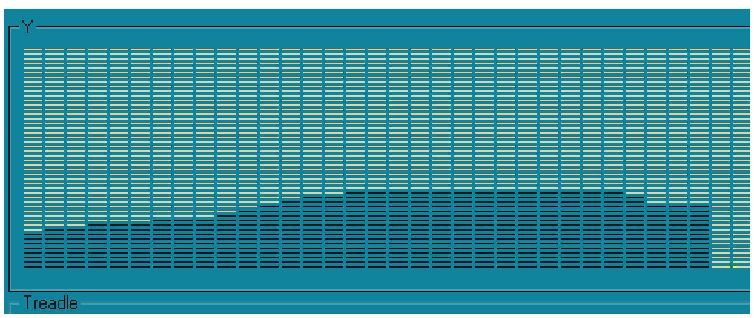
Technical Description

For

Model 210 Automatic Vehicle Classification System

Including

Doppler Radar, Laser Scanner, Axle Detection System and AVC Processor



TRANSPORT DATA SYSTEMS

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1.0 SUMMARY

The purpose of this document is to define the design of the Model 210 AVC Classification Equipment. This system provides the capability of classifying vehicles into a complex class structure based on vehicle length, height and width profiles and axle location.

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	Hitch
1	Motorcycle	2	No
2	Small 2 axle vehicles except for van	2	No
3	(Class 2 + 1 axle trailer)	3	Yes
4	(Class 2 + 2 axle trailer)	4	Yes
5	(Class 2 + 3 axle trailer)	5	Yes
6	Large 2 axle vehicle except for bus	2	No
7	(Class 6 + 1 axle trailer)	3	Yes
8	(Class 6 + 2 axle trailer)	4	Yes
9	(Class 6 + 3 axle trailer)	5	Yes
10	Van	2	No
11	Two axle bus	2	No
12	3 axle vehicle except for bus	3	No
13	3 Axle Bus	3	No
14	Dual wheel 4 axle vehicle	4	No
15	Dual wheel 5 axle vehicle	5	No
16	Dual wheel 6 axle vehicle	6	No
17	Dual wheel 7 axle vehicle	7	No
18	Dual wheel 8 axle vehicle	8	No
19	Dual wheel 9 axle vehicle	9	No

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 1.5 meters at speeds of less than 60 kilometers per hour. At 150 kilometers per hour, the system will differentiate between two vehicles separated by a distance of 3.0 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.

3.0 SYSTEM DESIGN

The AVC system consists of the laser scanner, Doppler radar, single strip fiber treadle and AVC processor. 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 **Exhibit 3.0-1; AVC Block Diagram**.

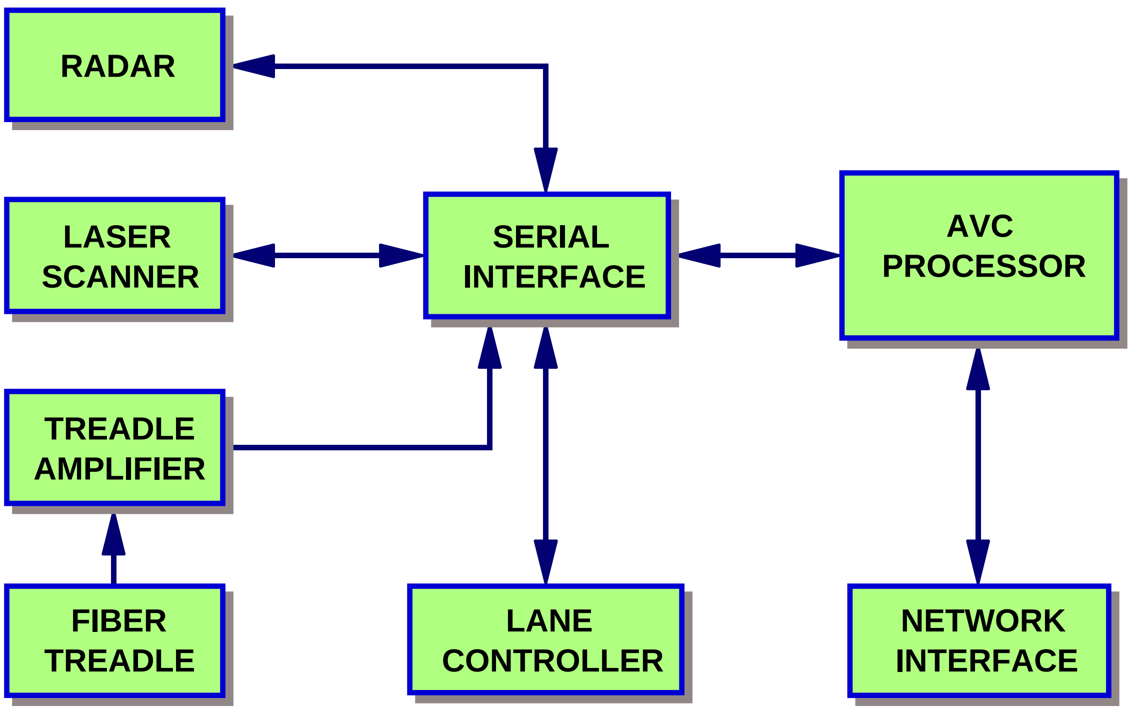

Exhibit 3.0-1; AVC Block Diagram

The lane layout for the AVC lane is shown in **Figure 3.0-2; AVC Lane Geometry**.

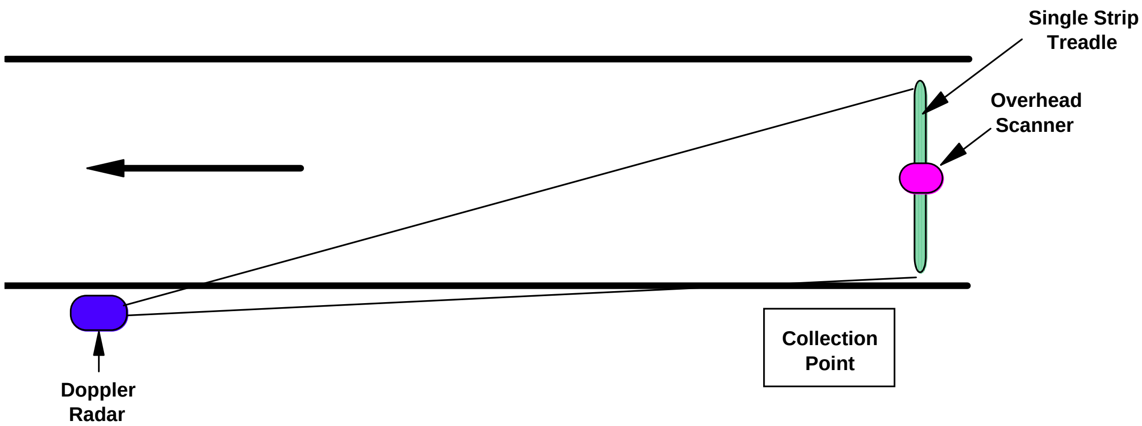

Exhibit 3.0-2: AVC Lane Geometry

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 - Sample

Vehicle Type	Toll Classification	Vehicle Characteristics
Motorbike	1	Length < 7 feet, width < 4 feet, height profile, two axles
Small 2 axle vehicle except for van	2 thru 5 depending upon trailer	Length > 7 feet, < 20 feet Height < 6 feet Two axles
Large 2 axle vehicle except for bus	6 thru 9 depending upon trailer	Length > 20ft without a van/bus profile (height > 6 feet)
Van	10	Two axles Height > 6 feet Length >7 feet, < 20 feet Height profile
2 axle bus	11	Two axles Height > 6 feet Length > 20 feet Height profile
3 axle vehicle except for bus	12	Three axles Height profile
3 axle bus	13	Three axles Height Profile
4 or More Axle	14 thru 19 depending upon	Axle count

	axle count

3.1 Features

The TDS Automatic Vehicle Classifier (AVC):

- Satisfies all of the individual classification requirements based on axles. It also provides the length and the height/width profile of the vehicle for generation of additional classes.
- 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 can be 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 3.0-1; System Block Diagram**. The basic building blocks of the system include a laser scanner, a high frequency CW Doppler radar, a fiber treadle, and a processing system for processing of the sensor data. The laser scanner provides a method for determining a detailed cross-section of the vehicle looking from the top as the vehicle passes through the scanner. The Doppler radar provides velocity data to allow for linear generation of the samples taken by the scanner 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, the number of tires, and a height by width 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 **Exhibit 3.2-1; Vehicle Profile**. The top portion of the image is the height profile of the vehicle. The bottom line represent the individual output of the single fiber treadle strip used for the axle detection.

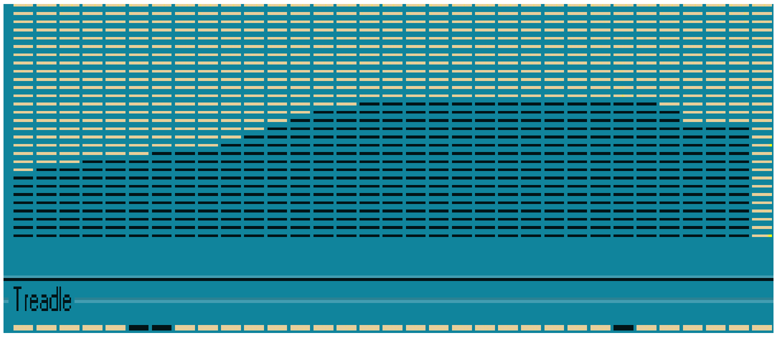

Exhibit 3.2-1; Vehicle Profile

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

While the laser scanner 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 laser scanner and treadle sample. This process continues until the scanner no longer detects a presence in the laser scan path. 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 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 it 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 under the laser scanner. 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. Front and rear camera trigger messages are provided for the image capture system. In a given lane, the trigger points are determined from the relative locations of the laser scanner and the image capture focal point. The locations of these trigger points are specified in an AVC configuration file. This method allows the trigger points to be easily configured on an individual lane basis to accommodate differing lane geometries/layouts.

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 laser scanner acts as a laser curtain to provide 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 will provide for the following functions:

- Receipt of data from the radar
- Receipt of data from the laser scanner
- Receipt of data from the axle detector
- Vehicle presence detection
- Vehicle position tracking through the collection zone
- Determination of the vehicle classification
- Vehicle speed
- Front and rear camera triggers for the VES system
- 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 lane controller

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

The use of the overhead laser scanner provides excellent vehicle separation and hitch detection. The hitch detection module uses information from several different range samples to determine the presence of a hitch. This insures that the system accurately detects the presence of a hitch, thereby eliminating the possibility of two classifications being generated for the same vehicle or connecting two closely spaced vehicles into a single vehicle. The combination of the laser scanner, the radar, and the treadle provides sufficient information to effectively filter out non-vehicle traffic through the lane (i.e. collectors).

The width resolution is also useful in determining if multiple vehicles (motorcycles) are passing through the lane simultaneously.

4.0 SYSTEM HARDWARE

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.

4.1.1.1. Features

- K-Band Antenna
- Directional
- RS232 Serial Port
- 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 Laser Profiler

The laser profiler is a model LMS211 produced by Sick Optic-Electronic. It is a non-contact measuring system that scans its surroundings two dimensionally. The scanner does not require any reflectors or positional markers to function as a scanning system.

The LMS 211 operates by measuring the time of flight of laser light pulses. The time between emission and reception of a light pulse, after it has been reflected from a surface, is directly proportional to the distance between the light source and the object. The laser can scan a large area by using a pulsed laser beam deflected by a rotating internal mirror. The LMS can produce the contour of an object using a rapid sequence of distance measurements. The serial data itself is sent to the lane controller in real time via the RS-422 link.

The unit operates at a scanning rate of 75 scans per second. The scan angle that is reported is programmable. For this application it will be set to 68 degrees. The beam width of the laser beam is approximately 1 degree. The reported angular scanning resolution is programmable. For this application it will be set to 4 degrees, resulting in 17 segments being reported per scan. The range resolution of this configuration is approximately 50 millimeters.

The unit includes internal heaters for environmental control. A built-in thermostatically controlled heater and a front screen heater enable the LMS to be used at temperatures to minus -30 degrees Centigrade. The heaters are activated at 10 degrees Centigrade to prevent any thawing from occurring within the unit.

The unit is delivered with an optional dust prevention shield. This shield prevents direct exposure of the front screen to precipitation or sources of dirt.

The scanner unit weighs approximately 9 kilograms. The unit is delivered with a separate mounting bracket that provides adjustment of the device in both of the relative axes.

The electronic part of the sensor is powered directly from a regulated 24 VDC 1 amp power supply. The scanner heater is also powered from 24 VDC at 6 amps. The heater supply does not require regulation. Both the electronics and the heaters can be powered from the same primary power supply if desired.

TDS provides a maintenance screen in the AVC software package that allows a technician to easily align the scanner and configure the height and lane width settings during installation.

4.3 Axle Detector

The axle detector will consist of a single fiber optic treadle with a length of 3 meters.

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 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. 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/2000/7, 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.

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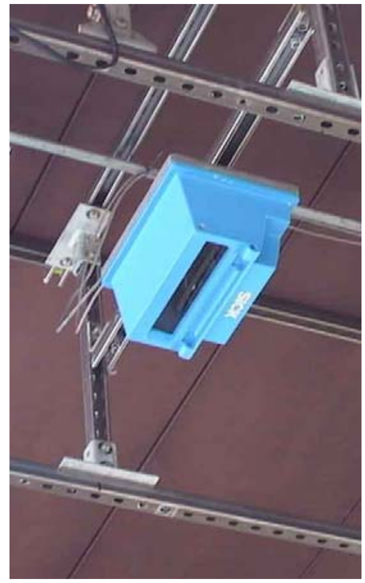
5.0 INSTALLATION

5.1 Laser Scanner Installation

The laser installation consists of:



- Mounting the laser mount on the overhead structure.
- Mounting the laser power supply near the scanner. The laser power supply will need to be put into an enclosure for external mounting.
- Installing a single cable between the power supply and the scanner.
- Installing a single cable between the scanner and the AVC processor.

The laser scanners must be installed overhead at a height of approximately 18 feet from the road surface.

5.1.1. Scanner Installation

The scanner is supplied with a mounting bracket for attachment to the structure. The mount is adjustable to allow for alignment of the scanner.

5.1.2. Scanner Power Supply Installation

The scanner requires a special 24 volt DC power supply. TDS will supply this power supply in a separate rugged container for installation near the scanner installation. The power supply for the scanner must be mounted either on the gantry or at the base of the gantry

5.1.3. Scanner Cabling Installation

The scanner is connected to the AVC processor via an RS-422 link. A single cable connects the scanner to the AVC processor and the scanner power supply. The cable will be supplied with the scanner connector installed and the AVC processor connections left un-terminated. This cable should be run inside of a conduit to the AVC processor location.

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. A conduit is connected to the junction box for routing of the fiber connection to the treadle interface box installed near the lane controller.

The treadle carrier is delivered 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.