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16. Abstract

Monitoring freeway traffic conditions in construction zones is difficult. A 17.7 kilometer (11 mile) section of U.S. 59 (Eastex) Freeway from I-610 North Loop to Beltway 8 North in Houston, Texas is under construction and was chosen for this demonstration project. The selected sensor technologies were the Doppler Radar and side-fire microwave ranging. Wooden utility poles installed near the freeway lanes provided sensor placements. Mobility of the sensor is paramount. At report time, the equipment had been purchased, an electrical contractor chosen, and equipment was being installed.

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INTERIM TRAFFIC MONITORING SYSTEM ON U.S. 59 (EASTEX) FREEWAY: YEAR ONE REPORT

by

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Research Report 2900-1
Research Study Number 7-2900
Research Study Title: Interim Traffic Monitoring System on U.S. 59 (Eastex) Freeway Using Alternative Sensor Technologies

Sponsored by the
Texas Department of Transportation

December 1995

TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION STATEMENT

This report presents the initial project installation efforts of the two types of alternative traffic sensors used: Doppler radar and side-fire distance ranging microwave. The testing of several Doppler radar sensors provided useful project results which are presented. The majority of equipment installation was incomplete at report time.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes.

ACKNOWLEDGMENT

This report was developed as part of study 7-2900 "Interim Traffic Monitoring System on U.S. 59 (Eastex) Freeway Using Alternative Sensor Technologies" conducted by the Texas Transportation Institute (TTI) and sponsored by the Texas Department of Transportation (TxDOT).

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SUMMARY

The primary project objective is to use emerging technology in freeway construction sections to measure traffic flow status and communicate this information in a timely fashion to alert TxDOT to possible incident status conditions. To accomplish this task, a section of U.S. 59 Eastex Freeway undergoing major reconstruction provided the test sites for implementing traffic measuring equipment. Soon after contract signing, the project experienced a major funding reduction. This cutback caused a reduction in the scope of the project. The final five-site selections occurred between I-610 North Loop and Beltway 8 North interchanges. Two types of traffic sensors were selected: Whelen Doppler radar for speed measures and side-fire remote traffic microwave sensor (RTMS) for lane volume, lane speed, and lane occupancy at preselected time intervals for up to twelve lanes. To provide portability at short notice (which could happen in construction areas), the Whelen radar units provided battery power with solar panels for continuous daytime charging. The RTMS units required more electrical energy than could be reasonably provided by battery/solar charging panels.

Equipment specifications were developed. All specified equipment was competitively bid. In addition to installing all field equipment, the electrical contractor's bid required on-call maintenance for a two-year period. To prove that the Whelen radar sensors provided acceptable speed measures, a set of discovery tests were established. The former Bryan Air Force Base, now the Riverside Campus, provided the basic test site. The tests provided adequate speed measurements for approaching traffic. The positive test results indicated acceptable use on Houston freeways.

At present, all equipment has been purchased and tested in an office environment, and the electrical contractor is installing wooden poles at each selected field site.

INTRODUCTION

At present, Houston freeway systems are being rebuilt, extensively rehabilitated, or are currently in the planning process for rebuilding. The more recently completed freeway systems have surveillance, communications, and control (SC&C) systems included. SC&C on each freeway system will enable the Texas Department of Transportation (TxDOT), Houston District, and the other cooperating agencies (Metropolitan Transit Authority of Harris County, City of Houston, and Harris County) to monitor traffic conditions in the future TranStar Center. The traffic conditions monitoring, at present, includes both traffic sensors (loop detection and visual imaging processing) and visual information from closed circuit television (CCTV) surveillance. Those freeway systems currently under construction do not have the SC&C or CCTV infrastructure completed for any type of surveillance and do not support any monitoring activities. Therefore, when an incident occurs in these freeway construction sections, the only notification of such conditions are often from cellular telephone calls, the private traffic monitoring services, and police reports. These traffic incident conditions can exist for a considerable time period before reception and response. Thus, there is a need to provide traffic conditions detection and communications for those freeway systems that are undergoing construction activities. Those incidences in these construction zones require a quicker response than is now experienced. Traffic access areas may block access areas or require time consuming detours around the normal street systems in order to reach the incident scene. This research project supports this area of incident detection in a timely manner and communication of traffic condition measures to the TranStar Center.

Texas Transportation Institute (TTI) contracted to TxDOT's Houston District to purchase equipment, have the equipment installed, place the equipment into operations, and operate/maintain the equipment for five years. Local vendors or manufacturers contracted to provide the equipment and detection components. All were competitively bid. The installation contract award went to the low electrical contractor bid. The equipment has been partially installed at this reporting time of the contract.

In the early stages of the contract, the project experienced a reduction in funding from the Federal Highway Administration (FHWA) and TxDOT. This reduction decreased the expected equipment and roadway coverage by fifty percent. After the reduction of equipment and the roadway coverage, TxDOT Regional Construction Engineer's Office confirmed the final sites based on TTI recommendations. The freeway construction section selected was U.S. 59 (Eastex) Freeway between I-610 North Loop and Beltway 8 North interchanges (Figure 1). The five sites selected were instrumented with two types of sensors: radar and microwave. Field PCs installed at each site in pole-mounted cabinets enabled monitoring of traffic measures. The operation plan requires a master PC to operate at the Interim Traffic Management Center (ITMC) office and dial up each site via the installed telephone service. After connection through the telephone modem to the field PC, the master PC can continually monitor traffic measures. The radar sensors utilize Doppler technology to measure traffic speed in an approaching or departing direction (Figure 2). The microwave technology utilizes a side-fire (90 degrees signal delivery to the traffic direction) distance ranging signal that provides lane volume, lane speed, and lane occupancy by several selectable time intervals for up to twelve lanes over 61 meters (200 feet) distance (Figure 3).

The electrical contractor installed wooden poles at the right-of-way (ROW) boundary line, installed intermediate size cabinets, prepared equipment for electrical power and telephone service connections, and provided technical assistance to trouble shoot all installed equipment (see Appendix A). The Doppler radar sensors required installation adjacent to the freeway lanes in order to secure adequate speed measures. This near-the-freeway necessity required additional wooden pole implementation. To date, the final wooden poles and supportive equipment are being installed and placed into operation.

Information from the Doppler radar manufacturer was incomplete as to detection distances from the sensor at various angles of the approaching or receding traffic. A testing regime, conducted at the TTI Riverside Campus, provided operation evidence that the sensors would reliably function as intended. A complete test sequence conducted on two of six sensors performed adequately. The remaining four sensors utilized a 30 degree angle for approaching

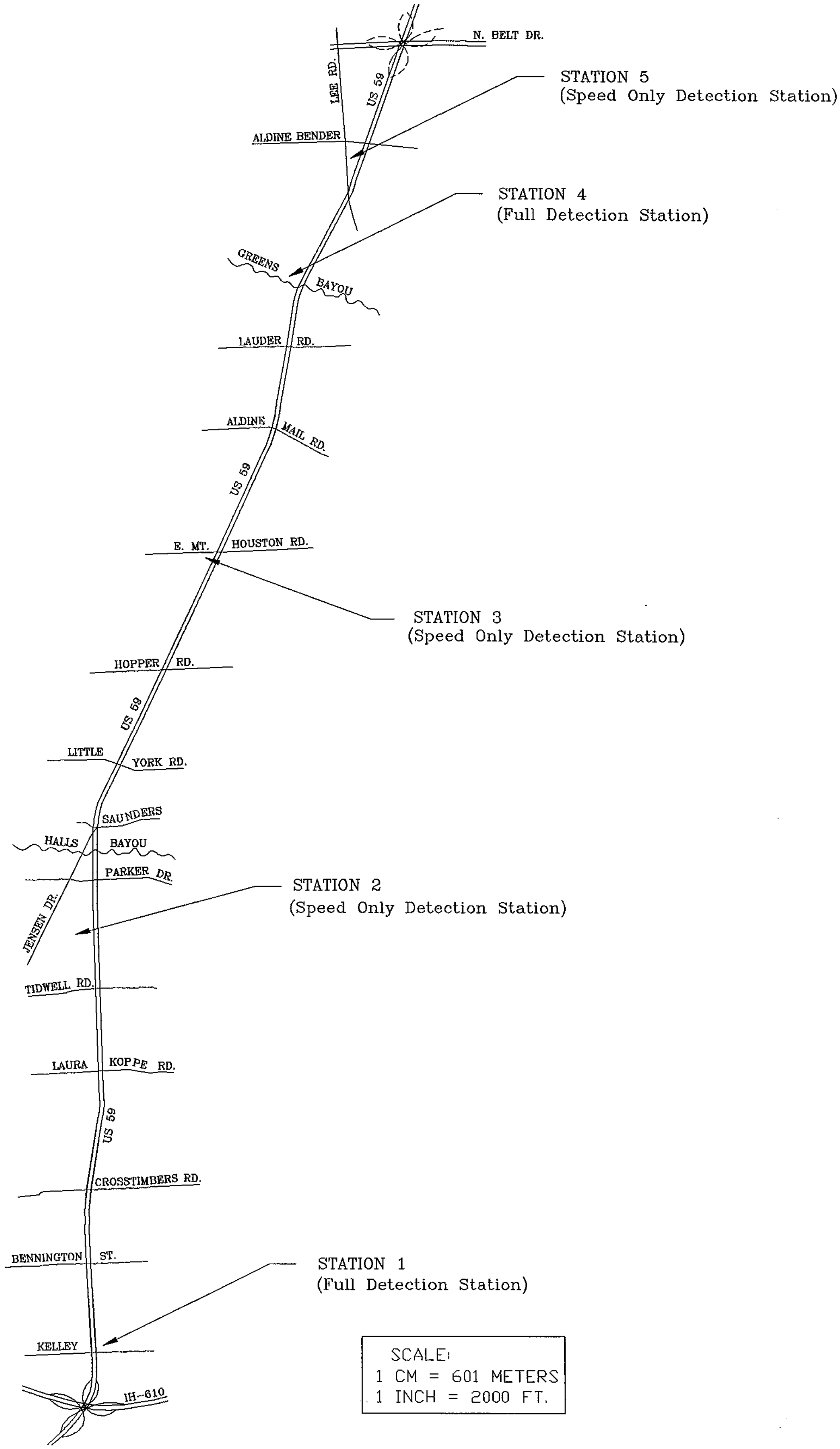


Figure 1. Eastex Freeway Project - Overview of Study Sites

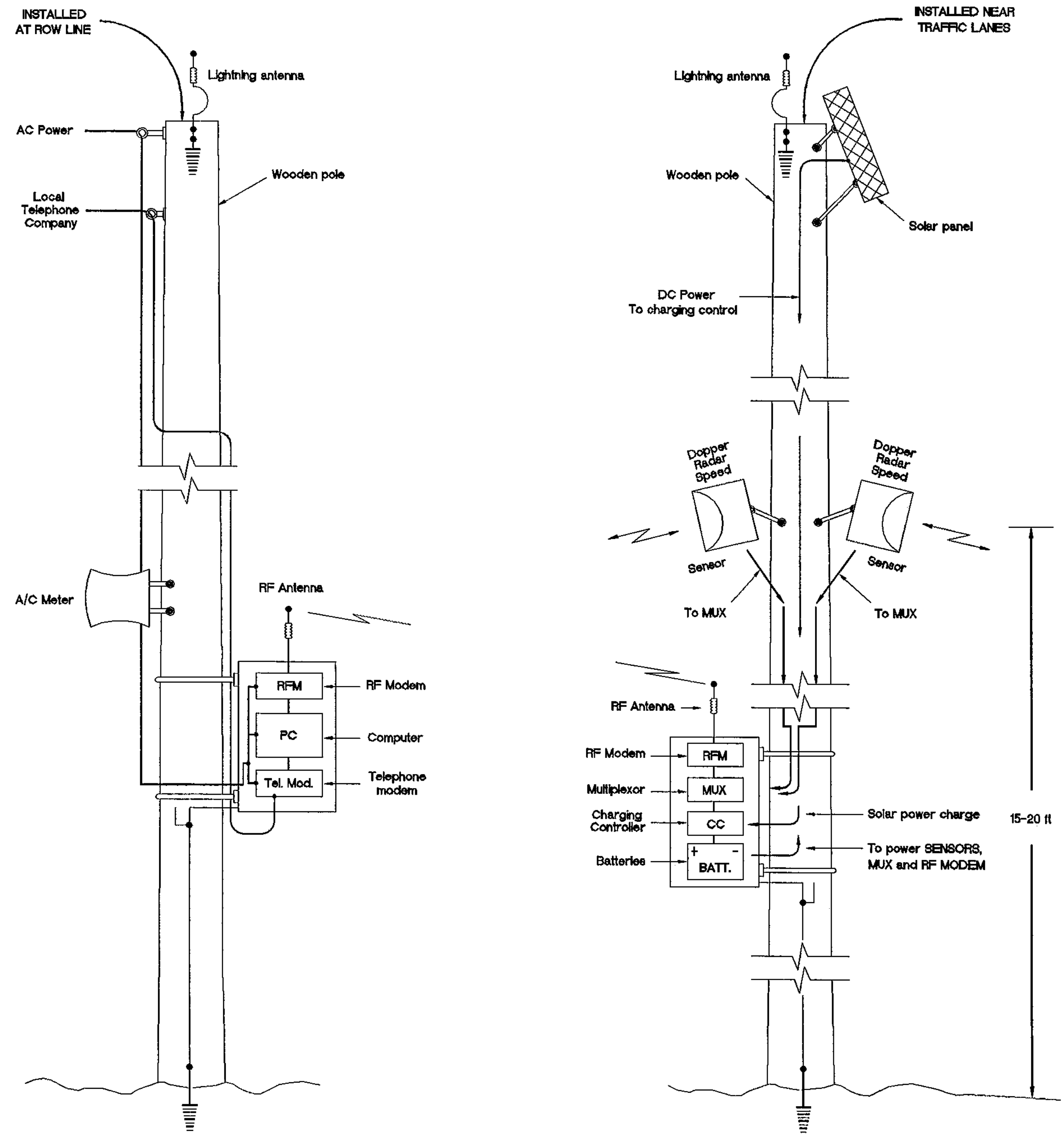


Figure 2. Typical Speed Site - Approaching or Receding Whelen Doppler Radar

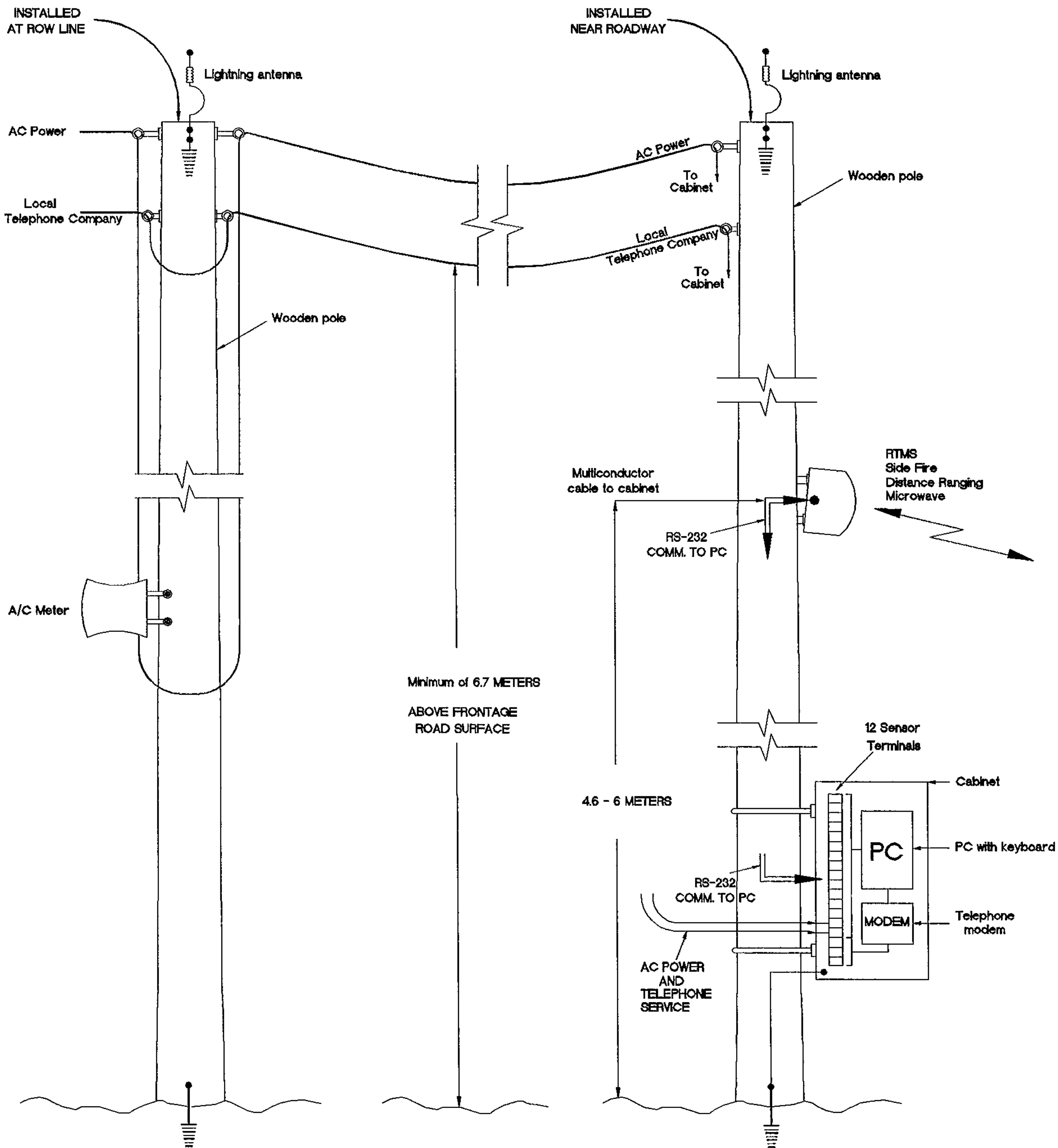


Figure 3. Typical Side-Fire RTMS Installation Site

and receding test vehicle movements. This angle represents the largest probable detection angle predicted in the Houston project. One of four sensors provided weak detection ranges and was sent back to the manufacturer for service. Upon return, each unit tested was accepted. In all cases, speed measures for approaching traffic always detected at greater distances from the sensor than did the departing traffic. The manufacturer provided no information as to why the sensor units performed in this manner. This information indicated selection of detection zones for approaching traffic rather than receding.

The final equipment installations are in process. Placing this equipment into operation is currently being completed. Final orders for connection of electrical and telephone services have been completed. The installation and initial operation aspects of the project are scheduled to conclude in the early phase of next year's project work.

PROJECT OBJECTIVES

The determination of the applicability of new emerging detection equipment for use in measuring traffic conditions at temporary locations in freeway construction zones serves as the primary objective. One of the first test items investigated develops the detection zones at angles from head-on (zero degrees off center) out to forty degrees off center. To accomplish the development of these detection zones required the field installation of the equipment at the Riverside Campus (formerly the Bryan Air Force Base). Once the equipment installation concluded, multiple test vehicle drive-throughs proceeded at prepositioned radar sensor angles to the approaching and receding test vehicle. The test vehicle traveled at a known speed for each drive through test. The distances and speeds from the sensor, measured with a laser radar "gun", provided Doppler radar sensor indications into and out of the radar's beam.

The second objective was to install and operate the selective equipment in freeway construction zones. The U.S. 59 (Eastex) Freeway from just north of the downtown central business district northwards to FM 1960 is in various stages of freeway reconstruction. This freeway section was chosen since this area was in long-term reconstruction. Also, the ten (10) sites chosen would enable the traffic measures taken from these sites to provide general information about the traffic status throughout this section. Previously, the only traffic reports received at the ITMC were from the public traffic reporting services, police reports, and telephone calls.

Budgetary reduction in funding required a major change in the project limits before the equipment could be purchased and installed. Finally, only five sites remained. Three of the sites used conventional Doppler radar and two sites provided side-fire ranging microwave signaling. These sites were chosen to yield spot traffic status reporting over standard public telephone commercial two-wire services. The selected freeway section for the project equipment installation to the final roadway sites are shown in Figure 1.

An additional objective is to operate the equipment over the project's time period while conducting calibration testing on the installed equipment for continued accuracy measures.

Freeway construction completions require repositioning roadside sensor equipment. To conduct this removal and reinstallation requires the availability of nearby construction zones on the Eastex Freeway. TxDOT may provide alternate sites along this corridor if freeway construction completion occurs before the project's termination.

The final objective includes the attainment and implementation of new, emerging detection equipment that can serve as stand-alone traffic measuring devices. These units must contain simplistic setup, portability, low power demands, communications capabilities, and competitive pricing. Several equipment types suitable for acceptance to the above terms are being researched at this time for possible inclusion.

STUDY DESIGN

The original study design depicted ten (10) detection stations on the U.S. 59 (Eastex) Freeway from just north of I-610 North Loop to the Greens Road overpass encompassing approximately 17 kilometers (11 miles) of coverage. TxDOT's Houston District and the Federal Transportation Agency (FTA) experienced a reduction and reallocation of Congestion Mitigation and Air Quality (CMAQ) and TxDOT matching funds. This funding modification dictated implementation of only half as many detection sites.

Figure 1 depicts the location of each of the final sites chosen after several field trips with TxDOT representatives, power, and telephone services personnel. Further complicating the selection process was the continual change in construction work which brought about traffic realignments that also affected the potential detection sites. After the selection process had been completed, the final sites chosen provided traffic monitoring at equal distance intervals. While not completely equalized, as shown in Figure 1, Stations 2 and 3 had an elongated separation distance. The primary reason was that from south of Parker to north of Little York is the roadway section between Stations 2 and 3, and it is continually elevated. Providing a temporary detection site in this elevated roadway section would be costly since wooden pole placements are difficult to secure in concrete. Attaching the detection equipment to any other above-the-roadway structures was not acceptable for various reasons, primarily cost, security, and detection zone placements.

Two types of vehicle sensing equipment, chosen because of availability, had not been used by TxDOT in a similar activity and did not require installation directly over the roadway lanes. The equipment chosen was the Whelen Doppler radar for speed measures in approaching or receding directions (Figure 2). The other unit was the Electronic Integrated Systems, Inc. (EIS) side-fire remote traffic microwave sensor (RTMS) unit that provides up to twelve (12) equal distance zones for volumes, speeds, and lane occupancy. Furthermore, the equipment mounted near the roadway on a wooden pole sufficiently above ground level afforded some measure of equipment safety from theft and be out of the way of wide loads possibly damaging the sensor. Figure 3 depicts the detector site when utilizing the side-fire

RTMS unit. For best detection, as suggested in the operations manual, sensor height mounting above the roadway surface requires distances from 4.6 meters (15 feet) to 5.5 meters (18 feet). The literature describes twelve (12) detection zones equally distributed across 36.6 meters (120 feet). The first detection zone should begin no closer than 4.57 meters (15 feet) from the base of the mounting structure. A multiconducter cable extends from the sensor head. The cable connects external power to the sensor and provides communications from the sensor's microcomputer to external communication devices. There are twelve (12) contact closures furnished by the sensor providing closure operations to an external computing device. The RTMS unit emulates a loop detector's solid state contact closure operation. In addition, a serial communication circuit enables the user to configure the sensor's detection zones with the aid of a laptop computer as well as exporting summarized volumes, speeds, and occupancy. The side-fire RTMS unit's control logic and the manufacturer's incomplete RS-232 communications logic implementation necessitates a roadside configuration in lieu of a possible remote access via a telephone modem. Power and telephone services connects the TxDOT right-of-way (ROW) area to the sensor pole at roadside. The total electrical power usage required by the sensor and the telephone modem was borderline if provided by the batteries/solar panels as used in the Whelen speed sensor applications. Side-fire RTMS equipment installations occur in only two of the five detection sites.

The second sensor type is the Whelen Doppler radar speed measuring sensor for use where traffic is basically advancing directly towards or away from the sensor position. This sensor device is very much like the long used Doppler radar unit operated by law enforcement personnel. These particular speed unit's initial applications provided speed measurements in construction and maintenance zones in Canada. A loud siren warns work personnel whenever a vehicle's detection exceeds the posted speed limit. The trailer mounted sensor had its own gas powered electrical generator to power both speed sensors and siren.

The Whelen Company had developed three types of radiating/collector sensor heads. These labeled units were wide beam, narrow beam, and medium beam. An early test in Dallas, where the radar units installed on the bridge overpass on the North Central

Expressway, found the narrow beam unit provided the best combination of sensing width, depth, and distance.

As depicted in Figure 2, two Whelen speed measuring sensors mounted on the same wooden utility pole direct the sensor's detection zones towards approaching traffic. On this same pole are the supporting equipment that maintains the radar sensors operation as well as providing the communication via spread spectrum radio units. The maximum distance between the radio frequencies (RF) units (transmitter-to-receiver) is 152 meters (500 feet). While this separation distance is not extensive, it does provide flexibilities to move either or both the roadside and ROW pole locations, which can be the determining factor between installation or no installation.

The basic functionality requires the solar powered cells to generate electrical current whenever exposed to the sun during daytime hours. The generated voltage powers a charging circuit and into the dual battery storage units. The batteries provide electrical energy to power the Whelen radar sensors, the RF modem, and a multiplexor. The multiplexor enables the two (2) radar sensors transmission through one RF modem. The multiplexor serializes up to a maximum of eight separate speed sensor values. The present applications require only two speed sensors per site. The RF transmitter modem receives the serialized information from the multiplexor and transmits to the RF receiver modem at the ROW pole cabinet. The solar panels and the battery units accommodate several days of operation without sunlight or without stopping detection and transmission. The energy generation and storage equipment performance necessitates reporting of its functionality during the project.

At the ROW pole installation, electrical and telephone services provides for the equipment operation. The RF modem receives the roadside transmissions and provides the serialized information to the PC. The activation of selected software programs in the ROW PC extends from the master PC in the ITMC. The basic program summarizes the speeds over a 20-second or 1-minute time period and transmits this information to the ITMC on demand. Another program enables the individual speed by sensor to be sent to the ITMC on demand. Also, a program provides time/date updates. The telephone modem provides for incoming or outgoing connections. One definite requirement is that the antenna for either RF modem must have "line of sight" without any type of blockage. During RF modem cabinet installation, the antenna had to have an outside hole drilled with the antenna installed. The antenna implementation required an outside installation with the remaining interior electronics connection included. The only uncluttered place in the cabinet interior was on the underside of the cabinet top. To install the antenna required drilling holes in the cabinet top. Each hole had water repellent polysealant adhesive liberally applied. Each RF modem's antenna had a clear line of site.

WHELEN RADAR SENSOR TESTING AT RIVERSIDE CAMPUS

The potential field applications where reliable detection must occur depend on the distances and angles between the sensor and vehicles. The detection yields a vehicle's speed measure based on the vehicle's movement in relation to radar detection beam. The manufacturer provided few actual test results on which to determine mounting angles, heights, and detection distances. Therefore TTI conducted more extensive tests at the Riverside Campus. The tests performed determined the detection distance limits, the range of the detection angle off a direct approach (or a directly receding direction) and speed corrections based on the detection angles. This information would be the minimum necessary to plan for the actual field site selections.

The Riverside Campus provides an excellent physical plant for conducting this test. The former air base has concrete aprons and runways laid out in a general north-to-south direction. The tests occurred in the apron area, which was clear of any obstacles that would interfere with test vehicle movements. The apron area construction consisted of concrete rectangular blocks 3.8 meters (12.5 feet) in the east/west direction and 7.6 meters (25 feet) in the north/south direction. An area longer than 250 meters (greater than 1,000 feet) was available as depicted in Figure 4. A metal pole, installed at the southeast corner of the test area, provided space for one Whelen radar sensor on this pole 3.4 meters (11 feet) above the concrete surface. The sensor's programming only detected approaching vehicles. After the conclusion of all test runs in the approaching direction, the sensor's directional detection program was reversed to the receding direction. Upon the detection direction reversal, the receding traffic measures provided additional data. Each set of the test vehicle's travels was started in lane 1 nearest to the sensor pole and moved westward on each travel run. At the metal pole, an observer recorded when the sensor first detected the vehicle, the vehicle's speed, and when the vehicle was no longer detected. Table 1 indicates the recorded measures. A second person stationed directly west of the metal pole straddled the concrete edge line of the rectangle block in which the vehicle was traveling. Upon notification by the person at the metal pole that the vehicle was detected by the Whelen radar unit, the lane line person used

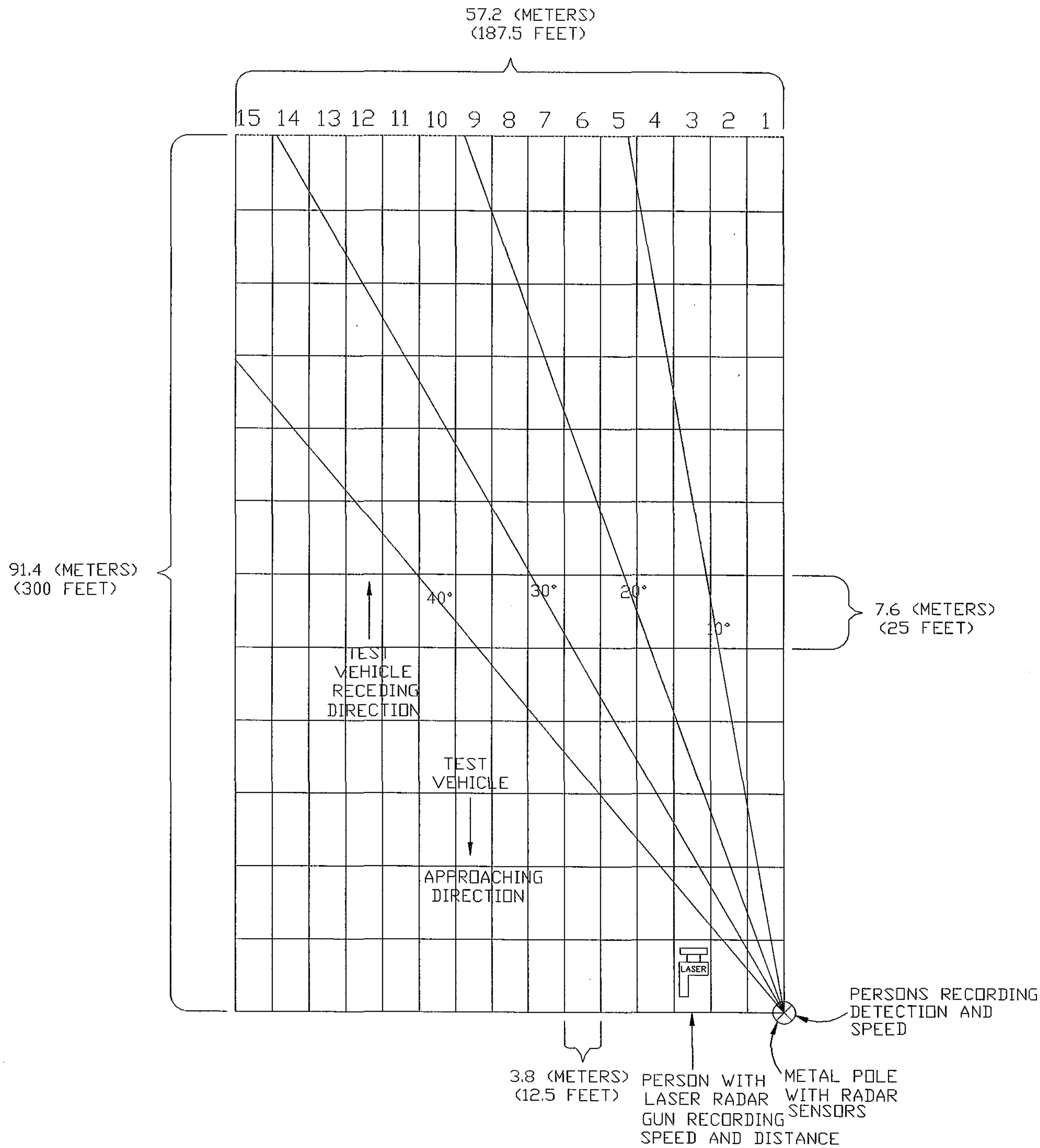


Figure 4. Test Setup for Whelen Radar Sensors

TABLE 1. WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005 Height 3.4 meters (11 feet) S.N. 524
Angle 30 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
LANE	FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5		43 (27)	4.6 (15)	0	Approaching
2	25.0		45 (28)	9.1 (30)	0	"
3	37.5		none			"
4	50.0	50 (31)	46 (29)	13.7 (45)	0	"
5	62.5	50 (31)	50 (31)	28.0 (92)	4.6 (15)	"
6	75.0	51 (32)	48 (30)	32.0 (106)	14.3 (47)	"
7	87.5	51 (32)	48 (30)	40.5 (133)	20.7 (68)	"
8	100.0	56 (35)	53 (33)	47.2 (155)	27.7 (91)	"
9	112.5	56 (35)	50 (31)	50.6 (166)	33.2 (109)	"
10	125.0	53 (33)	48 (30)	55.8 (183)	37.5 (123)	"
11	137.5	53 (33)	48 (30)	64.0 (210)	47.8 (157)	"
12	150.0		none			"
13	162.5		none			"
14	175.0					"
15	187.5					"
1	12.5		none			Receding
2	25.0		none			"
3	37.5		none			"
4	50.0		none			"
5	62.5	55 (34)	43 (27)	57.6 (189)	81.7 (268)	"
6	75.0		none			"
7	87.5	51 (32)	38 (24)	67.0 (220)	82.6 (271)	"
8	100.0		none			"
9	112.5		none			"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

the laser radar "gun" to denote the distance to the moving test vehicle and noted its speed. When the Whelen radar sensor observer noted that the moving test vehicle was no longer being detected, the observer notified the lane line person. The lane line person used the laser radar "gun" to record the distance to the moving vehicle. These measures are shown in Table 1. Detection of the test vehicle's speed occurred in two ways: the Whelen device measured the speed at an angle to the travel line direction while the laser hand-held sensor measured the speed "head-on" or directly approaching or receding. The laser radar speed measures are the "true speeds" while the Whelen speeds require modification by the cosine of the directional angle. Appendix B indicates the results of tests for two sensors at angles of 0, 10, 20, 30, and 40 degrees. As the Whelen radar beam moves from 0 degrees to 40 degrees, the detected radar speed reduces relative to the true "head-on" speed. Corrections to the Whelen speeds should be a function of the cosine of the angle between the vehicle's direction of travel and the radar beams direction relative to the vehicle's travel direction.

The creation of Figure 5 stems from the measures recorded in Table 1. As the test vehicle progressed from lane 1 to the other adjacent lanes, the recording of the detection distances occurred. The plotting of the distances denoted when just being detected and not being detected creates a beam zone for detection as shown in Figure 5. The beam zone displacement from the actual beam direction occurred as the delay developed between recognizing detection by the pole observer and notifying the lane line observer. At 9.1 meters per second (30 mph or 44 feet per second), several seconds of delay will explain the beam zone displacement.

The testing results are shown in Appendices B and C. For almost all examples, more vehicular detection occurs in the approaching direction than in the receding direction. The manufacturer has no explanation of this inequity. The approaching direction provided adequate detection distances [at least 61 meters (200 feet) at 30 degrees], which enabled the decision to use the Whelen radar sensors in Houston.

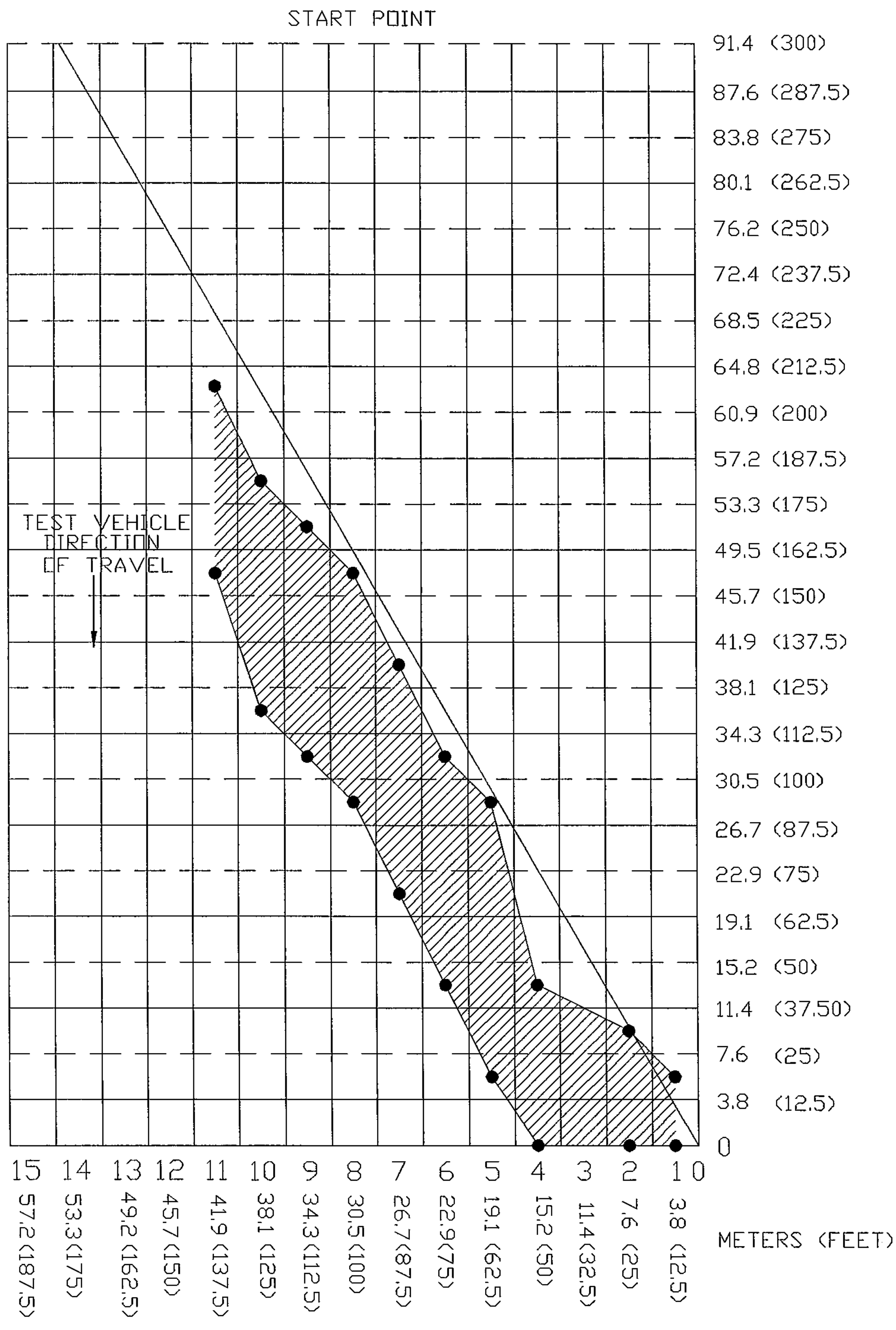


Figure 5. Plots of Detection Distances by Approaching Test run in Relation to the Radar Detection Angle of 30 Degrees Date 5/18/95 Sensor 524 at 30 Degrees

One other component group in the Whelen radar units operation remained untested. These vehicle detection devices must be adjacent to moving lanes of traffic so the speed measures are as accurate as possible. These lanes may be in construction zones. In some cases, the sensor setup requires, at short notice, immediate pole moving action. To make these units as mobile as possible, storage batteries and solar charging cells implementation provides power for the radar sensors, multiplexor, and RF modem. The solar cells and batteries choice by Whelen provides the required electrical energy for two weeks of total darkness. Only actual operating time will determine if the solar charging and batteries were properly sized and implemented.

The EIS's RTMS unit had been presented to TxDOT in a prior demonstration as a possible candidate for visual imaging vehicle detection system (VIVDS) replacement. While this demonstration was only one week of operation, it presented several interesting possibilities. Those traffic detection applications where every vehicle's detection need not be measured would possibly have an application in this project. The unit is working in other states. Therefore, the RTMS equipment was determined to be usable in the Houston project.

CONTRACTING

EQUIPMENT

TTI solicited bids on equipment items that cost more than $1,000. Several of the items, if separated from the overall project, would have cost much less than the maximum upper limit of $1,000, yet the University Purchasing/Contracting Services required all items to be bid. Table 2 contains the actual bid prices of the separated items. There was an item that required the vendor to package (and guarantee functionality) several components into a complete system unit. The radar speed sensor unit specified at least two speed sensors per unit connected to a multiplexor unit capable of monitoring and reporting from more than one speed sensor. Connected to the multiplexor was a low power spread spectrum radio frequency (RF) modem. A National Equipment Manufacturers Association (NEMA 4) cabinet included two (2) storage compartments. In the lower sealed compartment were two chargeable gel cell batteries. Included in the top compartment were an adjustable voltage regulator circuit, radar sensors multiplexor, and the RF modem. Required were the batteries with the solar charging equipment as the speed station is designed to be attached to a wooden pole placed near the freeway lanes but without electrical AC power. The speed sensors required placement of 3.4 meters (11 feet) above the roadway surface and in line with approaching or receding vehicles in order to record acceptable speed measures. As such, securing electrical power and telephone services would require expensive overhead or underground access because, in some locations, the roadside pole with the sensor unit separation from the meter pole at the ROW line exceeded 152 meters (500 feet) or more. The RF modem provides communications between the sensor cabinet and the ROW pole cabinet. Therefore, the vendor supplying the Doppler radar sensors must also supply the other component equipment along with the interface compatibilities. This vendor must deliver the speed measures to the ROW cabinet (where a PC will collect the speeds).

The only other biddable equipment that required multiple component integration were the large cabinets for the side-fire ATMS sensors. The cabinet vendor had to supply extra terminal strips installed on the inside cabinet wall. The ATMS unit can provide up to twelve lanes of detection and data available through twelve solid state contact closures. The terminal strips provide connection points between the ATMS contact closures and a potential 16-channel digital input card residing in the field PC. Inclusion of this digital input card remains a future implementation. While the ATMS unit can provide summarized volume, speed, and occupancy information at preselected time intervals, the contact closure operations can make available to the field PC real-time data collection possibilities. The only requirements for the RTMS unit for this project was to supply one-minute volume summaries, one-minute occupancy measures, and a one-minute average speed. Each measure was to be by lane (detection zone).

INSTALLATION

The installation of different detection equipment and associated components satisfactory to the requirements and procedures of TxDOT and other governing agencies (City of Houston, Harris County, State of Texas, etc.) required an electrical contractor (EC). TTI created a set of specifications concerning the requirements for the EC to accomplish. TxDOT reviewed the document. Because of ease of installation and possible frequent movement of traffic in the construction area, this area required wooden service poles. TxDOT requested minimum standards for the poles. The specifications as adapted for this application (Appendix A) included the wooden pole minimum standards.

The EC must know the procedures for locating where to drill holes on TxDOT right-of-way (ROW) areas because aerial and underground utilities also share this space. The EC has the responsibility to provide maintenance with problem determination included with repairs for up to two years on a time and materials base. The equipment operation and functionality is the responsibility of TTI. If a pole requires moving (due to traffic movement change required by roadway construction), the EC has proposed a pole movement charge.

TTI had to solicit bids on the detection and related equipment and accumulated said equipment for the EC's use. The same vendor provided Items 1 and 3 in Table 2. The first equipment purchased, delivered, and tested was Item 5 (personal computers). Item 1 (side-fire

RTMS sensors from EIS) required test programs completed and applied by TTI. The connector pins between the sensor and the field PC required changes. EIS, Inc. provided an update operational program. The RTMS units successfully tested in an office environment did not require additional effort. The selected vendor for the telephone modems (Item 4) ceased business operations after being awarded the contract. Discovery of this discrepancy required four weeks duration. The second lowest bidder agreed to supply the modems at its bid price. Within ten working days, the vendor supplied the telephone modems. The modems were tested in the office environment and found acceptable.

TABLE 2. COST PROJECTIONS FOR PROJECT EQUIPMENT

ITEM		QUANTITY	UNIT PRICE	TOTAL
1.	EIS (RTMS Ranging Radar)	2	$5,000	$10,000
	Cable	2	150	300
2.	Doppler Radar Sensors	6	846	5,076
	Multiplexors per Two Sensors	3	1,186	3,558
	Two Batteries per Location	6		
	Solar Cells/Charging Device per Location	3 } 3	3,400	10,200
	Cabinets	3		
	Cables (set)	3		
	RF Modems (set of 2)	3	1,300	3,900
3.	Aluminum Welded Cabinet with Connectors, Power Strip, etc.	5	2,500	12,500
4.	Telephone Modems	10	129	1,290
5.	PCs	5	828	4,140
	PC (extra memory and digital input board)	1	1,140	1,140

The Item 2 (Doppler radar sensors) vendor had to assemble various components (solar panels, gel cell DC batteries, cabinets, charging circuit, multiplexor, and radio modems) and undergo field testing of the Doppler radar units at the Riverside Campus. Several of these units had deficiencies, which required sending those units back to the vendor for modifications. After several months, tests of Item 2 equipment concluded. The equipment was assembled and transferred to Houston. In Houston, computer programs were written to test the Doppler radar, multiplexor, RF modems, and telephone modems. Testing revealed that the multiplexor and RF modems were malfunctioning. An RF modem unit was sent back to the vendor for adjustments under warranty. The vendor found no problem(s). All gel cell DC batteries were new, unused, and not assumed to be the problem. The DC batteries in each of the three units became suspect. Testing the batteries revealed low amperage, which resulted in all batteries receiving a charge. Afterwards, the RF modems and multiplexors operated correctly. The communications from the Doppler radar sensors through the multiplexor to the RF modem through the field PC operated to satisfaction in the office environment.

Item 3 (aluminum welded cabinets) when compared against the specifications met or exceeded same. All interior components were supplied as specified and included mounting brackets for strapping the cabinet to the wooden poles.

The EC's responsibility included contracting the local utility coordinating committee for the location of above and below ground level utilities. The sensor poles did not require specific installation site(s) and, as such, could accommodate relative small changes (up to several meters) if permanent utilities already existed. And in several locations, the right-of-way meter poles required movement from the original setting, so as to relieve the aerial utilities congestion. The first installation date had to be on a Sunday morning because of the reduced mainlane traffic demand. The East Mount Houston overpass location did not require a freeway lane closure, but it did require a emergency lane closure. This emergency lane closure did not unduly limit the normal traffic flow in any way.

The first pole installed was at the Kelley location as shown in Figure 1. This site required installing an ATMS side-fire microwave ranging unit near the mainlanes. Current construction has opposing traffic separated by about 30 meters (100 feet). The ideal location for the roadside sensor pole should have been about 4.5 to 5.5 meters (15 to 18 feet) from the first detection zone. Because of the frontage road placement and width, there was not sufficient non-pavement area between the mainlane and frontage road to set the roadside pole. To gain the utility of this immediate area required the installation of the roadside pole. Incomplete coverage of both directions may be the resultant of this decision. After the roadway is rebuilt and opposing traffic lanes move towards the center of the overall right-of-way, a detection advantage requires sensor station movement. The roadside pole had the lightning protection attachment installed.

The installation of the second roadside pole occurred at Station 5, which is near Aldine-Bender Road (see Figure 1). The lightning protection attachments required installation. While at this site, a damaged hydraulic hose on the auger drilling equipment required replacement which delayed the EC's work for two-plus hours.

The third and final pole installed on this Sunday was the roadside pole near Sparks Street at Station 2. The only attachments secured to the wooden pole were the lightning rod, the conducting wire braid cable, and the ground rod. For all practical purposes, work stopped for the duration of the fiscal year, which ended on the last day of August 1995. At this location, the drill truck had to sit on new pavement in an acceleration lane servicing an (as yet opened) entrance ramp. The drill truck's potential position on the median's severe slope discouraged the EC's use. The drill truck's position in the closed acceleration lane did not influence traffic even after 12:00 noon. Typically, traffic flow rates were in Level of Service B or better at all times. The pole trailer utilized the inside lane of the three-lane service road. Frontage road traffic in this area was almost non-existent. No traffic queues developed as frontage road traffic was typically three or four vehicles per minute. Barrel and cones were setup in both roadways in advance of the work areas. The actual time to drill the hole and install the pole normally took about one hour.

INSTALLATION PROCEDURES

The most difficult items to install were the wooden poles. Each pole was 12.19 meters (40 feet) in length with the average installed depth of 2.44 meters (8 feet). The work personnel experienced an additional hardship. Recently, the wooden poles had been creosote treated as required in the specifications. Due to the daily heat generated in the daylight hours, creosote evaporation from the wood created strong fumes. The fumes seemed to collect on any exposed skin area or in the breathing passage. These fumes caused itching and irritation of all exposed skin even forming temporary skin rashes. No long-term disabilities existed. The immediate effect was for the personnel to become more concerned with personal comfort than work efforts and details. The purchase of future wooden poles will require investigation of alternate wood treatment chemicals.

The ROW areas were, for the most part, level and accessible. The roadside pole locations were more difficult to drill for two sites (Sparks and E. Mount Houston) because each site was on an inclined embankment. Figure 6 presents the relative lengths of the pole at the pole unloading equipment. Figure 7 depicts the intermediate auger depth located just behind the concrete median barrier (CMB). The pole setting equipment deployment is shown in Figure 8 along with the hand-by-hand tamping with fill dirt for a typical pole. Each pole has a lightning rod conducting wire and grounding rod implementation as shown in Figure 9 along with the solar panel installation. Included with the top of the pole solar panels were the Whelen radar sensors (Figure 10) securely installed approximately 3.0 meters (10 feet) to 4.6 meters (15 feet). Near the bottom of the pole is the pole mounted two-compartment equipment cabinet (Figure 11). Figure 11 indicates venting for the battery compartment on the bottom portion of the cabinet, while the top compartment has a snug fit. The RF modem's antenna is shown mounted through the top of the cabinet. Figure 12 presents the Whelen radar sensor pole with all equipment components as they were installed.

The electrical contractor's personnel prepared the equipment to accept the electrical power connection as presented in Figure 13. Each ROW pole required similar wiring connections.

Figure 6. Unloading a Creosote Wooden Pole

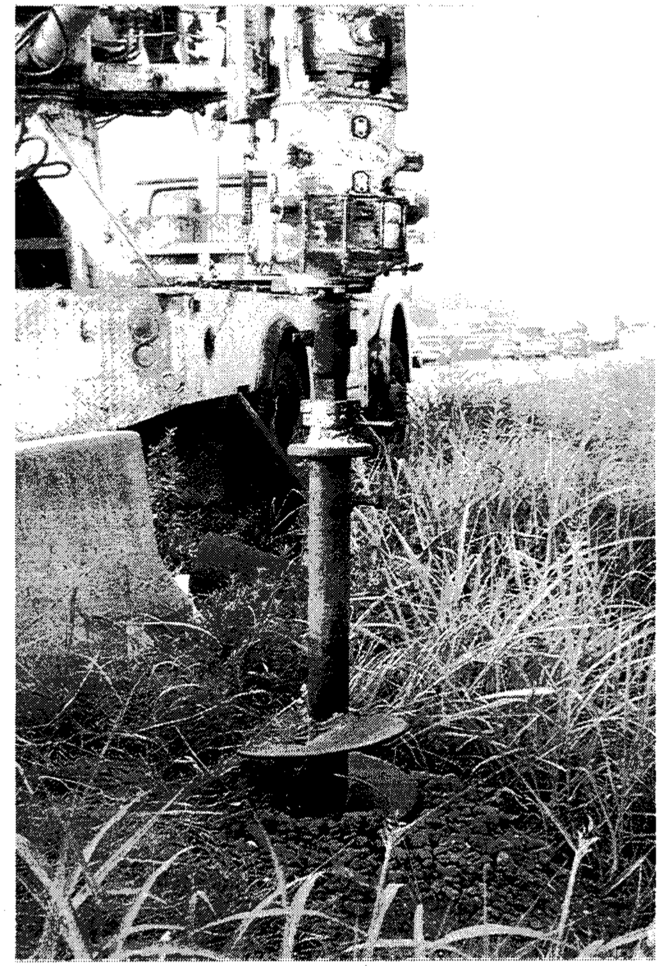


Figure 7. Intermediate Auger Depth

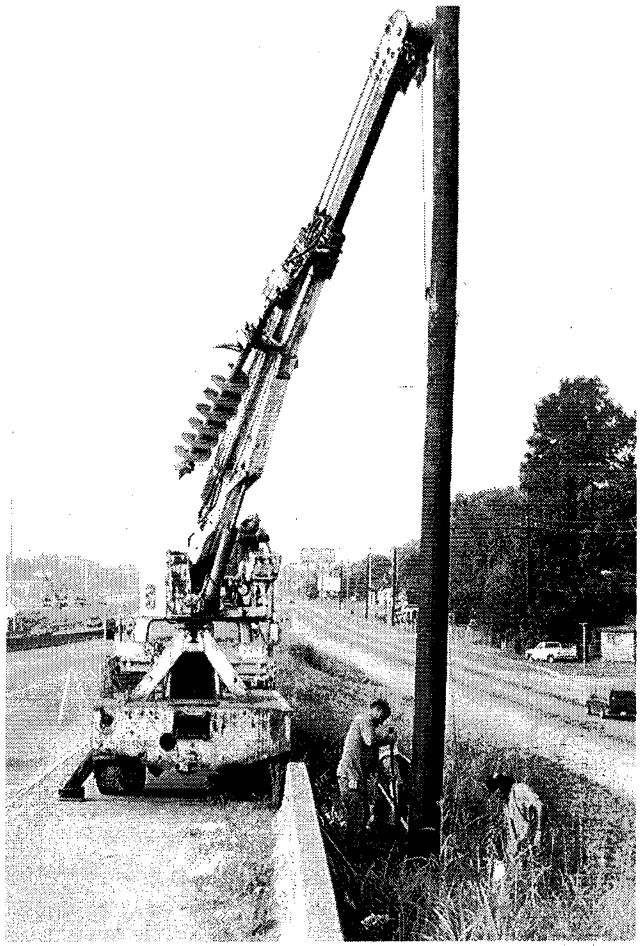


Figure 8. Equipment Deployment along with Manual Tamping Activities

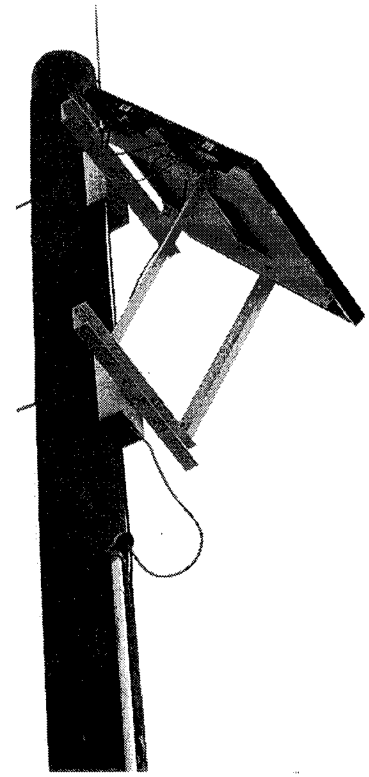


Figure 9. Typical Solar Panel Installation

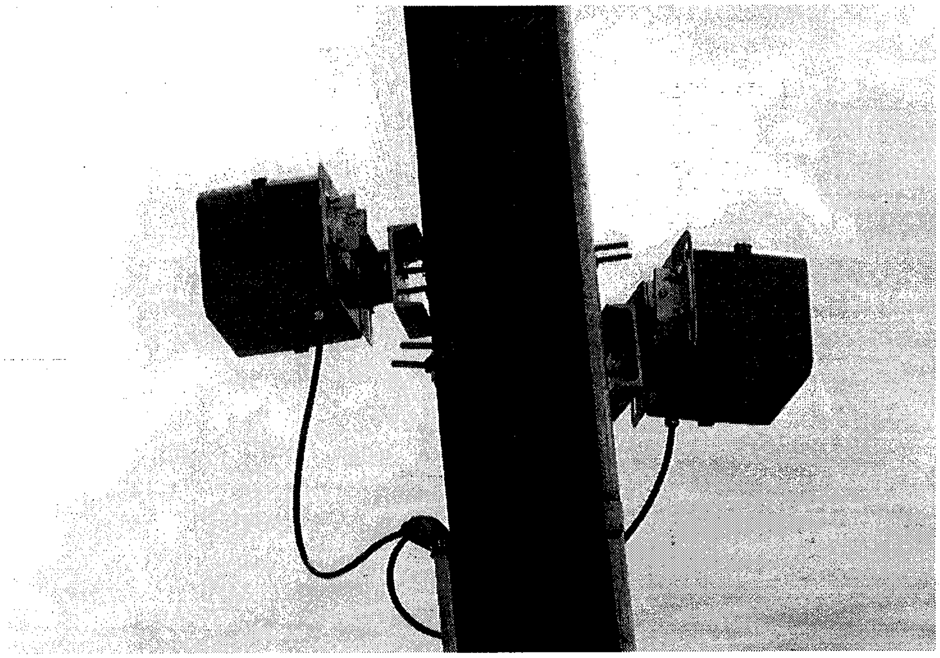


Figure 10. Two Whelen Radar Units Installed on the Same Pole

Figure 11. Whelen Furnished Cabinet with Separate Battery Enclosure and RF Modem Antenna Exposed

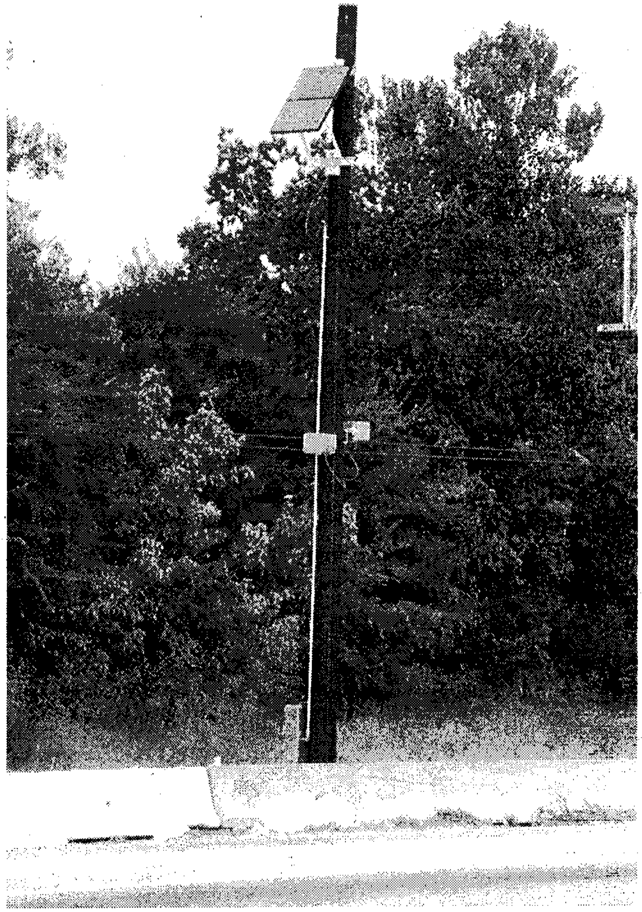


Figure 12. Roadside Dual Whelen Radar Sensors Located at Station 5 (near Aldine-Bender Road)

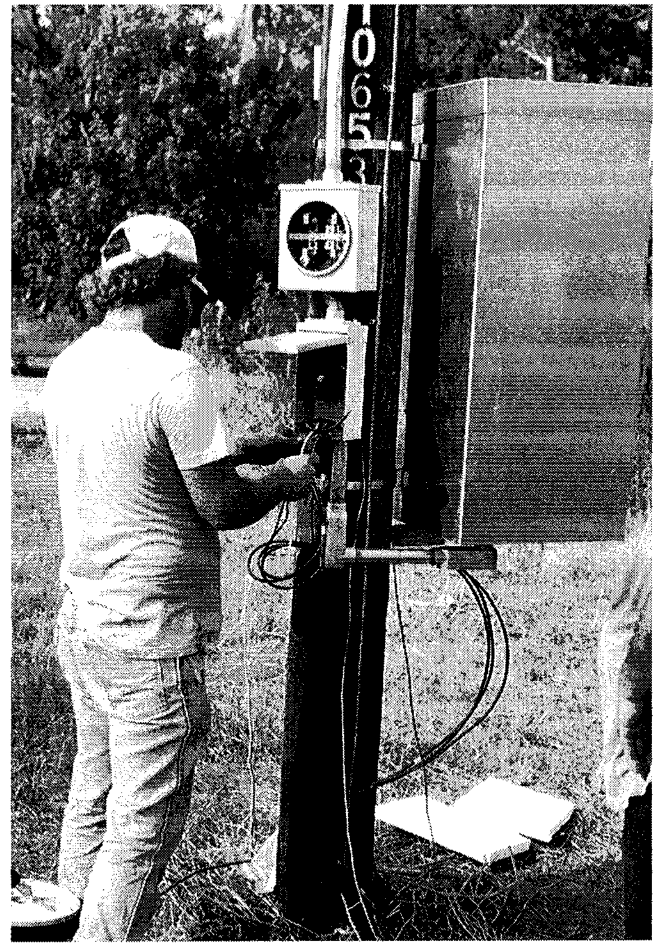


Figure 13. Wiring Electrical Service through the Breaker Box

The connection for electrical and telephone services, when provided to the roadside cabinet for the RTMS unit, is shown in Figure 14. The conduit provides electrical power in one and the telephone connection in the second conduit. The RTMS sensor's mounting height is near 3.7 meters (12 feet) above the roadway and 12 meters (40 feet) or more from the closest moving lane of traffic.

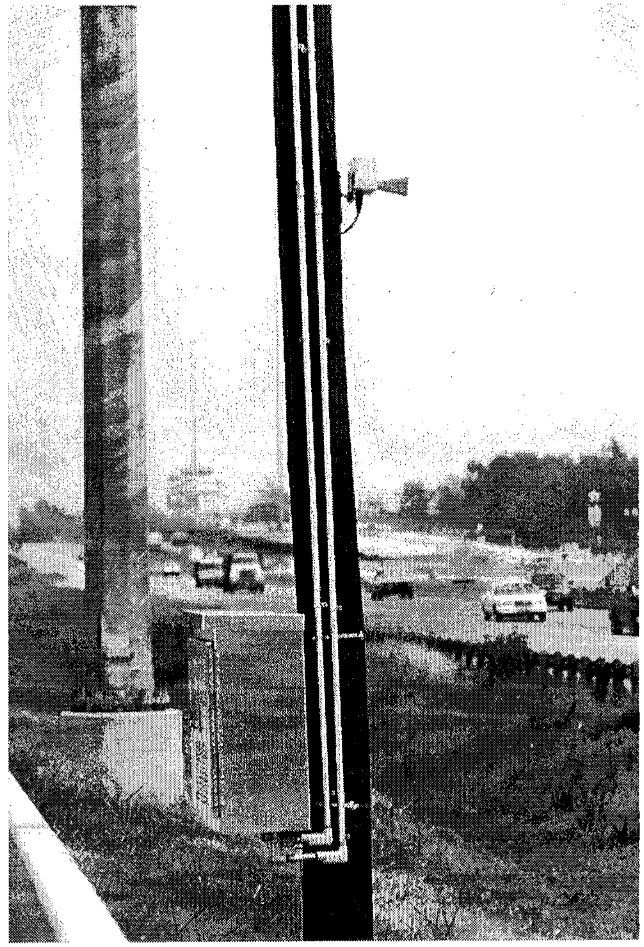


Figure 14. EIS's RTMS Equipment Pole Mounted at Greens Bayou Location (Station 4)

CONCLUSION

The primary project objective is to use emerging technology in freeway construction sections to measure traffic flow status and communicate this information in a timely fashion to alert TxDOT to possible incident status conditions. To accomplish this task, a section of U.S. 59 Eastex Freeway undergoing major reconstruction provided the test sites for implementing traffic measuring equipment. A major funding reduction for this project occurred soon after contract signing. This caused a reduction in the scope of the project. The final five sites selected fell between I-610 North Loop and Beltway 8 North interchanges. Two types of traffic sensors selected provided: Whelen Doppler radar for speed measures and side-fire remote traffic microwave sensor (RTMS) for lane volume, lane speed, and lane occupancy at preselected time intervals for up to twelve lanes. To provide portability at short notice (which could happen in construction areas), the Whelen radar units required battery power with solar panels for continuous daytime charging. The RTMS units required more electrical energy than could be reasonably provided by battery/solar charging panels.

A set of equipment specifications required acceptable competitive bid quotes. In addition, an electrical contractor's bid quote included installing all equipment and providing on-call maintenance for two years. To insure that the Whelen radar sensors would provide acceptable speed measures, a series of tests at the Riverside Campus, which is the site for the former Bryan Air Force Base, resulted in providing adequate speed measure detections for approaching traffic. The Whelen equipment was installed in Houston.

At present, all equipment has been purchased and tested in an office environment, and the electrical contractor is installing wooden poles at each selected field site. The two alternative traffic sensing equipment chosen for this project have not been field installed and, as such, have no operational experiences to which evaluational issues can be addressed.

APPENDIX A.

ELECTRICAL CONTRACTOR REQUIREMENTS

INVITATION TO BID

Mail Sealed Bid to ⟶ **Texas A&M University**
Department of Procurement and Materials Services
Agronomy Road
College Station, Texas 77843-1477

BID MUST BE SUBMITTED ON OR ATTACHED TO THIS SIGNED FORM.

Bid Opening Date: March 22, 1995 at 2:00 p.m.

Bid Invitation Number: R125058 Re-Bid

Show Bid Opening Date and Bid Invitation Number in lower left hand corner of sealed bid envelope and show return address of firm.

Bidder **Must** Fill in & Sign **Vendor ID #** ☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Name of Firm, Company

Mailing Address

City State ZIP

Phone Number FAX Number

BUSINESS SIZE (see definitions on reverse side)
Check where applicable
☐ Small
☐ Large
☐ Minority (please specify:)
☐ Black ☐ Hispanic ☐ Woman-Owned ☐ Asian Pacific ☐ American Indian

Print or Type Name Title **Authorized Signature** Date

By signing this bid a bidder affirms that he or she has not given, offered to give, nor intends to give at any time hereafter any economic opportunity, future employment, gift, loan, gratitude, special discount, trip, favor, or service to a public servant in connection with the submitted bid. By signing this bid form, a bidder acknowledges the Information for Bidders on the reverse side of this bid invitation. Failure to sign the bid, or signing it with a false statement, shall void the submitted bid or any resulting contracts, and the bidder shall be removed from all bid lists.

Item No.	Item & Description	Quantity	Unit	Unit Price	Extension
	If quoting other than the item(s) specified, descriptive literature and/or specifications must be enclosed. TEXAS A&M UNIVERSITY RESERVES THE RIGHT TO REJECT ANY AND ALL BIDS OR ANY PART THEREOF.				
	Bid to install VEHICLE DETECTION SYSTEM on the U.S. 59 Eastex Freeway in Houston, TX from F.M. 525 to I-610 North Loop Freeway per the attached specifications, requirements, and general statement of work.				
	<u>INSTALLATION</u> (Including all labor and materials)				
1.	Station 1 (Full Detection)	1	ea		
2.	Station 2 (Speed only detection station)	1	ea		
	Option (if required) with AC service meter and pole	1	ea		
3.	Station 3 (Speed only detection station)	1	ea		
4.	Station 4 (Full detection station)	1	ea		
5.	Station 5 (Speed only detection station)	1	ea		
	Option (if required) with AC service meter and pole	1	ea		
	ALL BIDS FOB DESTINATION. TRANSPORTATION CHARGES BORNE BY SELLER UNLESS OTHERWISE NOTED. If freight charges are not included in bid price, please show estimated cost.				

TERMS: ______________ FOB: DESTINATION DELIVERY IN ______ DAYS **TOTAL**

<u>STATE SALES TAX EXEMPTION:</u> "Purchases made for state use are exempt from the State Sales Tax—Art. 20.04 (F) 3, Chapter 20, Title 122A—Taxation, General, R.C.S. 1925, as amended by the 57th Legislature first called session, 1961. **<u>DO NOT INCLUDE TAX IN YOUR BID.</u>**
The State is exempt from Federal Excise tax.

NOTE: See reverse side for specific bid conditions.

Joseph White
Procurement Services

Phone 409/845-4534
FAX 409/845-3800

FD219/211 — REV. 8/'93

Item No.	Item & Description	Qty	Unit	Unit Price	Ext
	SYSTEM MAINTENANCE (for 3 years from installation)				
6.	Hourly charges with the following stipulations: Estimate to Maintain the System for 36 Months. TTI proposes to contract for the services of an electrical contractor to maintain the vehicle detection system o the U.S. Eastex Freeway from I-610 North Loop to Beltway 8. For the system described in items above and the quantities indicated, the bidder should provide an hourly cost estimate to provide maintenance to the system over a three-year period with the following stipulations: • TTI will not be responsible (pay for) repairs or replacement of any equipment or parts supplied by vendor during installation. • The hourly cost will not include the costs to repair the equipment supplied by TTI, but will include the cost of replacement of a defective unit with spare parts or equipment supplied by TTI. • Malfunctions of the system resulting from failure of vendor supplied components or equipment must be repaired within 24 hours. • TTI will not pay for service calls to repair or replace vendor supplied components or equipment. • Any malfunction must be responded to within 24 hours. In the event of failure or malfunction of TTI supplied equipment, vendor shall remove the equipment and return it to the Houston TTI office. Vendor will re-mount equipment after repairs are made by TTI. **MAINTENANCE: $________/HOUR** 144	hrs			
	Optional Quotes (will not be figured in the award of this bid)				
7.	Relocation of any one of the "speed only" sites during the 36 month period (min. of 3, max of 9 of estimated)	1	ea		
	BASIS OF AWARD This basis of award for this order will be the total cost for installation (items 1-5) plus the cost of maintenance based on 36 regular maintenance calls of 4 hours each. Prior to beginning work, successful bidder must submit current and valid insurance certificates indicating coverages per the attached requirements. Any and all expenses must be delineated on this bid document or an attached proposal. Only charges for items/services indicated herein will be considered for payment. Any additional work required, found not to be biddable, will require prior written approval of TxDOT, TTI, and TAMU Purchasing.				

1.0 GENERAL STATEMENTS OF WORK

TTI proposes to contract for the services of an electrical contractor (Contractor) to install a vehicle detection system on the U.S. 59 Eastex Freeway in Houston from FM 525 to I-610 North Loop Freeway (Figure 1).

1. The Successful Bidder will provide the materials and labor to install, connect, and checkout various vehicle sensor units to be provided by TTI.

2. The Successful Bidder will provide the equipment and services for electrical power to operate the sensors and associated equipment in the field when it is determined that HL&P power sources are available.

3. The Successful Bidder will arrange for the installation of telephone equipment at the field locations and at the project office to transmit the information from the sensors to a TTI supplied computer at the project office.

4. The Successful Bidder will be responsible for maintaining circuit continuity for electrical power and for the transmission of appropriate data from the sensors to a designated project office for three years after the installation of the system.

5. TTI will provide spare parts for all of the equipment provided by TTI.

6. TTI will pay the monthly charges for power and telephone service.

7. TTI will pay for poles used for electrical service, telephone service, and sensors.

2.0 BIDDER RESPONSIBILITIES

2.1 Prior to the installation of the wooden poles, the Successful Bidder shall contact the utility companies or the utility coordinating committee for each location to prevent any damage or interference to present facilities. The Utility Coordinating Committee and the Texas One Call System shall be notified at the following numbers.

Houston Metropolitan Area (HMA) (223-4567)
Outside HMA Toll Free (1-800-245-4545)

2.2 In areas not in the City of Houston, the Successful Bidder shall contact the local Municipal Utilities District (MUD) for verification of water and sanitary sewer lines. This action shall in no way be interpreted as relieving the bidder of his/her responsibilities under the terms of the agreement. The Bidder shall repair any damage caused by his/her operations at the Bidder's expense and shall restore facilities to service in a timely manner.

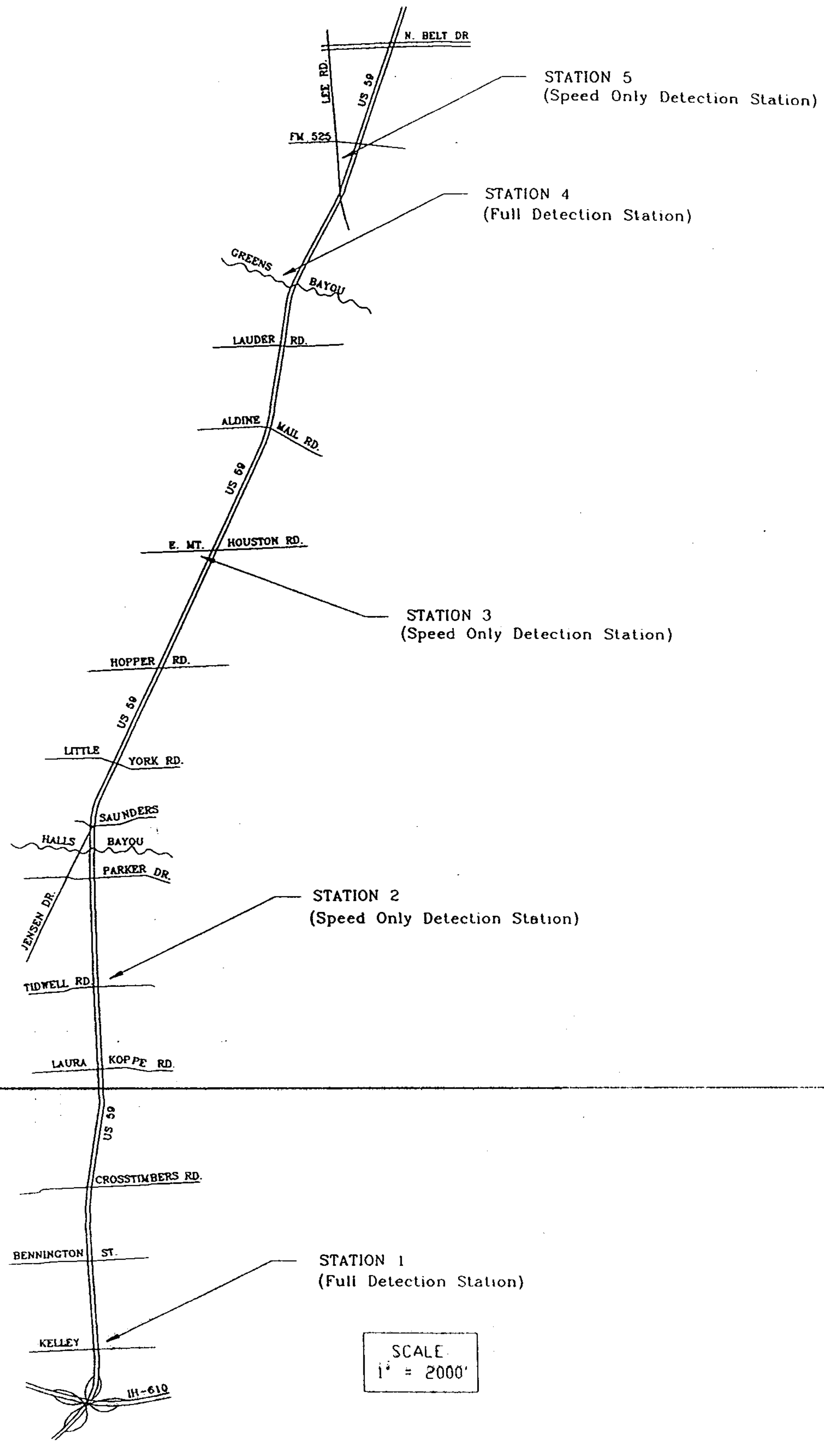


FIGURE 1. EASTEX FREEWAY PROJECT - OVERVIEW OF STUDY SITES

2.3 Any damage to existing water mains and sanitary sewer lines shall be repaired by the Bidder at no cost to the City of Houston, the local MUD, TxDOT, or the Texas Transportation Institute (TTI). the Bidder shall verify all existing water mains and sanitary sewer lines and contact the City of Houston utilities operations (NE, SE, SW, and NW) quadrant or the local MUD 48 hours prior to excavating near water mains or sanitary sewer lines. Any adjustments necessary to the water mains or sanitary sewer lines shall be coordinated with the City of Houston or the local MUD.

2.4 The Bidder shall be responsible for any damages done by the Bidder of subcontractors to any existing underground conduit, its internal contents, or utilities. Any damage done to the existing underground conduit, its contents, or utilities shall be replaced at the Bidder's expense.

2.5 When a wooden pole is to be erected where concrete riprap presently exists, the Bidder shall break out existing riprap for an area no greater than is required for pole placement. After the wooden pole has been erected, the Bidder shall wrap the periphery or the pole with 1/2 inch premolded mastic expansion joint material. The Bidder shall replace the remaining portion of the broken out riprap with class "C" concrete to the exact slope, pattern, and thickness of the existing riprap.

2.6 All cabinets and electronic equipment shall be picked up at 701 North Post Oak, Suite 430, Houston, Texas or as directed by TTI. The Bidder shall supply incidental wiring and connectors for final equipment implementation.

2.7 The Bidder shall be fully responsible for the electric equipment during the transporting, installation, pole, and equipment removal and reinstallation. The Bidder shall make adjustments or repairs which may be required and remedy any defects or damages that may occur at his expense.

2.8 Approximate locations of power service and telephone access points are shown in attached drawers (Figures 2-6). The Bidder shall make all necessary arrangements with Houston Lighting and Power (HL&P) and Southwestern Bell to provide single phase, 115 VAC power service and conditioned, data grade telephone lines at each of five locations. Two locations (Kelley and Greens Bayou) will require power to be delivered to the sensor pole (and sensor device) which will be located across the frontage road from the PC interface (and power) in the right-of-way cabinet.

2.9 When pulling cables or conductors through conduit, manufacturer's recommended pulling tensions shall not be exceeded.

2.10 All circuits shall test clear of faults, grounds, and open circuits. All electrical work done shall be in conformance with the National Electrical Code (N.E.C.). All conductors shall be continuous without splices from terminal point to terminal point or as otherwise directed by TTI. The Bidder shall verify and coordinate service pole locations with the appropriate utility district.

2.11 At each pole location, a standard 5/8" diameter by 8 foot copperclad steel ground rod with mounting attachments shall be furnished by TTI and installed by the Bidder. Each time the pole and equipment are moved, the ground rod shall be removed b the Bidder for reinstallation. TTI shall provide lightning protection equipment to be installed on poles as shown in the plans. Each pole removal will require removal of the lightning protection components by the Bidder to the extent necessary. All lightning protection components should be reusable or replacements shall be furnished by the Bidder.

2.12 The service enclosure shall be attached with galvanized channel (UNISTRUT, KINDORF, or equal) to the service pole. The ends of channel shall be pointed with zinc rich paint.

2.13 The Bidder shall permit the electrical work to be inspected by TxDOT and the City of Houston, but will not be required to comply with the provisions and requirement of the City electrical ordinance. Such inspections will in no sense make the City a party to this agreements.

2.14 One high intensity, yellow, rotating dome light shall be required on any heavy duty, slow moving equipment used by the Bidder. These lights shall be mounted high enough to be visible from all directions and shall be used when the equipment is within 30 feet of the travelway. All other equipment, such as trucks, trailers, autos, etc., shall be equipped with emergency flashers and the flashers shall be used while within the immediate area of work.

2.15 Flag persons may be required during certain phases of construction and shall be equipped with the proper reflective clothing and two-way radios, or as directed by TTI.

2.16 The Bidder is required to coordinate work activities with TxDOT and TxDOT contractors.

2.17 The Bidder is required to repair malfunctions within 24 hours. Normal service hours, Monday through Friday, will be 8:00 a.m. until 5:00 p.m. excluding holidays. No overtime charges will be allowed.

2.18 The Bidder shall have a physical presence within a 20-mile radius of the Houston Central Business District (CBD).

2.19 The Bidder shall have a functional cellular phone in service units.

2.20 The Bidder shall have a local Houston telephone number with an electronic voice recorder. A recorded message shall serve as official notification of an accepted service call by time and date.

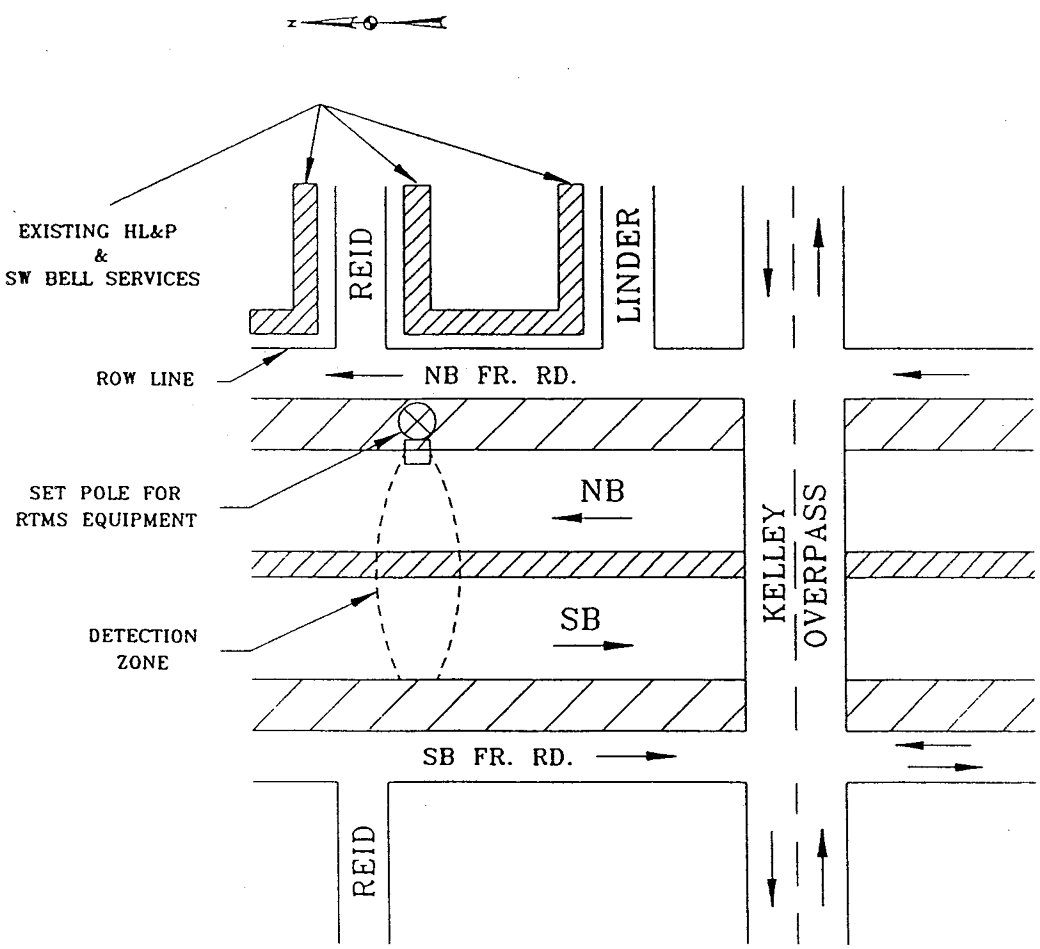
2.21 Inclement weather or water saturated soil within the TxDOT ROW lines will supersede service call responses.

STATION 1

JUST NORTH OF KELLEY STREET AND ON NORTHEAST EMBANKMENT

VOLUME, SPEED & OCCUPANCY
AC POWER, RTMS, MODEM, PC
& SECURE CABINET.

Approximate street address: 6000 Eastex Frwy 77026



NOTE: There are existing HL&P and SW BELL services on REID and LINDER street. If required, a service pole for HL&P meter can be set along NB service road at ROW line. The RTMS equipment pole to be set on inside shoulder on NB service road where frontage road grade and freeway grade meet. The AC power and telephone service will need to be installed over the NB frontage road.

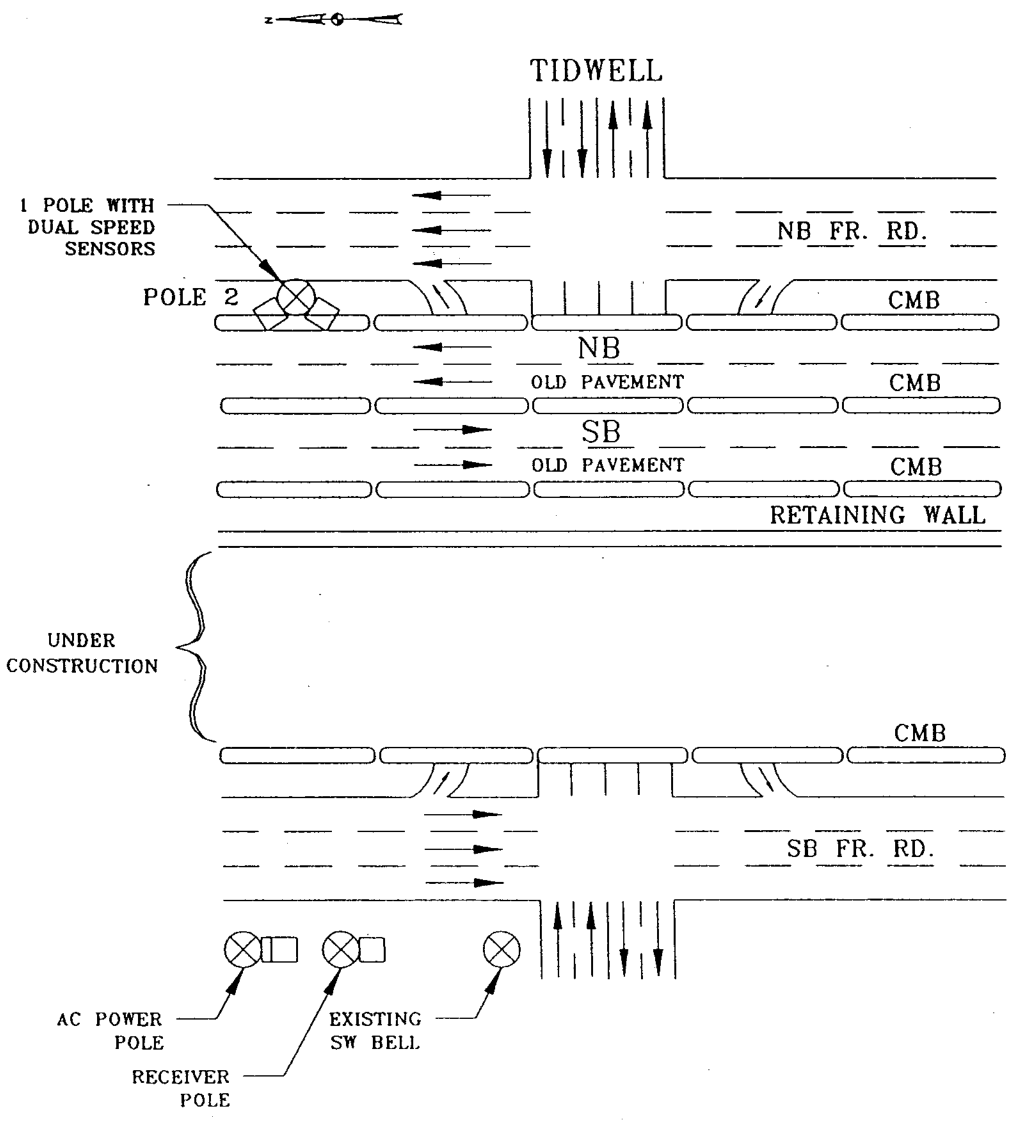
FIGURE 2. KELLEY ST. - RTMS DATA

STATION 2

NORTH SIDE OF
TIDWELL OVERPASS

SPEED STATION
DUAL RADAR SENSORS,
and SECURE CABINET WITH
CHARGING CONTROLS, RADAR
MUX, BATTERY and RF MODEM

Approximate street address: 9201 East Frwy
77093



• At receiver pole with secure cabinet with RF modem, PC and telephone modem.

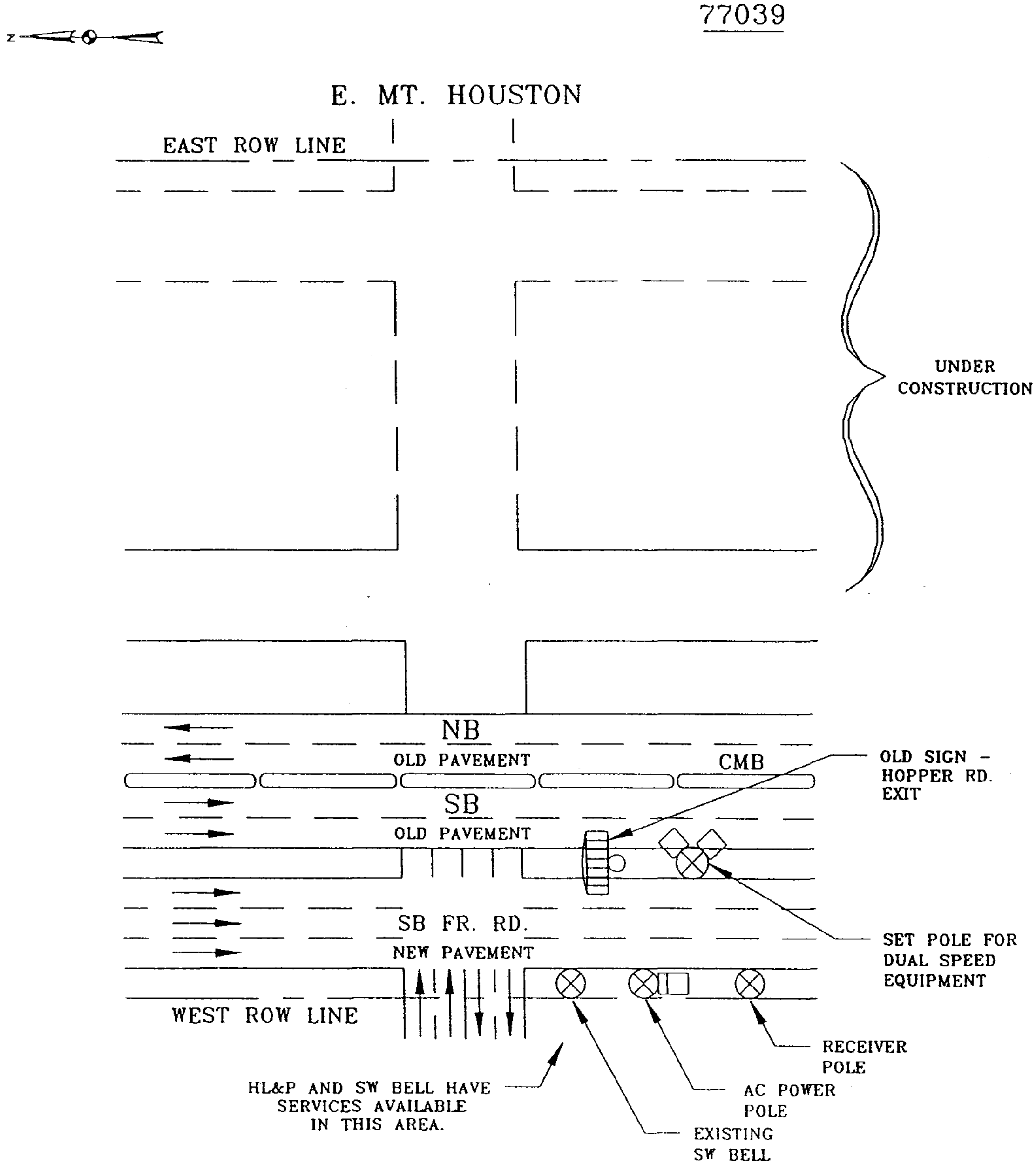
FIGURE 3. TIDWELL STREET - RADAR SPEEDS

STATION 3

E. MT. HOUSTON ROAD

SPEED STATION
DUAL RADAR SENSORS, SOLAR and SECURE CABINET WITH CHARGING CONTROLS, RADAR MUX, BATTERY and RF MODEM

Approximate street address: 11,691 U.S. 59 77039



* At receiver pole will be secure cabinet with RF modem, PC and telephone modem

FIGURE 4. E. MT. HOUSTON - RADAR SPEEDS

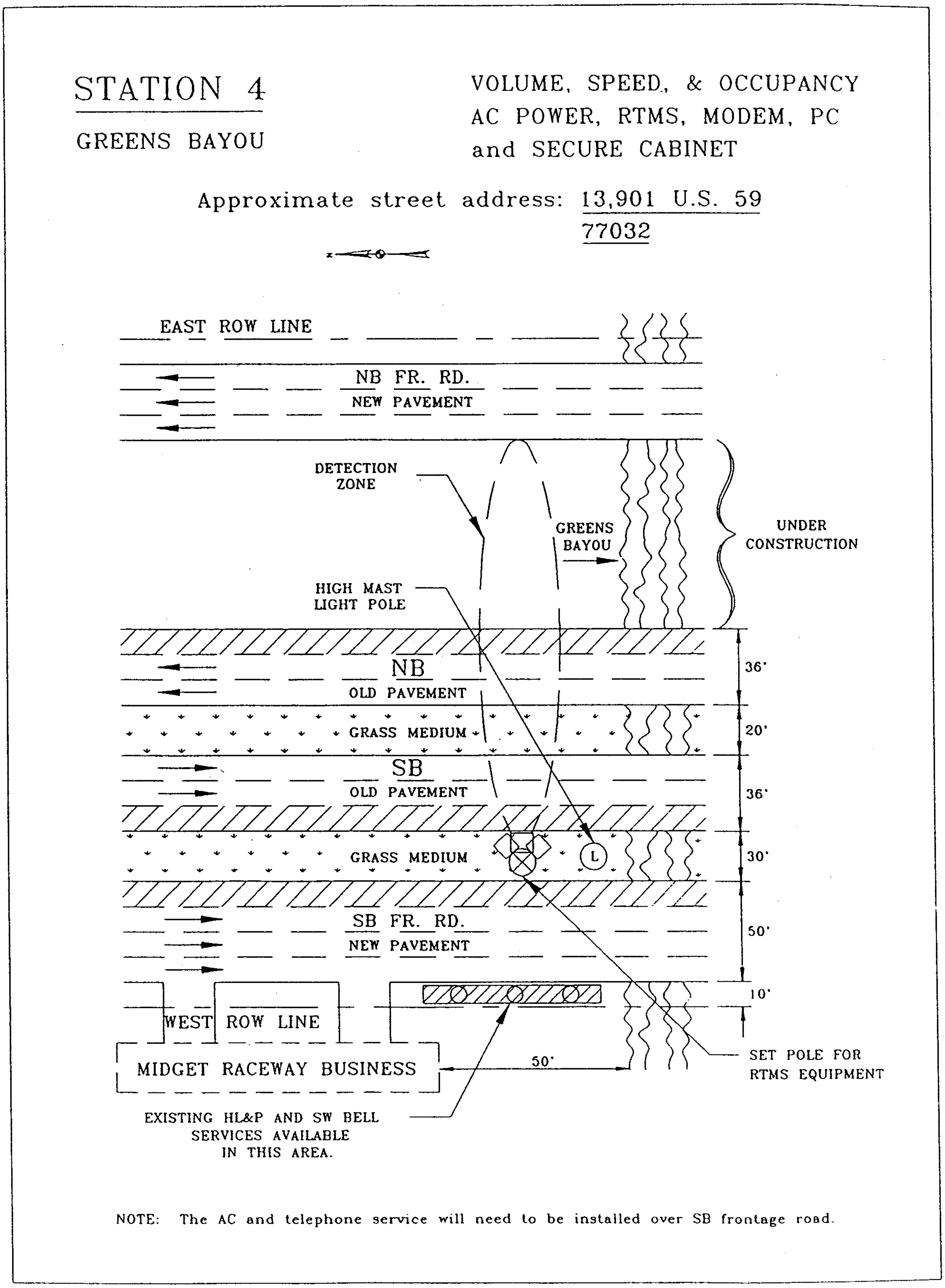


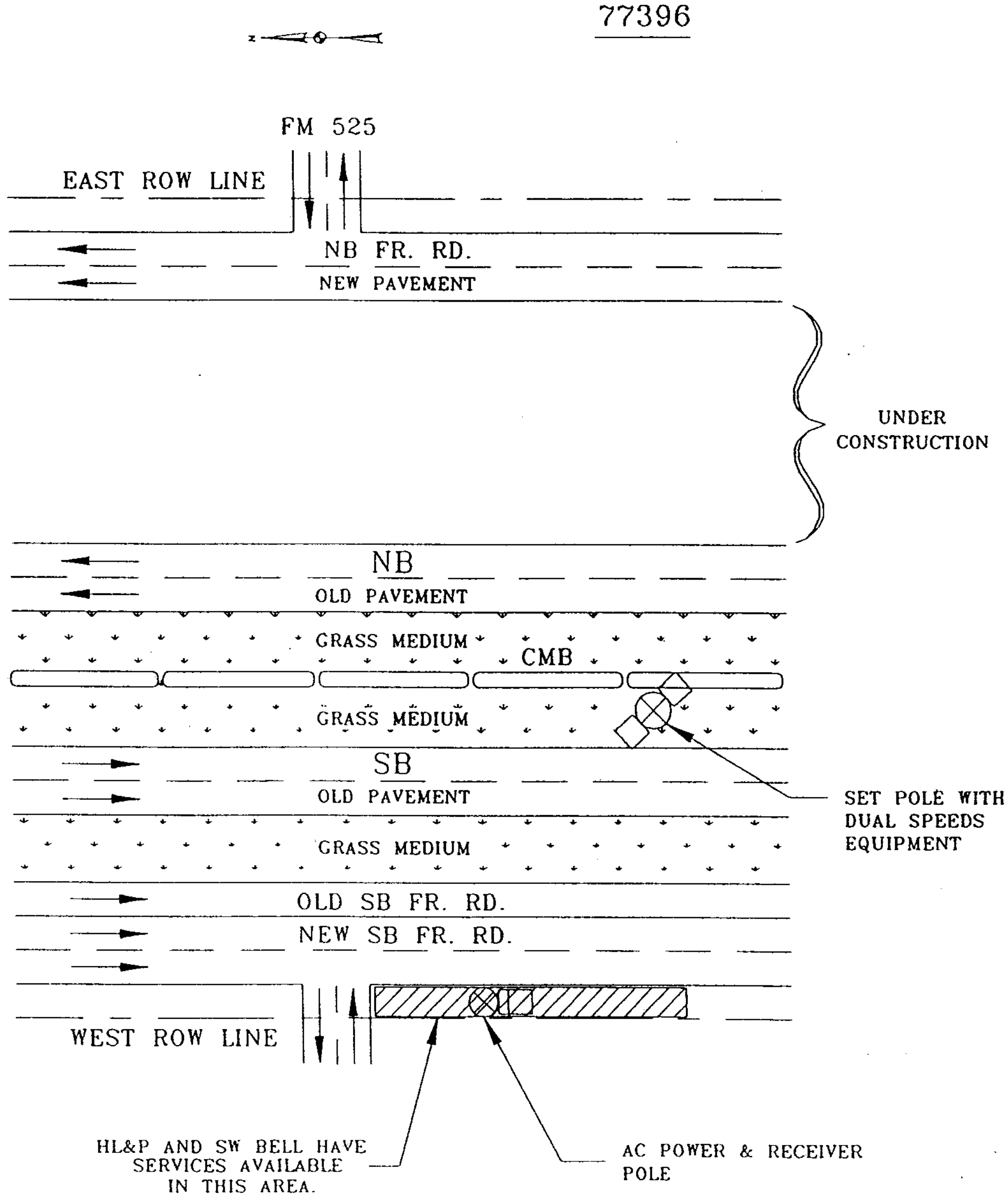
FIGURE 5. GREENS BAYOU - RTMS DATA

STATION 5

NEAR FM 525

SPEED STATION
DUAL RADAR SENSORS, SOLAR and SECURE CABINET WITH CHARGING CONTROLS, RADAR MUX, BATTERY and RF MODEM

Approximate street address: 14,501 U.S. 59
77396



* At receiver pole with secure cabinet with RF modem, PC and telephone modem

FIGURE 6. FM 525 - RADAR SPEEDS

2.22 The Bidder shall complete and submit as built drawings within fifteen days of the completion of installation and all five locations are delivering data to ICCF.

3.0 ITEM 627-TREATED TIMBER POLE REQUIREMENTS

3.1 Description. This item shall govern the acquisition and installation of treated timber poles of the various types as shown on the plans.

3.2 Materials. All materials furnished by the Bidder shall be new. Timber poles shall be treated southern pine and shall be in accordance with ANSI 05.1, "Specifications and Dimensions for Wood Poles," and the additional requirements of this Item.

3.3 Unless otherwise shown on the plans, treated timber poles for electrical services shall be ANSI Class 5. Poles for all other uses shall be ANSI Class 2.

3.4 Tops and butts of poles shall be free from pit holes. The depth of a trimmed scar shall not be greater than one (1) inch or 1/10 the pole diameter at that location, whichever is smaller.

3.5 Any deviation from straightness shall not exceed two (2) inches in a five (5) foot (or less) section. A pole may have sweep in one (1) plane and one (1) direction (single sweep), provided a straight line joining the midpoint of the pole at the butt and midpoint of the pole at the top does not at any intermediate point pass through the external surface of the pole. Poles with sweep in two (2) phases (double sweep) will not be accepted.

3.6 Timber poles with more than one (1) complete twist of spiral grain will not be accepted.

3.7 Butt slivering due to felling will be permitted if the distance from the outside circumference is not less than 1/4 of the butt diameter and the height is not more than one (1) foot.

3.8 Preservative treatment shall be in accordance with AWPA C4. Minimum net retention of preservative, measured by gauge or weight, shall be as follows:

TREATMENT	RETENTION
Creosote (AWPA P1)	10 lb. per cu. ft.
Pentachlorophenal (AWPA P8 & P9)	0.6 lb. per cu. ft.
ACA/CCA (AWPA P3)	0.6 lb. per cu. ft.

3.9 Inspection. Inspectors representing TTI shall have access to all parts of facilities used in the conditioning and treating of forest products. The supplier shall provide the necessary assistance for the proper inspection of the materials being furnished. For projects requiring 10 or less timber poles, the poles may be accepted from a local supplier if an acceptable certificate of treatment is furnished and the poles are properly marked.

3.10 Markings. All poles shall be marked by branding as follows:

Supplier's code or trademark (for example: PTC-Pole Treating Company)

Plant location and year of treatment (for example: F-23--Forestville, 1963)

Species and preservative code (for example: SPC--southern pine, creosote)

Class-length (for example: 5-35--Class 5, 35 foot pole)

3.11 The bottom of the brand shall be placed squarely on the face of the pole 10 feet (plus or minus two (2) inches) from the butt.

3.12 Construction Methods. Installation of poles located near any overhead or underground utilities shall be accomplished using established industry and utility safety practices. The Bidder shall consult with the appropriate utility company prior to beginning such work.

3.13 Unless otherwise shown on the plans, minimum pole setting depth shall be as follows:

POLE LENGTH (FT)	MINIMUM SETTING DEPTH (FT)
25 or less	4.5
26-30	5.0
31-35	5.5
36-40	6.0
41-45	6.5
46-50	7.0

3.14 Timber poles shall be installed at locations shown on the plans or as directed by TTI. Holes for setting poles shall be a minimum of 1.5 diameters of the pole butt. Unless otherwise shown on the plans, poles shall be set plumb. Holes shall be backfilled by thoroughly tamping in six (6) inch lifts. After tamping to grade, additional backfill material shall be placed in a six (6) inch high cone around the pole to allow for setting.

3.15 Where existing surfacing is removed for placing foundations, repair shall be made by backfilling with material equal in composition and density to the surrounding area and by replacing any removed surfacing, such as asphalt pavement or concrete riprap, with like material to equivalent condition.

4.0 EQUIPMENT

4.1 Bid to Install Two Full Detection Stations (Figures 2 and 5). The bidder will provide bids by site to install, connect, check, and place into service the following equipment (Figure 7):

Figures 2 and 5 (see attached).

- One sensor wooden pole installed, as per plans, with the following equipment supplied by TTI:
  - -- lightning protection (arrestor);
  - -- RTMS sensor; and
  - -- cabinet with microcomputer and telephone modem.

  (Optional)
- One potential AC service meter and pole at the ROW line along with telephone line drop (if required). Bidder must coordinate and assist if required.

The ROW pole may not be required providing existing pole(s) can be used to provide access to power and telephone service.

4.1 Bid to Install Three Speed Only Detection Stations (Figures 3, 4, and 6). The bidder will provide bids by site to install, connect, check, and place into service the following equipment (Figure 8):

- One wooden pole installed at the ROW line with the following equipment furnished by TTI:
  - -- lightning protection;
  - -- AC power drop with meter (contractor must coordinate and assist if required);
  - -- telephone drop (contractor must coordinate and assist if required); and
  - -- cabinet with RF modem, microcomputer, and telephone modem.
- One wooden pole installed near the freeway (or as shown by the Plans) with the following equipment furnished by TTI:
  - -- lightning protection;
  - -- solar panels;
  - -- speed sensors;
  - -- cabinet with RF modem, batteries, electronic charging circuit, and speed multiplexor unit.

The Bidder will provide all other equipment and supplies necessary to install and operate the equipment.

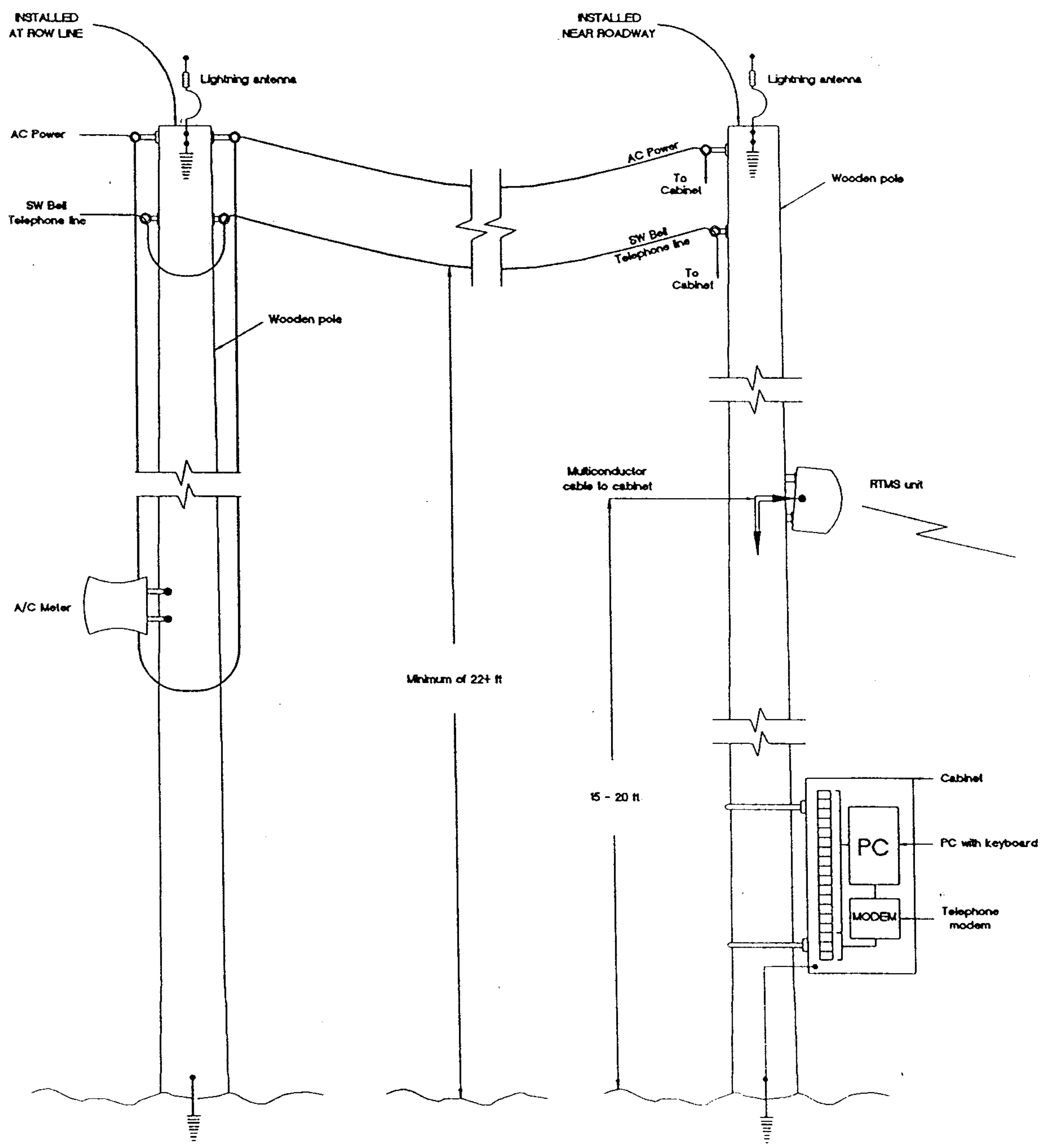


Figure 7. Typical RTMS Installation Site

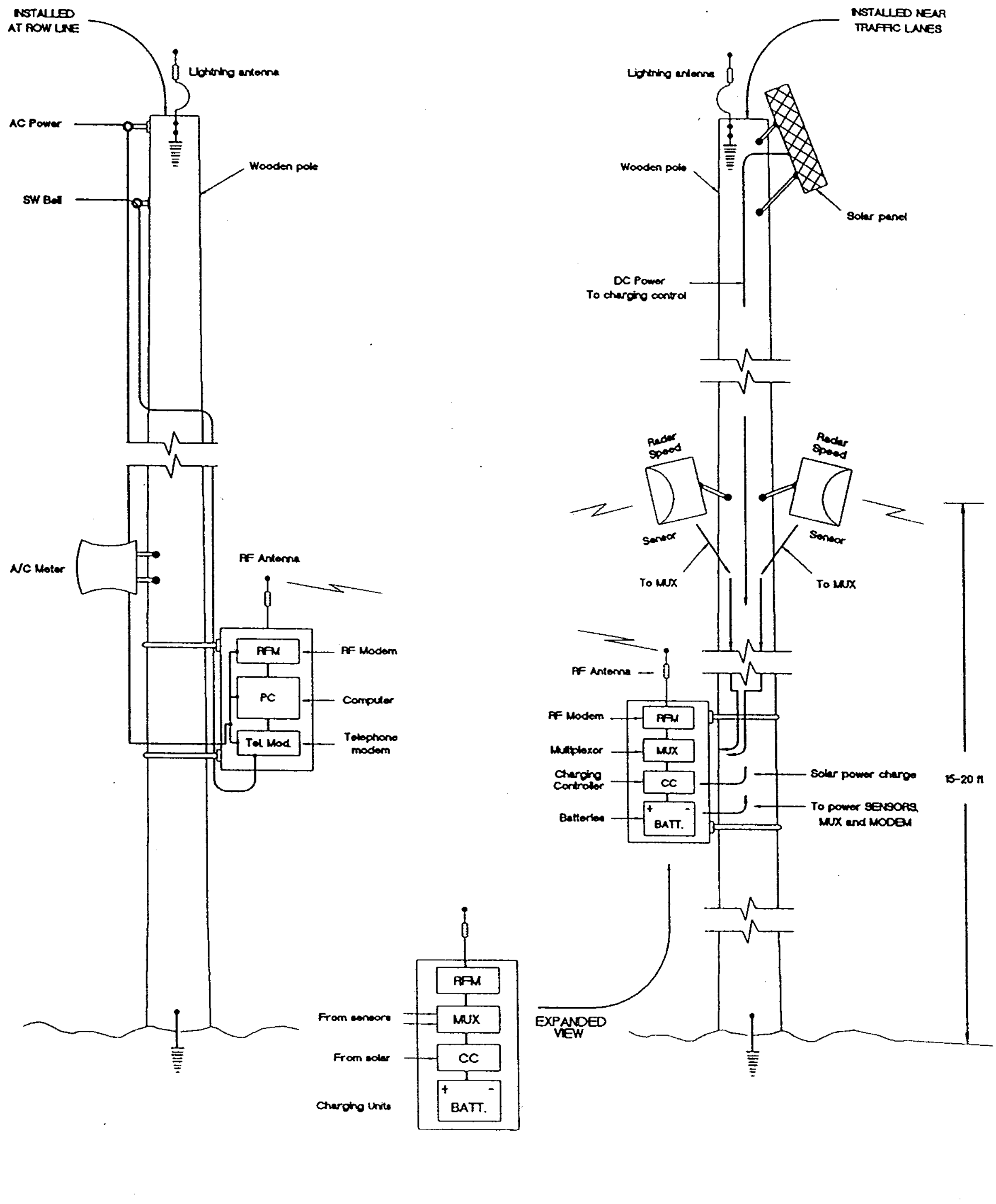


Figure 8. Typical Speed Site - Whelen Doppler Radar

The number of maintenance calls required of the system will be determined by the operation of the system. There will not be a predetermined minimum or maximum number.

APPENDIX B.
TWO WHELEN RADIO SENSORS
IN APPROACHING AND RECEDING DIRECTIONS
IN 0, 10, 20, 30, AND 40 DEGREES

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 524
Angle 0 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
LANE	FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5	10.0 (33)	10.4 (34)	100.6 (330)	61.9 (203)	Approaching
2	25.0	10.0 (33)	10.4 (34)	122.8 (403)	95.7 (314)	"
3	37.5		none			"
4	50.0		none			"
5	62.5					"
6	75.0					"
7	87.5					"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					"
1	12.5	10.0 (33)	9.4 (31)	65.8 (216)	180.7 (593)	Receding
2	25.0	9.8 (32)	9.4 (31)	114.3 (375)	149.7 (491)	"
3	37.5		none			"
4	50.0		none			"
5	62.5					"
6	75.0					"
7	87.5					"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95 S.N. 524
Project 429005 Height 3.35 meters (11 feet) Angle 10 degrees

LANE	/ FEET	SPEED KMPH (MPH) TRUE SPEED	WHELEN SPD.	DISTANCE METERS (FEET) DIST. IN	DIST. OUT	DIRECTION
1	12.5	10.4 (34)	10.7 (35)	46.0 (151)	0.0 (0)	Approaching
2	25.0	10.4 (34)	11.0 (36)	73.2 (240)	4.6 (15)	"
3	37.5	11.0 (36)	10.7 (35)	90.2 (296)	9.1 (30)	"
4	50.0	10.7 (35)	11.0 (36)	114.6 (376)	35.0 (118)	"
5	62.5	10.4 (34)	10.7 (35)	145.4 (477)	86.0 (282)	"
6	75.0	10.4 (34)	10.7 (35)	176.2 (578)	119.8 (393)	"
7	87.5	11.0 (36)	11.3 (37)	185.3 (608)	151.2 (496)	"
8	100.0	10.0 (33)	10.4 (34)	229.0 (751)	170.4 (559)	"
9	112.5	10.0 (33)	10.4 (34)	238.4 (782)	194.8 (639)	"
10	125.0		none			"
11	137.5	9.1 (30)	8.2 (27)	270.7 (888)	251.2 (824)	"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					"
1	12.5	10.4 (34)	10.4 (34)	43.3 (142)	78.3 (257)	Receding
2	25.0	9.8 (32)	10.0 (33)	54.3 (178)	85.3 (280)	"
3	37.5	9.8 (32)	10.0 (33)	65.2 (214)	88.4 (290)	"
4	50.0	9.8 (32)	10.4 (34)	106.7 (350)	147.0 (482)	"
5	62.5	10.0 (33)	10.7 (35)	119.2 (391)	141.4 (464)	"
6	75.0		none			"
7	87.5		none			"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 524
Angle 20 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
LANE	FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5	—	10.0 (33)	13.7 (45)	0.0 (0)	Approaching
2	25.0	—	10.0 (33)	13.7 (45)	0.0 (0)	"
3	37.5	—	9.8 (32)	13.7 (45)	4.6 (15)	"
4	50.0	10.7 (35)	10.4 (34)	42.4 (139)	9.1 (30)	"
5	62.5	11.0 (36)	10.7 (35)	55.8 (183)	18.9 (62)	"
6	75.0	10.4 (34)	10.4 (34)	68.6 (225)	29.0 (95)	"
7	87.5	9.4 (31)	9.4 (31)	81.7 (268)	45.4 (149)	"
8	100.0	11.3 (37)	10.7 (35)	91.1 (299)	52.4 (172)	"
9	112.5	10.4 (34)	10.4 (34)	87.5 (287)	54.6 (179)	"
10	125.0	10.4 (34)	10.7 (35)	96.0 (315)	76.2 (250)	"
11	137.5	10.0 (33)	9.8 (32)	96.9 (318)	79.3 (260)	"
12	150.0	10.7 (35)	10.4 (34)	110.0 (361)	93.9 (308)	"
13	162.5		none			"
14	175.0		none			"
15	187.5					"
1	12.5	10.0 (33)	9.8 (32)	26.8 (88)	47.9 (139)	Receding
2	25.0	9.8 (32)	7.3 (24)	34.7 (114)	52.4 (172)	"
3	37.5	9.4 (31)	9.4 (31)	53.3 (175)	71.0 (233)	"
4	50.0	9.4 (31)	6.1 (20)	60.0 (197)	78.3 (257)	"
5	62.5	9.4 (31)	7.0 (23)	65.5 (215)	84.1 (276)	"
6	75.0	10.4 (34)	9.8 (32)	73.1 (240)	91.7 (301)	"
7	87.5		none			"
8	100.0		none			"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 524
Angle 30 degrees

LANE / FEET	SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1 12.5	—	8.2 (27)	4.6 (15)	0.0 (0)	Approaching
2 25.0	—	8.5 (28)	9.1 (30)	0.0 (0)	"
3 37.5	—	none			"
4 50.0	9.4 (31)	8.8 (29)	13.7 (45)	0.0 (0)	"
5 62.5	9.4 (31)	9.4 (31)	28.0 (92)	4.6 (15)	"
6 75.0	9.8 (32)	9.1 (30)	32.3 (106)	14.3 (47)	"
7 87.5	9.8 (32)	9.1 (30)	40.5 (133)	20.7 (68)	"
8 100.0	10.7 (35)	10.0 (33)	47.2 (155)	27.7 (91)	"
9 112.5	10.7 (35)	9.4 (31)	50.6 (166)	33.2 (109)	"
10 125.0	10.0 (33)	9.1 (30)	55.8 (183)	37.5 (123)	"
11 137.5	10.0 (33)	9.1 (30)	64.0 (210)	47.9 (157)	"
12 150.0		none			"
13 162.5		none			"
14 175.0					"
15 187.5					"
1 12.5		none			Receding
2 25.0		none			"
3 37.5		none			"
4 50.0		none			"
5 62.5	10.4 (34)	8.2 (27)	57.6 (189)	81.7 (268)	"
6 75.0		none			"
7 87.5	9.8 (32)	7.3 (24)	67.1 (220)	82.6 (271)	"
8 100.0		none			"
9 112.5		none			"
10 125.0					"
11 137.5					"
12 150.0					"
13 162.5					"
14 175.0					"
15 187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 524
Angle 40 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
LANE	FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5		none			Approaching
2	25.0		none			"
3	37.5		none			"
4	50.0		none			"
5	62.5		none			"
6	75.0	8.2 (27)	—	9.1 (30)	—	"
7	87.5		none			"
8	100.0	9.8 (32)	7.9 (26)	25.3 (83)	9.1 (30)	"
9	112.5	9.4 (31)	8.5 (28)	28.7 (94)	9.1 (30)	"
10	125.0	9.8 (32)	7.9 (26)	35.0 (115)	9.1 (30)	"
11	137.5	9.8 (32)	8.2 (27)	38.7 (127)	20.1 (66)	"
12	150.0	10.7 (35)	7.6 (25)	43.3 (142)	13.7 (45)	"
13	162.5		none			"
14	175.0		none			"
15	187.5					"
1	12.5		none			Receding
2	25.0		none			"
3	37.5		none			"
4	50.0		none			"
5	62.5	10.4 (34)	8.2 (27)	57.6 (189)	81.7 (268)	"
6	75.0		none			"
7	87.5	9.8 (32)	7.3 (24)	133.1 (220)	82.6 (271)	"
8	100.0		none			"
9	112.5		none			"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 525
Angle 0 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
		TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5	10.0 (33)	10.4 (34)	116.1 (381)	94.5 (310)	Approaching
2	25.0	10.0 (33)	10.7 (35)	108.5 (356)	92.7 (304)	"
3	37.5		none			"
4	50.0		none			"
5	62.5					"
6	75.0					"
7	87.5					"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					"
1	12.5	9.4 (31)	10.0 (33)	63.1 (207)	164.0 (538)	Receding
2	25.0	9.1 (30)	9.4 (31)	114.9 (377)	184.7 (606)	"
3	37.5		none			"
4	50.0		none			"
5	62.5					"
6	75.0					"
7	87.5					"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 525
Angle 10 degrees

LANE / FEET	SPEED KMPH (MPH) TRUE SPEED	WHELEN SPD.	DISTANCE METERS (FEET) DIST. IN	DIST. OUT	DIRECTION
1 12.5	10.0 (33)	10.4 (34)	36.9 (121)	0.0 (0)	Approaching
2 25.0	10.7 (35)	11.0 (36)	67.7 (222)	13.7 (45)	"
3 37.5	10.7 (35)	11.0 (36)	78.0 (256)	9.1 (30)	"
4 50.0	10.0 (33)	10.4 (34)	112.8 (370)	27.1 (89)	"
5 62.5	10.4 (34)	10.4 (34)	128.0 (420)	36.6 (120)	"
6 75.0	10.4 (34)	10.4 (34)	148.1 (486)	104.9 (344)	"
7 87.5	9.4 (31)	9.4 (31)	191.1 (627)	153.9 (505)	"
8 100.0	10.7 (35)	11.0 (36)	205.4 (674)	171.9 (564)	"
9 112.5	9.8 (32)	10.0 (33)	227.4 (746)	196.0 (643)	"
10 125.0	9.4 (31)	8.5 (28)	245.4 (805)	227.0 (745)	"
11 137.5	10.4 (34)	9.8 (32)	225.6 (740)	203.6 (668)	"
12 150.0	9.8 (32)	9.1 (30)	266.4 (874)	248.7 (816)	"
13 162.5		none			"
14 175.0					"
15 187.5					"
1 12.5	10.0 (33)	9.8 (32)	26.8 (88)	49.7 (163)	Receding
2 25.0	9.8 (32)	10.0 (33)	51.8 (170)	89.9 (295)	"
3 37.5	10.0 (33)	10.4 (34)	59.7 (196)	97.5 (320)	"
4 50.0	9.8 (32)	10.0 (33)	78.3 (257)	118.9 (390)	"
5 62.5	9.4 (31)	9.8 (32)	113.7 (373)	138.1 (453)	"
6 75.0	9.8 (32)	9.8 (32)	119.8 (393)	139.6 (458)	"
7 87.5		none			"
8 100.0		none			"
9 112.5					"
10 125.0					"
11 137.5					"
12 150.0					"
13 162.5					"
14 175.0					"
15 187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95 S.N. 525
Project 429005 Height 3.35 meters (11 feet) Angle 20 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
LANE	FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	DIRECTION
1	12.5	—	10.4 (34)	9.1 (30)	0.0 (0)	Approaching
2	25.0	—	10.4 (34)	9.1 (30)	0.0 (0)	"
3	37.5	10.0 (33)	10.0 (33)	22.6 (74)	4.6 (15)	"
4	50.0	10.4 (34)	10.0 (33)	39.9 (131)	9.1 (30)	"
5	62.5	9.8 (32)	9.8 (32)	49.7 (163)	18.0 (59)	"
6	75.0	9.4 (31)	9.4 (31)	67.4 (221)	29.0 (45)	"
7	87.5	9.8 (32)	9.8 (32)	70.4 (231)	37.8 (124)	"
8	100.0	9.8 (32)	9.4 (31)	84.4 (277)	32.9 (108)	"
9	112.5	10.4 (34)	10.0 (33)	90.5 (297)	51.5 (169)	"
10	125.0	10.0 (33)	9.4 (31)	93.6 (307)	72.5 (238)	"
11	137.5	9.4 (31)	9.4 (31)	107.9 (354)	72.8 (239)	"
12	150.0	10.0 (33)	10.0 (33)	119.5 (392)	81.1 (266)	"
13	162.5		none			"
14	175.0					"
15	187.5					"
1	12.5	9.8 (32)	9.8 (32)	30.2 (99)	52.7 (173)	Receding
2	25.0	9.4 (31)	9.1 (30)	31.1 (102)	50.3 (165)	"
3	37.5	10.0 (33)	10.0 (33)	47.2 (155)	70.4 (231)	"
4	50.0	9.8 (32)	8.2 (27)	55.2 (181)	76.8 (252)	"
5	62.5	10.0 (33)	9.8 (32)	57.9 (190)	80.2 (263)	"
6	75.0	10.0 (33)	10.0 (33)	65.5 (215)	103.3 (339)	"
7	87.5	10.4 (34)	10.0 (33)	80.2 (263)	103.6 (340)	"
8	100.0	10.0 (33)	10.7 (35)	89.3 (293)	130.5 (428)	"
9	112.5	9.8 (32)	9.4 (31)	95.4 (313)	116.1 (381)	"
10	125.0	10.0 (33)	10.4 (34)	106.1 (348)	141.4 (464)	"
11	137.5	10.7 (35)	10.7 (35)	112.8 (370)	149.3 (490)	"
12	150.0		none			"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95 S.N. 525
Project 429005 Height 3.35 meters (11 feet) Angle 30 degrees

LANE / FEET		SPEED KMPH (MPH) TRUE SPEED	WHELEN SPD.	DISTANCE METERS (FEET) DIST. IN	DIST. OUT	DIRECTION
1	12.5		none			Approaching
2	25.0		none			"
3	37.5	—	8.5 (28)	9.1 (30)	0.0 (0)	"
4	50.0	—	8.5 (28)			"
5	62.5	9.4 (31)	8.8 (29)	19.8 (65)	9.1 (30)	"
6	75.0	9.8 (32)	9.1 (30)	28.3 (93)	9.1 (30)	"
7	87.5	9.8 (32)	8.8 (29)	36.3 (119)	14.9 (49)	"
8	100.0	10.0 (33)	8.5 (28)	42.3 (139)	9.1 (30)	"
9	112.5	9.8 (32)	8.2 (27)	48.5 (159)	20.1 (66)	"
10	125.0	9.8 (32)	8.5 (28)	52.1 (171)	17.7 (58)	"
11	137.5	10.0 (33)	8.5 (28)	57.9 (190)	18.9 (62)	"
12	150.0	9.8 (32)	8.5 (28)	64.6 (212)	47.5 (156)	"
13	162.5		none			"
14	175.0					"
15	187.5					"
1	12.5		none			Receding
2	25.0		none			"
3	37.5	9.4 (31)	8.2 (27)	30.2 (99)	47.9 (157)	"
4	50.0	—	none			"
5	62.5	9.4 (31)	8.5 (28)	47.9 (157)	68.9 (226)	"
6	75.0	9.8 (32)	9.1 (30)	53.6 (176)	78.6 (258)	"
7	87.5	10.0 (33)	8.8 (29)	56.7 (186)	75.0 (246)	"
8	100.0	9.8 (32)	7.9 (26)	71.3 (234)	90.5 (297)	"
9	112.5	9.8 (32)	7.9 (26)	82.6 (271)	98.8 (324)	"
10	125.0	10.0 (33)	9.4 (31)	89.6 (294)	107.3 (352)	"
11	137.5		none			"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 05/18/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 525
Angle 40 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
		TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5		none			Approaching
2	25.0		none			"
3	37.5		none			"
4	50.0	—	7.0 (23)	9.1 (30)	0.0 (0)	"
5	62.5	—	7.0 (23)	9.1 (30)	0.0 (0)	"
6	75.0	—	7.6 (25)	9.1 (30)	0.0 (0)	"
7	87.5	9.4 (31)	7.9 (26)	21.3 (70)	9.1 (30)	"
8	100.0	9.4 (31)	7.6 (25)	24.1 (79)	9.1 (30)	"
9	112.5	9.4 (31)	7.6 (25)	29.6 (97)	9.1 (30)	"
10	125.0	10.0 (33)	7.9 (26)	29.0 (95)	12.5 (41)	"
11	137.5	9.8 (32)	7.9 (26)	37.5 (123)	9.1 (30)	"
12	150.0	9.4 (31)	7.0 (23)	40.2 (132)	18.9 (62)	"
13	162.5	9.8 (32)	7.3 (24)	42.4 (139)	24.1 (79)	"
14	175.0					"
15	187.5					"
1	12.5		none			Receding
2	25.0		none			"
3	37.5	8.8 (29)	7.3 (24)	23.2 (76)	38.7 (127)	"
4	50.0		none			"
5	62.5		none			"
6	75.0		none			"
7	87.5	10.4 (34)	9.1 (30)	50.0 (164)	66.1 (217)	"
8	100.0		none			"
9	112.5	9.8 (32)	6.7 (22)	63.7 (209)	79.2 (260)	"
10	125.0	10.4 (34)	8.5 (28)	67.4 (221)	81.1 (266)	"
11	137.5		none			"
12	150.0	9.8 (32)	8.5 (28)	74.7 (245)	93.0 (315)	"
13	162.5		none			"
14	175.0		none			"
15	187.5					

APPENDIX C.

RADAR SENSORS TESTED AT 30 DEGREES WITH ONE SENSOR HAVING REPAIRS AND PERFORMANCE IMPROVEMENTS

WHELEN RADAR TEST RESULTS FORM

Date 06/07/95
Project 429005

Height 3.35 meters (11 feet)

S.N. 520
Angle 30 degrees
Before Repair

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
		TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5					Approaching
2	25.0					"
3	37.5					"
4	50.0		none			"
5	62.5	7.9 (26)	7.6 (25)	27.7 (91)	13.7 (45)	"
6	75.0	8.2 (27)	8.5 (28)	31.1 (102)	19.5 (64)	"
7	87.5	8.5 (28)	7.9 (26)	37.8 (124)	22.5 (74)	"
8	100.0	8.8 (29)	8.2 (27)	47.5 (156)	38.4 (126)	"
9	112.5		none			"
10	125.0		none			"
11	137.5		none			"
12	150.0		none			"
13	162.5		none			"
14	175.0					"
15	187.5					"
1	12.5					Receding
2	25.0					"
3	37.5					"
4	50.0		none			"
5	62.5		none			"
6	75.0		none			"
7	87.5		none			"
8	100.0					"
9	112.5					"
10	125.0					"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 07/06/95
Project 429005

Height 3.35 meters (11 feet)

S.N. 520
Angle 30 degrees
After Repair

	SPEED KMPH (MPH)		DISTANCE METERS (FEET)		
LANE / FEET	TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	DIRECTION
1 12.5					Approaching
2 25.0					"
3 37.5					"
4 50.0					"
5 62.5	8.5 (28)	8.8 (29)	14.0 (46)	0.0 (0)	"
6 75.0	8.5 (28)	9.4 (31)	33.8 (111)	25.6 (84)	"
7 87.5	8.8 (29)	6.7 (22)	40.5 (133)	30.5 (100)	"
8 100.0	8.5 (28)	4.3 (14)	35.7 (117)	25.9 (85)	"
9 112.5	8.8 (29)	7.9 (26)	47.5 (156)	39.0 (128)	"
10 125.0	9.1 (30)	9.8 (32)	54.9 (185)	45.7 (150)	"
11 137.5	9.1 (30)	9.8 (32)	63.1 (207)	54.7 (180)	"
12 150.0	8.8 (29)	7.9 (26)	50.3 (165)	43.3 (142)	"
13 162.5					"
14 175.0					"
15 187.5					"
1 12.5					Receding
2 25.0					"
3 37.5					"
4 50.0					"
5 62.5	8.5 (28)	8.2 (27)	49.4 (162)	54.9 (185)	"
6 75.0	8.2 (27)	7.9 (26)	54.9 (185)	61.0 (200)	"
7 87.5	8.5 (28)	7.9 (26)	64.3 (211)	73.8 (242)	"
8 100.0		none			"
9 112.5					"
10 125.0					"
11 137.5					"
12 150.0					"
13 162.5					"
14 175.0					"
15 187.5					

WHELEN RADAR TEST RESULTS FORM

Date 06/07/95 S.N. 521
Project 429005 Height 3.35 meters (11 feet) Angle 30 degrees

LANE / FEET		SPEED KMPH (MPH)		DISTANCE METERS (FEET)		DIRECTION
		TRUE SPEED	WHELEN SPD.	DIST. IN	DIST. OUT	
1	12.5					Approaching
2	25.0					"
3	37.5					"
4	50.0	7.9 (26)	0.0 (0)	19.8 (65)	4.6 (15)	"
5	62.5	8.5 (28)	8.2 (27)	23.8 (78)	4.6 (15)	"
6	75.0	8.5 (28)	7.9 (26)	29.0 (95)	15.5 (51)	"
7	87.5	8.2 (27)	7.9 (26)	36.3 (119)	22.3 (73)	"
8	100.0	8.8 (29)	8.5 (28)	52.1 (171)	23.2 (76)	"
9	112.5	8.8 (29)	7.9 (26)	48.5 (159)	39.9 (131)	"
10	125.0	8.5 (28)	7.6 (25)	60.4 (198)	33.8 (111)	"
11	137.5	8.5 (28)	8.2 (27)	65.2 (214)	54.6 (179)	"
12	150.0	8.8 (29)	8.2 (27)	64.0 (210)	47.9 (157)	"
13	162.5	8.5 (28)	7.9 (26)	79.0 (259)	67.4 (221)	"
14	175.0					"
15	187.5					"
1	12.5					Receding
2	25.0					"
3	37.5					"
4	50.0	8.2 (27)	7.6 (25)	40.5 (133)	53.0 (174)	"
5	62.5	8.5 (28)	8.8 (29)	43.0 (141)	57.0 (187)	"
6	75.0	8.8 (29)	8.2 (27)	53.9 (177)	67.7 (222)	"
7	87.5	8.2 (27)	4.3 (14)	63.4 (208)	75.9 (249)	"
8	100.0		none			"
9	112.5		none			"
10	125.0		none			"
11	137.5		none			"
12	150.0		none			"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 06/07/95
Project 429005
Height 3.35 meters (11 feet)
S.N. 522
Angle 30 degrees

LANE	FEET	SPEED KMPH (MPH) TRUE SPEED	WHELEN SPD.	DISTANCE METERS (FEET) DIST. IN	DIST. OUT	DIRECTION
1	12.5					Approaching
2	25.0					"
3	37.5					"
4	50.0	8.2 (27)	7.9 (26)	16.8 (55)	4.6 (15)	"
5	62.5	7.9 (26)	7.0 (23)	26.8 (88)	9.1 (30)	"
6	75.0	8.5 (28)	7.9 (26)	32.3 (106)	16.2 (53)	"
7	87.5	8.5 (28)	5.5 (18)	39.6 (130)	9.1 (30)	"
8	100.0	8.5 (28)	7.9 (26)	41.5 (136)	23.5 (77)	"
9	112.5	8.5 (28)	7.3 (24)	52.4 (172)	19.8 (65)	"
10	125.0	9.1 (30)	10.0 (33)	56.1 (184)	37.5 (123)	"
11	137.5	8.8 (29)	7.6 (25)	51.8 (170)	37.5 (123)	"
12	150.0	8.5 (28)	7.6 (25)	68.6 (225)	54.3 (178)	"
13	162.5					"
14	175.0					"
15	187.5					"
1	12.5					Receding
2	25.0					"
3	37.5					"
4	50.0	7.9 (26)	7.6 (25)	39.6 (130)	52.1 (171)	"
5	62.5		none			"
6	75.0	8.2 (27)	7.6 (25)	54.3 (178)	66.8 (219)	"
7	87.5	8.2 (27)	7.6 (25)	56.4 (185)	71.0 (233)	"
8	100.0	8.2 (27)	8.8 (29)	64.9 (213)	76.5 (251)	"
9	112.5		none			"
10	125.0		none			"
11	137.5		none			"
12	150.0		none			"
13	162.5					"
14	175.0					"
15	187.5					

WHELEN RADAR TEST RESULTS FORM

Date 06/07/95 S.N. 523
Project 429005 Height 3.35 meters (11 feet) Angle 30 degrees

LANE / FEET		SPEED KMPH (MPH) TRUE SPEED	WHELEN SPD.	DISTANCE METERS (FEET) DIST. IN	DIST. OUT	DIRECTION
1	12.5					Approaching
2	25.0					"
3	37.5					"
4	50.0	8.5 (28)	6.7 (22)	15.5 (51)	0.0 (0)	"
5	62.5	8.8 (29)	7.9 (26)	24.4 (80)	4.6 (15)	"
6	75.0	8.2 (27)	7.6 (25)	34.7 (114)	9.1 (30)	"
7	87.5	8.8 (29)	7.6 (25)	39.0 (128)	9.1 (30)	"
8	100.0	8.5 (28)	7.6 (25)	43.6 (143)	14.3 (47)	"
9	112.5	8.2 (27)	7.3 (24)	49.7 (163)	24.4 (80)	"
10	125.0	8.2 (27)	7.9 (26)	58.8 (193)	31.1 (102)	"
11	137.5	8.2 (27)	9.4 (31)	65.2 (214)	48.1 (158)	"
12	150.0	8.2 (27)	7.3 (24)	60.0 (197)	47.8 (157)	"
13	162.5					"
14	175.0					"
15	187.5					"
1	12.5					Receding
2	25.0					"
3	37.5					"
4	50.0	8.2 (27)	7.6 (25)	32.6 (107)	48.8 (160)	"
5	62.5		none			"
6	75.0	8.5 (28)	8.2 (27)	45.7 (150)	59.1 (194)	"
7	87.5	8.2 (27)	7.9 (26)	49.4 (162)	78.0 (256)	"
8	100.0	8.2 (27)	7.3 (24)	57.6 (189)	78.9 (259)	"
9	112.5	8.2 (27)	7.9 (26)	68.0 (223)	81.1 (266)	"
10	125.0	8.5 (28)	10.0 (33)	71.0 (233)	84.7 (278)	"
11	137.5					"
12	150.0					"
13	162.5					"
14	175.0					"
15	187.5					