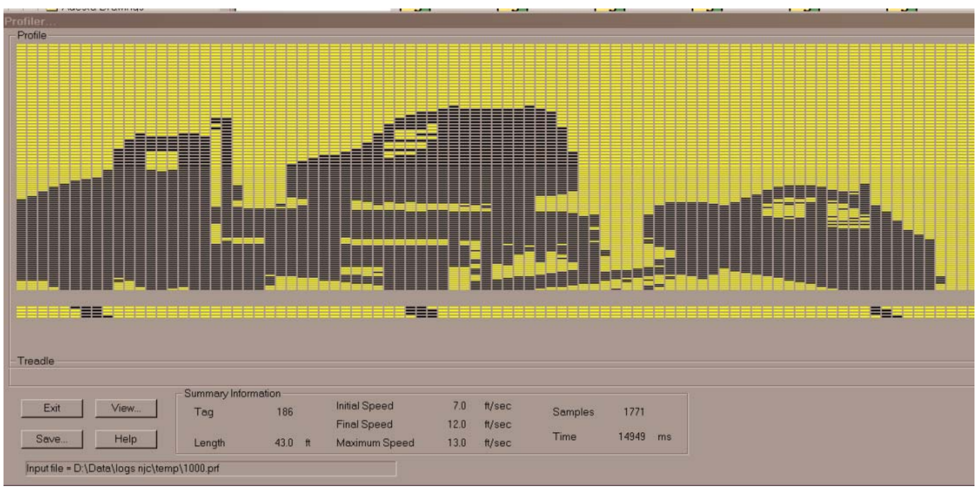
Technical Description

For

Model 120 Automatic Vehicle Classification System

Including

Doppler Radar, 10 Foot Light Curtain, Fiber Treadle, Dual Tire Detector and AVC Processor



TRANSPORT DATA SYSTEMS

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1.0 SUMMARY

The Model 120 AVC system provides automatic vehicle classification using a 10 foot light curtain, a Doppler radar and a fiber treadle based axle detection system including a dual tire detector.

2.0 CUSTOMER REQUIREMENTS

2.1 Vehicle Classes

A sample class table is shown in **Table 1; Sample Vehicle Classification Table** shown below. This table can be easily modified to fit other classification structures. Special classes such as buses can be added based on examination of the actual vehicle profiles. The final product will be customized to meet the customer class table.

Table 1; Sample Vehicle Classification Table

Class	Description	Axles	Dual Tires
1	Single wheel 2 axle vehicles (Auto, motorcycle, pickup)	2	No
2	(Class 1 + 1 axle trailer) Single wheel 3 axle vehicles	3	No
3	(Class 1 + 2 axle trailer) Single wheel 4 axle vehicles	4	No
4	(Class 1 + 3 axle trailer) Single wheel 5 axle vehicles	5	No
5	Dual wheel 2 axle vehicle	2	Yes
6	(Class 2 + 1 axle trailer) Single wheel 3 axle vehicles	3	Yes
7	(Class 2 + 2 axle trailer) Single wheel 4 axle vehicles	4	Yes
8	(Class 2 + 3 axle trailer) Single wheel 5 axle vehicles	5	Yes
9	Van	2	No
10	Two axle bus	2	Yes
11	Dual wheel 3 axle vehicle, 3 axle dual wheel	3	Yes
12	Three axle bus	3	Yes
13	Dual wheel 4 axle vehicle	4	Yes
14	Dual wheel 5 axle vehicle	5	Yes
15	Dual wheel 6 axle vehicle	6	Yes
16	Dual wheel 7 axle vehicle	7	Yes
17	Dual wheel 8 axle vehicle	8	Yes
18	Dual wheel 9 axle vehicle	9	Yes

2.2 Accuracy

The AVC shall classify vehicles to an accuracy of at least 99%.

2.3 Vehicle Speeds and Separation

The AVC system will differentiate between vehicles separated by a minimum of 0.3 meters at speeds of less than 100 kilometers per hour. At 200 kilometers per hour, the system will differentiate between two vehicles separated by a distance of 0.6 meters.

2.4 Interfaces

Sending vehicle's presence and class from the AVC to the host computer. Presence information can be used for vehicle separation.

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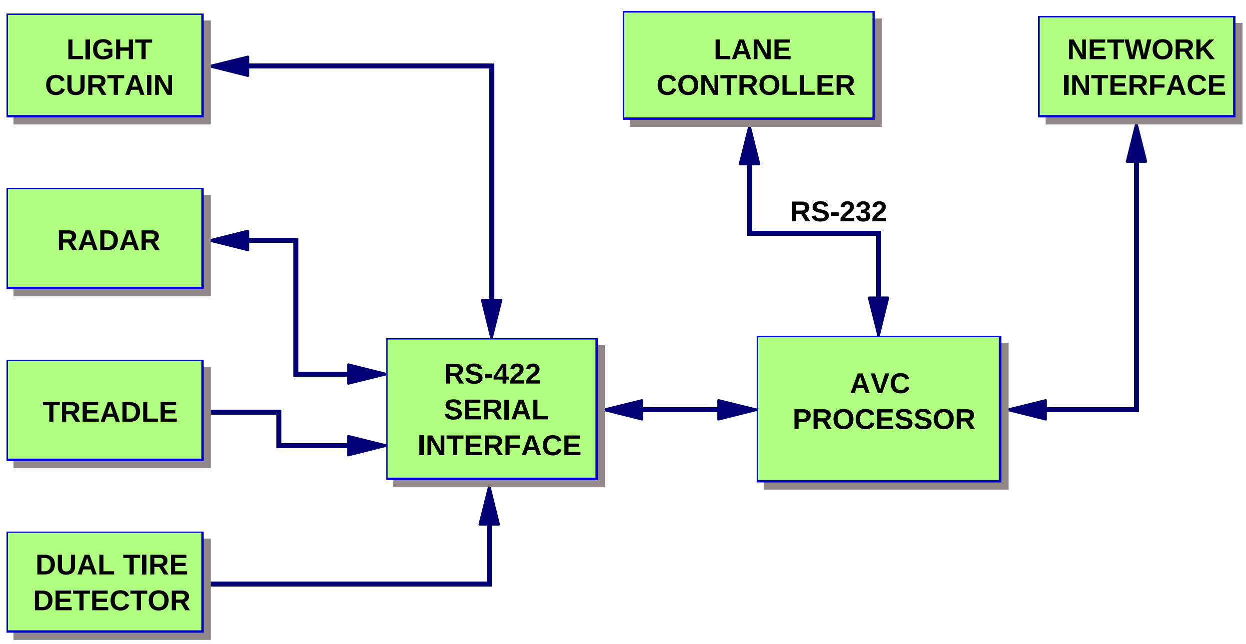
3.0 SYSTEM DESIGN

The AVC system consists of the light curtain, Doppler radar, single strip fiber treadle and dual tire detector. This system is capable of providing the classification accuracy to meet the requirements defined in Section 2.

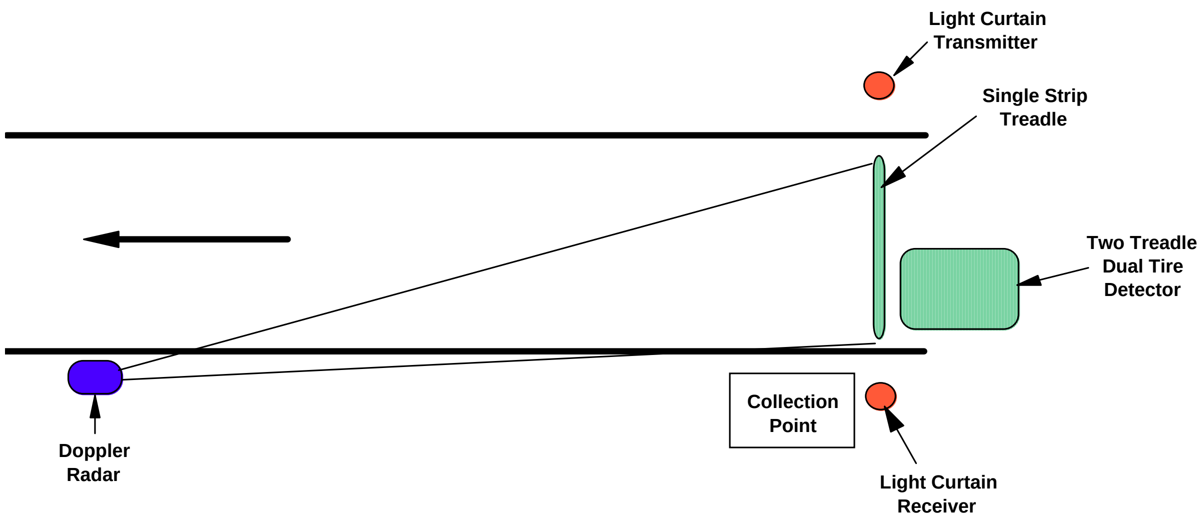
The block diagram of the AVC system is shown in Figure 3.0-1 below:

Figure 3.0-1; AVC Block Diagram



The lane layout for the AVC lane is shown in Figure 3.0-2 below:

Figure 3.0-2; AVC Subsystem Lane Geometry



The vehicle class types will be detected according to a set of rules similar to those described below in Table 3.0-1.

Table 3.0-1; AVC Produced Classes

Vehicle Type	Toll Classification	Vehicle Characteristics
Motorbike/Car	1 thru 4 depending on trailer	Two axles, Length<20 feet, No dual tires
Dual wheel 2 axle vehicle	5 thru 8 depending on trailer	Two axles, < 20ft without a van/bus profile, dual tires, height < 6 feet
Two Axle - Van	9	Two axles, No dual tires height > 6 feet length > 7 feet, flat height profile
2 Axle – Bus	10	Two axles, dual tires height > 6 feet, flat height profile length > 20 feet
3 Axle - Truck	11	Axle count, dual tires, variable height profile, axle location
3 Axle – Bus	12	Axle count, dual tires, flat height profile, axle location
4 or More Axle	13 – 18 depending on axles	Axle count

Additional classes can be added for each of these vehicle types pulling a trailer.

3.1 Features

The TDS Automatic Vehicle Classifier (AVC):

- Satisfies all of the individual classification requirements based on axles and tires. It also provides the length and the height profile of the vehicle for generation of additional classes.
- Detects hitches to identify trailing vehicles.
- Allows easy modification of classification categories to readily accommodate future rate structure changes or additional classes.
- Provides accurate vehicle velocity (max and/or average) – accuracy = 1% +/- 0.2 mph.
- Maintains the position of the vehicle at all times while in the collection zone. This includes stop and go operation as well as reverse motion.
- Transmits entry and exit information to the lane controller. This information is used by the lane controller to augment the lane logic and trigger the image capture system.
- Is composed of off-the-shelf technology from major suppliers.
- Has a system MTBF in excess of 20,000 hours.

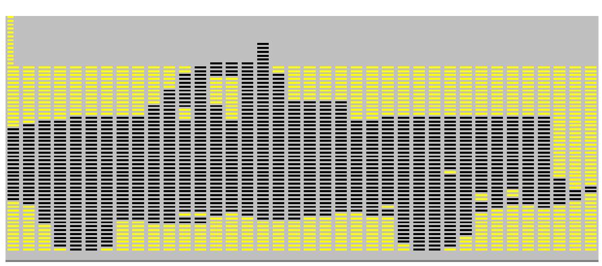
The system block diagram is shown in **Figure 1; System Block Diagram**. The basic building blocks of the system include a light curtain, a high frequency CW Doppler radar, a fiber treadle, a dual tire detector, and a processing system for processing of the sensor data. The light curtain provides a method for determining a detailed vertical profile of the vehicle looking from the top as the vehicle passes through the light curtain. The Doppler radar provides velocity data to allow for linear generation of the samples taken by the curtain elements. These various sensor inputs are fed to a processing system that is able to discriminate between various vehicle types based upon the number of axles, the number of tires on each axle, and the existence/position of a hitch.

The vehicle types will be segregated into categories consistent with the fare schedule. The equipment will be specifically programmed to recognize these individual categories.

3.2 Operational Philosophy

The automatic vehicle classification system described herein is a pattern recognition system that relies on special pattern recognition algorithms to categorize vehicles into a number of distinct types. It uses the length of the vehicle, the number and spacing of axles, and a height matrix depiction of the vehicle to form a complex pattern. This pattern is then fed to discrimination software that correlates with one of a predetermined set of vehicle types. A picture of an actual profile of an automobile is shown in **Figure 3.2-1; Vehicle Profile**.

Figure 3.2-1; Vehicle Profile



Vehicle detection and profiling are accomplished by processing the sensor data from the radar, light curtain, and treadle detector. The AVC processor receives frequent sensor messages from the radar and light curtain. Each radar message reports the distance and velocity of up to seven targets that the radar is currently sensing in its beam. Each light curtain message provides a report of the beam status of each of the 120 beams. The treadle inputs are sampled each time a light curtain message is received. The vehicle detection process begins when the light curtain reports sufficient penetration concurrent with a radar report of an object moving in the vicinity of the lane in the path of the light curtain beams. A filter is implemented to eliminate false classifications from being reported due to penetration of the light curtain by objects other than vehicles.

While the light curtain is sufficiently penetrated, the processor creates a profile of the vehicle using the Doppler radar velocity information to determine which position in the vehicle profile to store each light curtain and treadle sample. This process continues until the light curtain no longer detects a presence in the path of the light curtain beams. The vehicle profile is then sent to the correlation process where the classification will be determined.

The correlation process begins with the series of tests to determine the characteristics of the vehicle. These characteristics are the length of the primary vehicle, the presence/location of a hitch, the maximum height and height variance of the primary vehicle, the number of axles and their locations, and certain other discrimination criteria. The test results are then correlated with a table of characteristic values that is configured for the customer classification schedule. This table of characteristics is stored in a configuration file that is separate from the AVC application software. This provides an easy method for updating the class schedule should the customer require modifications. After the classification has been determined the classification message is transmitted to the lane controller application. The classification message includes the maximum velocity of the vehicle measured during the period that it was within the light curtain. The message also includes the vehicle height and length as well as the total axle count.

After the vehicle has been classified the system continues to track the location of the vehicle in the lane.

A key element in this design is the use of the CW Doppler radar. When vehicles are traveling at higher speeds, the problem of resolving two vehicles in close proximity is particularly vexing. However one characteristic that these two vehicles have in common is that their velocities are obviously very nearly the same. Therefore the Doppler return from each of the vehicles is also nearly the same. The light curtain provides excellent vehicle separation. The current design allows for separating two vehicles that are within 4 foot of each other at a velocity of 100 miles per hour. At more reasonable speeds (60 mph), the vehicles may be within two feet of each other and at manual lane speeds, the vehicles may be within 8 inches of each other. The processor uses the velocity provided by the Doppler radar to determine the positioning of the various samples in the vehicle profile. Since in this particular case the velocities of the two adjacent vehicles and the corresponding Doppler radar outputs are nearly identical, errors in the sampling distance that are due to returns from the adjacent vehicle are negligible.

The output from the Doppler radar provides an excellent measure of the vehicle velocity. This data will be transmitted to the lane controller as part of the primary AVC message.

The AVC software can provide any/all of the following functions:

- Receipt of data from the radar
- Receipt of data from the light curtain
- Receipt of data from the axle detector
- Hitch detection
- Vehicle presence detection
- Vehicle position tracking through the collection zone
- Determination of the vehicle classification
- Vehicle speed
- Lane entry and exit messages
- Vehicle At ACM message for associating coins with a vehicle
- AVC system diagnostics (remote or local)
- Error reporting to the host processor

The processor will be able to handle all types of vehicle motion including negative speeds. It will identify back-outs and terminate the transaction.

4.0 DETAILED DESCRIPTION – EQUIPMENT

4.1 Doppler Radar

The SI-3 was designed to meet a wide variety of demands, including radar message trailers, computers, and conveyer belt controls. A self-contained, stand-alone unit, the SI-3's internal firmware is customizable, allowing changes to range, output format as well as many other options.

4.1.1. Features

- K-Band Antenna
- Directional
- RS232 Serial Port
- Stationary Mounted Radar Systems
- 5-150 mph (8-241 km/h) Speed Range
- Range: 1,500 ft default; 3,000 ft max.

The radar is a very low power device (< 5 milliwatts CW). It has complete FCC approval for operation on the open road and is not an RF hazard to humans under any conditions.

4.2 STI Light Curtain

The Light Curtain is a Model VS 6500 Vehicle Scanner manufactured by Scientific Technologies Inc. (STI). The Light Curtain consists of 120 vertically mounted, infrared beams housed in a rugged aluminum case.

The specifications for the scanner are as follows:

- 10 foot high consisting of 120 infra-red beams (80 beams at vertical spacing of 0.75 inches, 40 beams at vertical spacing of 1.5 inches).
- RS422 interface to AVC processor
- High degree of immunity to all kinds of ambient lighting
- Non-volatile RAM to store user's settings
- Special software ignores small objects such as snowflakes while still detecting narrow trailer hitches.
- 220/240 VAC (50 Hz) Power Supply.

The curtain functions solely as a sensor providing raw data to the AVC processor. The data supplied by the curtain supports the primary profiling function in addition to requirements for axle detection. The curtain will consist of a pair of primary stanchions containing respectively, the transmit and receive elements required for 120 beams. The curtain is supplied by Scientific Technology Incorporated (STI).

4.2.1. Curtain Array

The light curtain array will be ten feet in height and will contain 120 beams. The bottom five feet of the curtain will contain 80 beams at a beam spacing of 0.75 inch. The top five feet will contain 40 beams at a beam spacing of 1.5 inches. The lower segment of the curtain, with the tight beam spacing will readily detect a hitch with a vertical width of one inch.

4.2.2. Curtain Processor

A single curtain processor will be supplied which controls the polling of the curtain and the secondary elements. The processor scans the entire 120 elements in approximately 7 milliseconds. The data is transferred in a 15 byte message at 38.4 kilobits/second. The standard processor is mounted in a NEMA case. The unit will operate from 220 VAC input. The maximum input power requirement is 100 mA.

4.2.3. Stanchion Enclosures

Enclosures will be supplied to protect the transmit and receive structures from the environment. The enclosures will include environmental controls to adequately control the internal temperature and humidity of the enclosures. Each unit will have a front door, which will open to provide access to the actual equipment. Each door will contain a special window through which the beams are transmitted and received. Internal heating will ensure that condensation does not build up on the windows. Each housing will require 220 VAC @ 1.5A for the operation of the environmental control unit.

4.3 Axle Detector/Dual Tire Detector

The axle detector will consist of a single fiber optic treadle with a length of 3 meters. The dual tire detection will use two fiber optic treadles, each with a length of 2 meters. The two fiber optic treadles are placed at a nominal 14 inch separation at an angle of 30 degrees relative to the flow of traffic.

4.3.1. Fiber Treadle

The fiber optic treadle is manufactured by Sensorline GmbH, a German firm. The fiber treadle installation includes the following items:

- SPZ-Series Fiber Optic Traffic Sensors
- SL MD-220 Optical Transmittance Analyzer

4.3.2. SPZ-Series Fiber Optic Traffic Sensors

These sensors are available in any length from 1m to 4m. Sensitivity can vary from few grams up to many tons by selecting the mode of installation. Their completely non-metallic structure ensures the highest protection against any kind of electromagnetic interference. The SPZ-series sensors have a fiber optic structure fitted into a special conduit that is designed for permanent embedding into the road surface. The materials used enable a range of in-ground operating temperature from -40°C to +80°C (-40°F to 176°F). The feeder cables are spliced to the sensor fiber, so the feeder length must be specified in advance.

4.3.3. SL MD-220 Optical Transmittance Analyzer

The SL MD-220 Optical Transmittance Analyzer is a small two-channel dynamic (AC-coupled) interface device in a plastic module housing. An internal Schmitt-Trigger with light-level-controlled threshold enables sensor-independent trigger sensitivity. The unit includes internal failure detection to indicate out-of-range conditions (i.e. broken fiber) by a particular output signal.

The unit provides optocoupler outputs for trigger and failure signals. The analog signal outputs are short-circuit-protected. The input power connections include reverse power protection. No adjustment necessary to the unit. The unit uses a powerful VIS LED (Red) for feed cable lengths up to 125m or a NIR LED (Class 3A Laser) for feeder cable lengths over 125m.

The SL MD-220 is an interface ideally suited for all common axle detection, axle counting and speed measuring purposes, but also a convenient means to simply feed light into an optical fiber and measure light emerging from a fiber. It is designed in a way that it can easily be programmed to meet a maximum number of custom requirements that can be further extended by supplementary circuits for additional functionality.

The SL MD-220 feeds a variable amount of light into the fiber thus providing automatic adaptation for large variations in the sensor and feeder transmittance.

4.3.4. Fiber Treadle Quick Replacement Frame and Carrier

The fiber treadle is designed to be installed directly into the roadway using a special epoxy to encapsulate the fiber treadle. This provides excellent performance. However in the event of a failure of the treadle, the encapsulation and the enclosed fiber treadle must be physically removed from the roadway and replaced. This will typically remove the lane from service for a minimum of 24 hours while the epoxy cures.

In those applications where a quicker replacement is required, SensorLine offers a plastic treadle frame and carrier combination. The frame is installed into the roadway and the carrier is then bolted into the frame. The fiber treadle is encapsulated with resin into the carrier by TDS. The user then installs the carrier into the frame. The fiber cable is routed through the junction box on the end of the frame.

4.4 AVC PROCESSOR

The AVC software module will be installed on an AVC Processor. TDS offers a choice of two different AVC processor options. One is for installation inside a controlled environment like the plaza and the other is for external installations.

For the inside installation, the processor is a Advantech ARK Series Industrial controller. It uses an Intel Core2Duo™ processor. It includes 2 gigabytes of RAM and a 200 Gb hard drive. It will contain dual Ethernet ports for LAN connections. The unit will run the Linux operating system.

For an external installation, the processor will be mounted in a hardened enclosure designed to be installed in tunnels and open air booths. The enclosure is equipped with a heat exchanger to allow for completely sealed operation.

The AVC unit will be equipped with a four channel RS-422 serial channel board for interfacing to the sensors. The AVC unit will include an RS-232 port for interfacing with the host computer. One processor is required for each lane.

In the event the user system design incorporates a lane controller running Linux or Windows XP/2000, the AVC software can be integrated into the lane controller. This does require a development effort by the system integrator.

4.4.1. AVC Diagnostics

The AVC module will monitor the operation of each of the sensors associated with the AVC subsystem. Whenever a failure occurs with any of these sensors, the AVC module will send a warning message to the user lane controller.

The AVC system will include a number of degraded modes to facilitate continued operation when one or more of the AVC sensors are not functioning properly.

5.0 INSTALLATION

5.1 Curtain Installation

The curtain consists of the transmit and receive elements with their enclosures and the processor unit. An STI supplied cable connects each of the two external elements with the processor unit.

5.1.1. Transmit/Receive Tower Installations

A pair of enclosures must be installed along the edge of the lane. The enclosure plate should be installed at a consistent distance above the roadway. Typically this should be approximately 6 to 8 inches above the level of the pavement. AC power must be brought to the enclosures in order to power the completely self-contained environmental control units.

Once the enclosures have been installed, the curtain transmit and receive elements are bolted into the enclosures and aligned. The curtain transmit and receive elements can be moved in both horizontal angle (azimuth) and vertical height to allow for alignment of the curtain. A separate gain control in the curtain processor is then adjusted to maximize the sensitivity of the light curtain thereby optimizing its ability to see small hitches.

5.1.2. Curtain Processor Installation

The curtain processor consists of an industrial case containing a power supply and a processor board. The power supply provides power to the processor board. The unit should be installed in the booth. The power supply will require 220 VAC power.

5.1.3. Curtain Cabling Installation

A single RS-422 cable will connect the curtain processor to the lane controller in the plaza. TDS assumes that the customer will provide the cable for this installation. Two STI supplied cables connect the curtain processor with the external transmit and receive elements. These cables are provided by TDS as part of the light curtain.

5.2 Radar Installation

The radar installation consists of:

- Mounting the radar mount on the island.
- Attaching the radar enclosure to the radar mount.
- Installing a single AC power cable to the radar.
- Installing a single fiber cable between the radar and the AVC processor.

5.2.1. Radar Installation

TDS uses a standard Pelco mount for the Doppler radar. The mount is attached to the island with four bolts. The mount is adjustable in both azimuth and elevation to allow for beam alignment of the radar.

5.2.2. Radar Signal Cabling Installation

A single fiber cable connects the radar to the AVC processor. Fiber converters are provided within the radar enclosure and at the AVC processor. The fiber cable will be supplied with the fiber connectors installed on both ends. This cable should be run inside of a conduit to the AVC processor location.

5.3 Treadle Installation

The treadle will be installed directly below the light curtain. The fiber is connected to the fiber interface box located near the AVC processors. The fiber must be run through ducting from the treadle to the fiber interface box. TDS will provide the fiber. Installation instructions for the installation of the fiber will be provided by TDS. The actual treadle sensor can be either permanently installed in the roadway or can be installed using a treadle frame and carrier for quick replacement.

5.3.1. Permanent Treadle Installation

In the permanent installation, the fiber treadle is potted into the road surface. A slot is cut into the concrete. The fiber treadle is positioned in the slot and the potting compound is poured into the slot. The potting compound used to install the treadle will be supplied by TDS. For a detailed description of this installation process, please visit the Sensorline website - http://www.sensorline.de/new/prd1.htm#instproc

5.3.2. Quick Replacement Treadle Installation

The use of the treadle frame and carrier allow for quick replacement of the treadle in the event of a failure. In this installation, the treadle frame is permanently installed into the concrete. The treadle carrier is delivered by Sensorline with the treadle already potted in place. Once the frame has been installed, the treadle carrier is bolted into the frame. Then the fiber is pulled through the conduit and the cover plate is installed.

5.4 AVC Processor Installation

The AVC processor can be located anywhere within 500 feet of the lane.