested in a rural setting.

## 6.1 WEIGH-IN-MOTION SYSTEM

- Based on data collected as part of this project, WIM signature matching can be a useful method of measuring travel times under the following conditions:

  – Between 5 and 10 percent of the vehicle stream has more than two axles.

  – A small percentage of vehicles enters or leaves roadway between the WIM stations.

– Vehicle speeds at WIM stations are at least 20 mph.

– Power and phone lines are available at both upstream and downstream sites.

- The WIM system itself, after installation and calibration, worked very reliably and gave accurate measurements with a great consistency. In spite of the fact that the P-1 equipment was connected to the SDAS trailer with a dedicated "dry line," there were some communication problems. The first problem was caused when the telephone company in the local station terminated the connection by accident. Even after the connection was made, communications were intermittent and much data from P-1 were lost during the final important weeks of the study.

- The work at the test site was greatly complicated by the fact that the construction trailer at the downstream site could not be located on the same side of the road as the WIM equipment. Test location sites should be chosen to minimize wiring to field sensors, power, and phone lines.

- Installing an extra dial-up modem line to allow remote control of the SDAS computer proved invaluable during software development and allowed remote data collection and analysis. Two phone lines are required if both remote access and message signs are being used.

- Until the software is more fully developed, it will still be necessary to have a trailer at a SDAS computer site. Even with the use of remote access software, the system is not mature enough to be installed in a stand-alone cabinet. Eventually, though, it should be possible to reduce the size of the equipment enough to fit into a small roadside cabinet.

- Because of the difficulty involved in installing phone lines in rural locations, the use of radio interconnect should be considered for connection between the WIM sites. Spread spectrum and packet radio systems are worth consideration. Cellular phones would not be economical for this application due to the requirements for continuous communication and 9.6 Kbps throughput.

- Because the WIM stations cannot read vehicles moving at speeds below about 20 mph, they should be sited in locations before and after any area where stop-and-go traffic is expected. If traffic is stopping over the WIM sensors, no matches will be possible because of unrecognizable separations between various vehicles.

- Pavement must be in good condition for the WIM sensors to measure weight accurately. In the 1997 tests, the pavement at the downstream site for this test was in poor condition introducing some imprecision in the data collected. This problem was repaired in 1998 and the WIM equipment performed flawlessly.

## 6.2 SPOT SPEED DETECTION SYSTEM

- One of the problems encountered with the spot speed detectors was telecommunications. The hand-held radios used for the radar spot speed measurements were a constant source of problems. They were very difficult to get working even with the improved antennae and traffic signal standards used in the 1998 tests. Even after they were all working properly, they did so intermittently, were sensitive to outside interference, and with the solar collectors, did not work well in the late summer months when the collectors were in the shade for a fair portion of the day.

- The weatherproof housing worked well. In the 1997 tests, the enclosure was nothing more than a cooler rigged to house the spot speed measurement equipment; however, coolers to house the equipment for outside use can only be used temporarily. They will not survive repeated weather changes. Cabinets, such as those used for the1998 tests, are probably necessary if equipment is left out in the environment for more than a few months.

- Close spacings of the radar stations, say at 1-mile intervals, are most efficient to give accurate travel time.

- Charging of the gel cell batteries during the 1997 tests became tedious. Fully charged, the batteries were 12.8 volts. After a few days of powering the midpoint radars, RPUs, radios, etc., they discharged to around 11.8 volts. The batteries then needed to be recharged for approximately 6 hours to be restored to full voltage. This required a lot of time and effort as well as rendering the site useless for gathering data during the recharging period. For the 1998 tests, the solar panels used to charge the batteries were more trouble-free. In mid-summer, it was not necessary to ever turn off the radar system as the panels adequately recharged the batteries during the daytime. However, as the fall approached, the panels spent part of the day in the shade and failed to recharge the system completely. Only by disconnecting the radars for a day or more were the panels able to charge the batteries for system operation.

- If gel cell batteries are used, various ranges of voltages should be tested powering the radar detectors to determine when they stop detecting speeds. The  radar detectors seemed somewhat sensitive to voltage drops. This should be verified to give an operator an idea of the time period between recharging the battery.

- Testing should occur during varying degrees of congestion rather than for free flow conditions.

## 6.3 VIDEO-BASED DETECTION SYSTEM

Significant delays in completing a successful installation occurred primarily due to problems with the communications system. When using unconditioned leased lines (“dry” lines), a telephone network map should be available for review prior to finalizing the installation plans. It is believed that this would have eliminated the resulting delays. Other high bandwidth solutions may also require review with the provider of the communications infrastructure prior to finalizing plans for the installation.

- When using pan-tilt-zoom cameras, a controller must be provided for each site. When cameras are not provided by the sensor vendor, camera operation and view should be fully verified prior to attempts to install the sensor system. Toward this end, the sensor vendor should provide specifications for a nominal view and potential obstructions should be cleared at the time of camera installation to avoid a requirement for subsequent site visits and additional coordination of organizations.

- A pre-installation staging of all equipment to be installed would permit resolution of most potential integration problems more quickly and easily than is possible in the field, especially when equipment is geographically distributed.

- The following enhancements to TrafficVision are planned, and will improve the functionality of the system:

  – A software filter could be provided for outlying travel times. When flow is low, it is possible to significantly perturb the results with a single erroneous data point.

  – The upper limit on the time window was not functioning as intended. This will be fixed.

  – Additional video tape will be made for data collection during varying weather conditions, to help improve the system to become more robust under poor weather and lighting conditions.

## 6.4 CHANGEABLE MESSAGE SIGNS

The Precision Solar Controls solar message center used in the summer 1998 tests proved to be reliable and versatile. Although it was never used to display information gathered by the SDAS, during tests it showed that it was perfectly capable of doing so. Messages were manually sent from the SDAS control center to change the messages on the sign, and the system worked well. There were periodic problems in telecommunications lapses and the automated voice from the sign were difficult to understand. However, these problems appeared transitory and there was generally easy communication via cell phone.

- Direct communication between the SDAS and the changeable message sign remained untested, since there was never enough traffic congestion to cause a connection.

- The signs used were solar powered. Potentially the signs did not have enough power to charge the local controller. However during the test period, most days were sunny and the signs were located away from any sources of shade. Recharging the batteries from sunlight should not have been a problem but possibly could be addressed in other applications.

- The signs were placed at one location throughout the duration of the test. The signs may have been located in an area where the cellular telephone signal strength was not great enough to make a connection; however, each sign was visited, and the local controller indicated that the signal strength was at least 3/8=s of capacity. It is believed that signal strength was not the problem as far as making a phone connection with the central computer; however, signs could possibly be located in different areas on other tests to verify this.

# 7. FUTURE ACTIVITIES

This chapter of the report makes several recommendations regarding future actions for further development of the system. The tests conducted under this project provided valuable insight regarding applications of various technologies for travel time monitoring in rural areas. The bulk of this work consists of validating travel time calculations, using various data collection systems.

It is recommended that an operational test of an advanced traveler information system be conducted in an area where recurrent congestion is problematic. This could include approaches to national parks, seashores, ski areas, or at a construction zone where real time delay information could be useful for travelers. The purpose of this operational test should be to assess the impact of such a traveler information system to enhance mobility of rural travelers and reduce frustrating delays at the test site. As part of this operational test, the following field tests should be conducted for each of the data collection approaches discussed in this report.

- In general, some testing of all three data collection systems during heavy congestion periods are recommended.

- With respect to WIM technologies, the following work is recommended:

  – Test runs should be made with specific vehicles to evaluate matching performance when the vehicle speed differs from one site to the next and to find out the lowest speed at which matches can be made reliably.

- The following work with spot speed detectors are recommended:

  – If daisy chain communication is not desirable, additional ways of communication should be explored, possibly spread spectrum radio or telephone lines if available.

- Finally, for video based travel time computations, recommendations for future activity are as follows:

  – Additional testing should be conducted under various lighting and weather conditions. Additionally, remote camera control capabilities should be tested.

  – Additional testing over an extended period, including 24 hour operation, would be informative.