SECTION 660
VEHICLE DETECTION SYSTEM

660-1 Description

Furnish and install a vehicle detection system in accordance with the Contract Documents. Use only vehicle detection systems that meet the requirements of this Specification and are listed on the Department's Approved Product List (APL).

660-2 Materials

660-2.1 Classification of Types: Vehicle detection and data collection systems are classified by the type of function they perform and the type of technology that they employ.

660-2.1.1 Functional Types: Provide the functional type detailed in the Plans.

660-2.1.1.1 Vehicle Presence Detection System: Vehicle presence detectors produce a corresponding output any time that a vehicle occupies the physical or virtual area of the detector.

660-2.1.1.2 Traffic Data Detection System: Traffic data detectors provide presence, volume, occupancy, and speed data for the lanes they are configured to monitor.

660-2.1.1.3 Probe Data Detection Systems: Probe data detection systems provide speed data and travel times for a road segment. Probe data detectors use automatic vehicle identification (AVI) technologies to establish a unique identifier for each vehicle they detect. This identifier is then transmitted to a central site where it can be matched to past or future detections of the same vehicle at different detector locations.

660-2.1.2 Technology Types: Provide the detection technology type detailed in the Plans. Detection technology types include inductive loop, video, microwave, wireless magnetometer, and AVI systems.

660-2.1.2.1 Inductive Loop: An inductive loop detection system uses a minimum of one inductive loop and loop detector. The system operates by energizing and monitoring wire embedded in the road surface to detect vehicle presence and provide an output to traffic controllers or other devices that can generate volume, occupancy, and speed data (detection output).

660-2.1.2.1.1 Inductive Loop Detector Units: Ensure rack mount inductive loop detector units meet the requirements of NEMA TS-2-2003. Ensure shelf mount detector units meet the requirements of NEMA TS-1-1989.

660-2.1.2.1.2 Loop Wire: Use No. 12 AWG stranded copper wire with Type XHHW cross-linked polyethylene insulation, or No. 14 AWG stranded copper wire with Type XHHW cross-linked polyethylene insulation and an additional outer sleeve composed of polyvinylchloride or polyethylene insulation that meets the requirements of International Municipal Signal Association (IMSA) 51-7.

660-2.1.2.1.3 Shielded Lead-in Cable: Use No. 14 AWG two conductor, stranded copper wire with shield and polyethylene insulation, meeting the requirements for IMSA 50-2.

660-2.1.2.1.4 Splicing Material: Butt-end connectors may be used for splicing the loop wire to the lead-in cable. Butt-end connectors must be non-insulated. Use resin-core solder for soldered splices. Splicing tape must be self-fusing silicone rubber. Ensure insulated tubing used to cover splice is heat-shrinkable, cross-linked polyethylene with a silicon sealant inside the tubing and an insulation rating of at least 600 V.

660-2.1.2.1.5 Loop Sealant: Ensure loop sealant is intended for traffic loop embedding in both asphalt and concrete pavement. Ensure that multi-component systems have simple mix rations of 1:1 or 2:1 or are supplied in pre-measured containers in which all contents of both packages are to be mixed.

Ensure that loop sealant is self-leveling when applied. Ensure that loop sealant does not run out of unlevel slots as tested for viscosity using ASTM D562 at 77°F. Ensure loop sealant is tack free within a maximum of 2 hours from time of application and when cured as tested for tack free time using ASTM C679 at 77°F.

Ensure loop sealant securely adheres to concrete and asphalt when installed in a 3/8 inch by 3 inch saw cut, cured for 2 weeks at 77°F as tested for adhesion using visual inspection. Ensure loop sealant shows no visible signs of shrinkage after curing when installed in a 3/8 inch by 3 inch saw cut, cured for 2 weeks at 77°F as tested for shrinkage using a dimensional measurement.

Ensure loop sealant resists weather, oils, gasoline, antifreeze, and brake fluid as tested for absorption using ASTM D570 for water, No. 3 oil, gasoline, antifreeze, and brake fluid for 24 hours. Ensure loop sealant resists penetration of foreign materials as tested for durometer hardness using ASTM D2240 Shore A for 24 hours.

Ensure loop sealant resists cracking caused by expansion and contraction due to temperature changes as tested for tensile strength and elongation using ASTM D412.

Ensure loop sealant does not become brittle with age or temperature extremes as tested for weight loss, cracking, and chalking using ASTM C1246.

Ensure loop sealant has a minimum shelf life of 1 year in undamaged containers when stored per manufacturer recommendations.

660-2.1.2.2 Video: A video vehicle detection system (VVDS) uses one or more cameras and video analytics hardware and software to detect vehicle presence, provides a detection output, and generates volume, occupancy, and speed data.

660-2.1.2.2.1 Configuration and Management: Ensure that the VVDS is provided with software that allows local and remote configuration and monitoring. Ensure that the system can display detection zones and detection activations overlaid on live video inputs.

Ensure that the VVDS allows a user to edit previously defined configuration parameters, including size, placement, and sensitivity of detection zones.

Ensure that the VVDS retains its programming in nonvolatile memory. Ensure that the detection system configuration data can be saved to a computer and restored from a saved file. Ensure that all communication addresses are user programmable.

Ensure that the detection system software offers an open Application Programming Interface (API) and software development kit available to the Department at no cost for integration with third party software and systems.

660-2.1.2.2.2 Detection Camera: Provide a camera that is furnished or approved by the video detection system manufacturer.

660-2.1.2.2.3 Machine Vision Processor: Ensure the VVDS includes a machine vision processor that allows video analysis, presence detection, data collection, and interfaces for inputs and outputs as well as storage and reporting of collected vehicle detection data.

660-2.1.2.2.4 Communications: Ensure that the VVDS includes a minimum of one serial or Ethernet communications interface.

Ensure the serial interface and connector conforms to Telecommunications Industry Association (TIA)-232 standards. Ensure that the serial ports support data rates up to 115200 bps; error detection utilizing parity bits (i.e., none, even, and odd); and stop bits (1 or 2).

Ensure that wired Ethernet interfaces provide a 10/100 Base TX connection. Verify that all unshielded twisted pair/shielded twisted pair network cables and connectors comply with TIA-568.

Ensure wireless communications are secure and that wireless devices are Federal Communications Commission (FCC) certified. Ensure that the FCC identification number is displayed on an external label and that all detection system devices operate within their FCC frequency allocation.

Ensure cellular communications devices are compatible with the cellular carrier used by the agency responsible for system operation and maintenance.

Ensure the system can be configured and monitored via one or more communications interface.

660-2.1.2.2.5 Video Inputs and Outputs: Ensure that analog video inputs and outputs utilize BNC connectors.

660-2.1.2.2.6 Solid State Detection Outputs: Ensure outputs meet the requirements of NEMA TS2-2003, 6.5.2.26.

660-2.1.2.2.7 Electrical Requirements: Ensure the system operates using a nominal input voltage of 120 volts of alternating current (V_{AC}). Ensure that the system will operate with an input voltage ranging from 89 to 135 V_{AC}. If a system device requires operating voltages other than 120 V_{AC}, supply a voltage converter.

660-2.1.2.3 Microwave: A microwave vehicle detection system (MVDS) transmits, receives, and analyzes a FCC-certified, low-power microwave radar signal to detect vehicle presence, provide a detection output, and generate volume, occupancy, and speed data.

Ensure that sidefire MVDS sensors used for data collection have a minimum 200-foot range and the capability to detect 8 lanes of traffic.

660-2.1.2.3.1 Configuration and Management: Ensure that the MVDS is provided with software that allows local and remote configuration and monitoring. Ensure that the system software can display detection zones and detection activations in a graphical format.

Ensure that the MVDS allows a user to edit previously defined configuration parameters, including size, placement, and sensitivity of detection zones.

Ensure that the MVDS retains its programming in nonvolatile memory. Ensure that the detection system configuration data can be saved to a computer and restored from a saved file. Ensure that all communication addresses are user programmable.

Ensure that the detection system software offers an open API and software development kit available to the Department at no cost for integration with third party software and systems.

660-2.1.2.3.2 Communications: Ensure that major components of the detection system (such as the sensor and any separate hardware used for contact closures), include a minimum of one serial or Ethernet communications interface.

Ensure the serial interface and connector conforms to TIA-232 standards. Ensure that the serial ports support data rates up to 115200 bps; error detection utilizing parity bits (i.e., none, even, and odd); and stop bits (1 or 2).

Ensure that wired Ethernet interfaces provide a 10/100 Base TX connection. Verify that all unshielded twisted pair/shielded twisted pair network cables and connectors comply with TIA-568.

Ensure wireless communications are secure and that wireless devices are FCC-certified. Ensure that the FCC identification number is displayed on an external label and that all detection system devices operate within their FCC frequency allocation.

Ensure cellular communications devices are compatible with the cellular carrier used by the agency responsible for system operation and maintenance.

Ensure the system can be configured and monitored via one or more communications interface.

660-2.1.2.3.3 Solid State Detection Outputs: Ensure outputs meet the requirements of NEMA TS2-2003, 6.5.2.26.

660-2.1.2.3.4 Electrical Requirements: Ensure the microwave detector will operate with a nominal input voltage of 12 V_{DC}. Ensure the microwave detector will operate with an input voltage ranging from 89 to 135 V_{AC}. If any system device requires operating voltages other than 120 V_{AC}, supply a voltage converter.

Ensure that the detector is FCC-certified and that the FCC identification number is displayed on an external label. Ensure that the detector transmits within a frequency band of 10.525 gigahertz, plus or minus 25 megahertz, or another FCC-approved spectral band.

660-2.1.2.4 Wireless Magnetometer: A wireless magnetometer detection system (WMDS) uses one or more battery-powered wireless sensors embedded in the road surface, which communicates data by radio to a roadside receiver. Wireless magnetometer systems detect vehicle presence and provide a detection output to traffic controllers or other devices that can generate volume, occupancy, and speed data.

660-2.1.2.4.1Configuration and Management: Ensure that the detection system is provided with software that allows local and remote configuration and monitoring.

Ensure that the WMDS allows a user to edit previously defined configuration parameters.

Ensure that the WMDS retains its programming in nonvolatile memory. Ensure that the detection system configuration data can be saved to a computer and restored from a saved file. Ensure that all communication addresses are user programmable.

Ensure that the detection system software offers an open API and software development kit available to the Department at no cost for integration with third party software and systems.

660-2.1.2.4.2 Communications: Ensure that components of the detection system (such as sensors, access points, and contact closure cards) include a minimum of one serial or Ethernet communications interface.

Ensure the serial interface and connector conforms to TIA-232 standards. Ensure that the serial ports support data rates up to 115200 bps; error detection utilizing parity bits (i.e., none, even, and odd); and stop bits (1 or 2).

Ensure that wired Ethernet interfaces provide a 10/100 Base TX connection. Verify that all unshielded twisted pair/shielded twisted pair network cables and connectors comply with TIA-568.

Ensure wireless communications are secure and that wireless devices are FCC-certified. Ensure that the FCC identification number is displayed on an external label and that all detection system devices operate within their FCC frequency allocation.

Ensure cellular communications devices are compatible with the cellular carrier used by the agency responsible for system operation and maintenance.

Ensure the system can be configured and monitored via one or more communications interface.

660-2.1.2.4.3 Solid State Detection Outputs: Ensure outputs meet the requirements of NEMA TS2-2003, 6.5.2.26.

660-2.1.2.4.4 Electrical Requirements: Ensure the detection system will operate with an input voltage ranging from 89 to 135 V_{AC}. If any system device requires operating voltages other than 120 V_{AC}, supply a voltage converter.

660-2.1.2.5 Automatic Vehicle Identification (AVI): AVI detection systems use one or more different methods to collect information that can be used to establish a unique identifier for each vehicle detected and the time and location that the vehicle was detected. AVI detection systems collect data using probe detectors that utilize radio-frequency identification (RFID), optical character recognition, magnetic signature analysis, laser profiling, Bluetooth®, or other technologies to establish vehicle identifier, time, and location.

660-2.1.2.5.1 Configuration and Management: Ensure that the detection system is provided with software that allows local and remote configuration and monitoring.

660-2.1.2.5.2 Communications: Ensure that components of the detection system (such as sensors, controllers, and processing hardware) include a minimum of one serial or Ethernet communications interface.

Ensure the serial interface and connector conforms to TIA-232 standards. Ensure that the serial ports support data rates up to 115200 bps; error detection utilizing parity bits (i.e., none, even, and odd); and stop bits (1 or 2).

Ensure that wired Ethernet interfaces provide a 10/100 Base TX connection. Verify that all unshielded twisted pair/shielded twisted pair network cables and connectors comply with TIA-568.

Ensure wireless communications are secure and that wireless devices are FCC-certified. Ensure that the FCC identification number is displayed on an external label and that all detection system devices operate within their FCC frequency allocation.

Ensure cellular communications devices are compatible with the cellular carrier used by the agency responsible for system operation and maintenance.

Ensure the system can be configured and monitored via one or more communications interface.

660-2.1.2.5.3 Probe Detector Requirements

1. Transponder Readers: Ensure transponder readers are compatible with multiple tag protocols, including Allegro and the protocol defined in ISO18000-6B.

2. Bluetooth Readers: Ensure that Bluetooth readers will operate using solar power and cellular communications. Ensure that Bluetooth readers will operate with a nominal input voltage of 12 V_{DC}.

3. License Plate Readers: License plate readers must not require the use of visible strobes or other visible supplemental lighting.

660-2.1.2.5.4 Electrical Requirements: Ensure the detection system will operate with an input voltage ranging from 89 to 135 V_{AC}. If any system device requires operating voltages other than 120 V_{AC}, supply a voltage converter.

660-2.1.3 Mechanical Requirements for all Detectors: Ensure that all parts are made of corrosion-resistant materials, such as plastic, stainless steel, anodized aluminum, brass, or gold-plated metal. Ensure that all fasteners exposed to the elements are Type 304 or 316 passivated stainless steel.

660-2.1.4 Environmental Requirements for all Detectors: Meet the environmental requirements of NEMA TS-2-2003.

660-2.2 Vehicle Presence Detector Performance Requirements: Ensure presence detectors provide a minimum detection accuracy of 98%. Ensure presence detectors meet the requirements for modes of operation in NEMA TS2-2003, 6.5.2.17.

660-2.2.1 Vehicle Presence Detection Accuracy: To verify conformance with the accuracy requirements in this Section and as a precondition for listing on the APL, sample data collected from the vehicle detection system will be compared against ground truth data collected during the same time by human observation or by another method approved by the FDOT Traffic Engineering Research Laboratory (TERL). Ensure sample data is collected over several time periods under a variety of traffic conditions. Weight each data sample to represent the predominant conditions over the course of a 24-hour period. Samples will consist of 15- and 30-minute data sets collected at various times of the day. Representative data periods and their assigned weights are provided in Table 660-1.

Table 660-1
Data Collection Periods

Period	Intended To Represent	Duration	Weight
Early morning (predawn) [EM]	12:30 a.m. – 6:30 a.m.	15 minutes	24
Dawn [DA]	6:30 a.m. – 7:00 a.m.	30 minutes	2
AM Peak [AMP]	7:00 a.m. – 8:00 a.m.	15 minutes	4
Late AM Off-Peak [LAOP]	8:00 a.m. – 12:00 p.m.	15 minutes	16
Noon [NO]	12:00 p.m. – 1:00 p.m.	15 minutes	4
Afternoon Off-Peak [AOP]	1:00 p.m. – 5:00 p.m.	15 minutes	16
PM Peak [PMP]	5:00 p.m. – 6:00 p.m.	15 minutes	4

Dusk [DU]	6:00 p.m. - 6:30 p.m.	30 minutes	2
Night [NI]	6:30 p.m. - 12:30 a.m	15 minutes	24
Total Sum of Weights			96

For instance, the sample gathered for the Late AM Off-Peak period is intended to represent typical traffic conditions between 8:00 a.m. and 12:00 p.m. Since the sample period's duration is 15 minutes and the actual period of time represented is 4 hours, the multiplication factor or weight assigned is 16, the number of 15-minute intervals in a 4 hour period.

660-2.2.1.1 Calculation of Vehicle Presence Detection Accuracy: Compute presence detection accuracy as described in this subsection.

Determine individual lane presence detection accuracy per period by calculating the percentage of absolute difference of the total volume measured by the detection system and the true volume computed using a method approved by the Engineer, divided by the true volume for the period under consideration.

In the equation in 660-2.2.1.1.1, "EM" represents the early morning period. The variable "i" represents a detector or detection zone and could vary from 1,…, N, where "N" is the maximum number of detectors observed. Substitute other detector numbers and periods as necessary to determine accuracy for all detectors during each period (i.e., dawn, AM peak, late AM off peak, etc.).

Variables used in the following calculations are identified as follows:

PA = Presence detection accuracy
TT = Total time
CET = Cumulative Error Time (duration of all false and missed calls)

660-2.2.1.1.1 Vehicle Presence Detection Accuracy for Single Detector During Early Morning Expressed in Percentage:

$$PA_{EM,\det_i} = 100 - \frac{\left|TT_{EM,\det_i} - CET_{EM,\det_i}\right|}{TT_{EM,\det_i}} x100$$

where:

$PA_{EM,\det_i}$ = Presence detection accuracy of detector *i* during the early morning period.

$TT_{EM,\det_i}$ = Total time that detector *i* was monitored (for instance, the 15-minute minimum duration specified in Table 660-1 for the early morning period).

$CET_{EM,\det_i}$ = Total time that detector *i* was in an error state (indicating a detection with no vehicle present or not indicating a detection when vehicle present) during the monitoring period using human observation or another method approved by the Engineer.

The period accuracy will be the arithmetic mean of all individual detector accuracies.

In the equation in 660-2.2.1.1.2, "EM" represents the early morning period and "*N*" is the maximum number of detectors tested. Substitute other periods as necessary to determine the accuracy for each period (i.e., dawn, AM peak, late AM off-peak, etc.).

660-2.2.1.1.2 Early Morning Vehicle Presence Detection Accuracy for All Detectors Expressed in Percentage:

$$PA_{EM} = \left(\frac{\sum_{i=1}^{N} PA_{EM,\det_i}}{N} \right)$$

Where:

PA_{EM} = Average accuracy of all detectors during the early morning.

$PA_{EM,\det_i}$ = Accuracy of detector *i* during early morning.

Calculate the roadway segment accuracy over all periods using the equation in 660-2.2.1.1.3.

660-2.2.1.1.3 Total Vehicle Presence Detection Accuracy of All Detectors Expressed in Percentage:

$$PA_{Total} = \frac{[PA_{EM}x24 + PA_{DA}x2 + PA_{AMP}x4 + PA_{LAOP}x16 + PA_{NO}x4 + PA_{AOP}x16 + PA_{PMP}x4 + PA_{DU}x2 + PA_{NI}x24]}{96}$$

Where:

PA_{Total} =Accuracy for all detectors for all periods
PA_{EM} = Accuracy of all detectors during early morning traffic conditions
PA_{DA} = Accuracy of all detectors during dawn traffic conditions
PA_{AMP} = Accuracy of all detectors during AM peak traffic conditions
PA_{LAOP} = Accuracy of all detectors during late AM off-peak traffic conditions
PA_{NO} = Accuracy of all detectors during noon traffic conditions
PA_{AOP} = Accuracy of all detectors during afternoon off-peak traffic conditions
PA_{PMP} = Accuracy of all detectors during PM peak traffic conditions
PA_{DU} = Accuracy of all detectors during dusk traffic conditions
PA_{NI} = Accuracy of all detectors during night traffic conditions

660-2.2.1.2 Vehicle Presence Detection System Field Acceptance Testing: Verify detection accuracy at installed field sites using a reduced method similar to those described in 660-2.2.1.1. Compare sample data collected from the detection system with ground truth data collected by human observation. For site acceptance tests, collect samples and ground truth data for each site for a minimum of five minutes during a peak period and five minutes during an off-peak period. For presence detection at intersections, ensure there are a minimum of three detections for each signal phase. Perform site acceptance tests in the presence of the Engineer.

660-2.3 Traffic Data Detector Performance Requirements: Provide a vehicle detection system capable of meeting the minimum total roadway segment accuracy levels of 95% for volume, 90% for occupancy, and 90% for speed for all lanes, up to the maximum number of lanes that the device can monitor as specified by the manufacturer.

660-2.3.1 Data Accuracy: To verify conformance with the accuracy requirements in this Section and as a precondition for listing on the APL, sample data collected from the vehicle detection system will be compared against ground truth data collected during the same time by human observation or by another method approved by the TERL. Ensure sample data is collected over several time periods under a variety of traffic conditions. Weight each data sample to represent the predominant conditions over the course of a 24-hour period. Samples will consist of 15- and 30-minute data sets collected at various times of the day. Representative data periods and their assigned weights are provided in Table 660-1.

660-2.3.1.1 Calculation of Volume Accuracy: Compute volume accuracy as described in this subsection.

Determine individual lane volume accuracy per period by calculating the percentage of absolute difference of the total volume measured by the detection system and the true volume computed using a method approved by the Engineer, divided by the true volume for the period under consideration.

In the equation in 660-2.3.1.1.1, "EM" represents the early morning period. The variable "i" represents a lane in a roadway and could vary from 1,…, N, where "N" is the maximum number of lanes on the roadway segment. Substitute other lane numbers and periods as necessary to determine the accuracy for each lane during each period (i.e., dawn, AM peak, late AM off-peak, etc.).

Variables used in the following calculations are identified as follows:

VT = Total volume

VD = Vehicle detection data (in this case, count data)

GT = Ground truth measurement utilizing a reliable method approved by the Engineer.

VA = Volume accuracy

660-2.3.1.1.1 Early Morning Lane Volume Accuracy Expressed in Percentage:

$$VA_{EM,\ln_i} = 100 - \frac{\left|VT_{EM,VD,\ln_i} - VT_{EM,GT,\ln_i}\right|}{VT_{EM,GT,\ln_i}} x100$$

Where:

VA_{EM,ln_i} = Volume accuracy for early morning traffic conditions in the i^{th} lane.

VT_{EM,VD,ln_i} = Total volume for the 15-minute early morning period using the vehicle detector in the i^{th} lane.

VT_{EM,GT,ln_i} = Total volume for the 15-minute early morning period in the i^{th} lane using human observation or another method approved by the Engineer.

The period volume accuracy will be the arithmetic mean of the lane volume accuracy over all lanes.

In the equation in 660-2.3.1.1.2, "EM" represents the early morning period and "N" is the maximum number of lanes in the roadway segment under test. Substitute other periods as necessary to determine the accuracy for each period (i.e., dawn, AM peak, late AM off-peak, etc.).

660-2.3.1.1.2 Early Morning Period Volume Accuracy Expressed in Percentage:

$$VA_{EM} = \left(\frac{\sum_{i=1}^{N} VA_{EM,\ln_i}}{N} \right)$$

Where:

VA_{EM} = Average volume accuracy for early morning traffic conditions for all lanes on the roadway segment.

VA_{EM,ln_i} = Volume accuracy for early morning traffic conditions in the i th lane.

Calculate the roadway segment accuracy over all periods using the equation in 660-2.3.1.1.3.

660-2.3.1.1.3 Total Roadway Segment Accuracy Expressed in Percentage:

$$VA_{Total} = \frac{[VA_{EM}x24 + VA_{DA}x2 + VA_{AMP}x4 + VA_{LAOP}x16 + VA_{NO}x4 + VA_{AOP}x16 + VA_{PMP}x4 + VA_{DU}x2 + VA_{NI}x24]}{96}$$

Where:

VA_{Total} = Volume accuracy for all lanes for all periods
VA_{EM} = Volume accuracy for early morning traffic conditions
VA_{DA} = Volume accuracy for dawn traffic conditions
VA_{AMP} = Volume accuracy for AM peak traffic conditions
VA_{LAOP} = Volume accuracy for late AM off-peak traffic conditions
VA_{NO} = Volume accuracy for noon traffic conditions
VA_{AOP} = Volume accuracy for afternoon off-peak traffic conditions
VA_{PMP} = Volume accuracy for PM peak traffic conditions
VA_{DU} = Volume accuracy for dusk traffic conditions
VA_{NI} = Volume accuracy for night traffic conditions

Position the detector and configure the detection zones so that a vehicle is detected when 70% or more of the vehicle width is inside a lane, and not detected when 15% or less of the vehicle width is in the lane. Use the detection zone configuration to minimize the occurrence of a double count for the same vehicle, while ensuring that it will be counted at least once.

660-2.3.1.2 Calculation of Speed and Occupancy Accuracy: Calculate speed accuracy as discussed in this subsection. Calculate occupancy in a manner similar to the speed computation methodology described below.

The difference between the volume accuracy and speed accuracy computation is that the volume of a particular lane can be aggregated over a period of time, while speed cannot. For computing the accuracy of the detector speed measurement, the average speed readings obtained from the detection system are compared to ground truth values on a particular roadway segment.

The equation in 660-2.3.1.2.1 represents the ground truth average speed computation procedure for a particular lane during a specific time period. The equation in 660-2.3.1.2.2 represents the average speed computation procedure for a particular lane during a specific time period using data gathered from the detection system.

In the equations in 660-2.3.1.2.2 and 660-2.3.1.2.2, the time period described is the early morning period, represented by “EM”, and the variable “k” represents a vehicle traveling on the roadway and could vary from 1,…, K, where “K” is the maximum number of vehicles in lane i during the time period under consideration. The variable “i” represents a lane in a roadway and could vary from 1,…, N, where “N” is the maximum number of lanes on the roadway segment. Substitute other lanes and periods as necessary and compute the accuracy for each lane for all time periods.

Variables used in the following calculations are identified as follows:

SA = Speed accuracy
S = Speed of an individual vehicle
veh = Vehicle

660-2.3.1.2.1 Early Morning Average Ground Truth Vehicle Speed:

$$S_{Avg,EM,GT,\ln_i} = \frac{1}{K}\sum_{k=1}^{K} S_{EM,GT,\ln_i,veh_k}$$

Where:

SA_{Avg,EM,GT,ln_i} represents the average ground truth vehicle speed for the i^{th} lane during the early morning period.

S_{EM,GT,ln_i,veh_k} represents the true speed for the k^{th} vehicle in the i^{th} lane during the early morning period using human observation or another method approved by the Engineer.

660-2.3.1.2.2 Early Morning Average Vehicle Detector Speed Measurement:

$$S_{Avg,EM,VD,\ln_i} = \frac{1}{K}\sum_{k=1}^{K} S_{EM,VD,\ln_i,veh_k}$$

Where:

S_{Avg,EM,VD,ln_i} represents the average speed recorded by the vehicle detector for the i^{th} lane during the early morning period.

S_{EM,VD,ln_i,veh_k} represents the speed for the k^{th} vehicle in the I^{th} lane during the early morning period using the vehicle detector.

The lane speed period accuracy is computed as a percentage of the absolute difference of the average lane speed calculated using detection system data and the average lane true speed calculated in the equation in 660-2.3.1.2.1 (or using another method approved by the Engineer), divided by average ground truth lane speed for the period.

In the equation in 660-2.3.1.2.3, "EM" represents the early morning period. The variable "*i*" represents a lane on a roadway and could vary from 1,…,N, where "N" is the maximum number of lanes on the roadway segment. Substitute other lanes as necessary to determine the accuracy for each period (i.e., dawn, AM peak, late AM off-peak, etc.).

660-2.3.1.2.3 Early Morning Lane Speed Accuracy Expressed in Percentage:

$$SA_{Avg,EM,\ln_i} = 100 - \frac{\left|S_{Avg,EM,VD,\ln_i} - S_{Avg,EM,GT,\ln_i}\right|}{S_{Avg,EM,GT,\ln_i}} \times 100$$

Where:

SA_{Avg,EM,ln_i} represents the average speed accuracy during early morning traffic conditions for all vehicles that traveled in lane i of the roadway segment.

The period speed accuracy will be the arithmetic mean of the lane speed accuracy, computed using the equation in 660-2.3.1.2.3, over all lanes.

In the equation in 660-2.3.1.2.4, "EM" represents the early morning period. The variable "i" represents a lane on a roadway and could vary from 1,…, N, where "N" is the maximum number of lanes on the roadway segment. Substitute data as necessary to determine the accuracy for each period (i.e., dawn, AM peak, late AM off-peak, etc.).

660-2.3.1.2.4 Early Morning Speed Accuracy Expressed in Percentage:

$$SA_{EM} = \left(\frac{\sum_{i=1}^{N} SA_{Avg,EM,\ln_i}}{N} \right)$$

Where:

SA_{EM} represents the average speed accuracy during early morning traffic conditions for all lanes on the roadway segment.

Calculate the roadway segment accuracy over all periods using the equation in 660-2.3.1.2.5.

660-2.3.1.2.5 Total Roadway Segment Accuracy Expressed in Percentage:

$$SA_{Total} = \frac{[SA_{EM}x24 + SA_{DA}x2 + SA_{AMP}x4 + SA_{LAOP}x16 + SA_{NO}x4 + SA_{AOP}x16 + SA_{PMP}x4 + SA_{DU}x2 + SA_{NI}x24]}{96}$$

Where:

SA_{Total} = Speed accuracy for all lanes for all periods
SA_{EM} = Speed accuracy for early morning traffic conditions
SA_{DA} = Speed accuracy for dawn traffic conditions
SA_{AMP} = Speed accuracy for AM peak traffic conditions
SA_{LAOP} = Speed accuracy for late AM off-peak traffic conditions
SA_{NO} = Speed accuracy for noon traffic conditions
SA_{AOP} = Speed accuracy for afternoon off-peak traffic conditions
SA_{PMP} = Speed accuracy for PM peak traffic conditions
SA_{DU} = Speed accuracy for dusk traffic conditions
SA_{NI} = Speed accuracy for night traffic conditions

660-2.3.1.3 Traffic Data Detection System Field Acceptance Testing: Verify detection accuracy at installed field sites using a reduced method similar to those described in 660-2.3.1. Compare sample data collected from the detection system with ground truth data collected by human observation. For site acceptance tests, collect samples and ground truth data for each site for a minimum of five minutes during a peak period and five minutes during an off-peak period. Perform site acceptance tests in the presence of the Engineer.

660-2.4 AVI Detection System Performance Requirements: Ensure that AVI detectors establish a unique and consistent identifier for each vehicle detected and the time and location that the vehicle was detected. Ensure that probe detectors provide a minimum penetration rate of 75%. Ensure AVI detection systems that match upstream and downstream detection of the same vehicle provide a minimum match rate of 5%. Ensure AVI detection systems meet a minimum total roadway segment speed and travel time accuracy level of 90%. Verify system performance over several time periods under a variety of traffic conditions as described in 660-2.3.1.

660-2.4.1 Calculation of Penetration Rate: Penetration rate is defined as the volume of vehicles detected, identified, and time stamped divided by the number of qualified vehicles that passed within the detection area of the probe detector.

660-2.4.1.1 Early Morning Penetration Rate Expressed as a Percentage:

$$PR_{EM} = 100 - \frac{\left|R_{EM,VD} - V_{EM,GT}\right|}{V_{EM,GT}} \times 100$$

Where:

PR_{EM} = Penetration Rate for early morning.

$R_{EM,VD}$ = Number of unique vehicle records captured by the vehicle detector.

$V_{EM,GT}$ = Total volume of vehicles that pass the detection area for the 15-minute early morning period using human observation or another method approved by the Engineer.

660-2.4.1.2 Calculation of Match Rate: Match rate is the percentage of the total vehicle population of a road segment that is detected and matched at consecutive probe data detection sites.

660-2.4.1.2.1 Early Morning Match Rate Expressed as a Percentage:

$$MR_{EM} = 100 - \frac{\left|M_{EM,VD} - V_{EM,GT}\right|}{V_{EM,GT}} \times 100$$

Where:

MR_{EM} = Match Rate for early morning.

$M_{EM,VD}$ = Number of matched detections between two probe vehicle detection sites (typically a pair of sites at each end of a roadway segment) during early morning.

$V_{EM,GT}$ = Total volume of vehicles that pass the detection area for the 15-minute early morning period using human observation or another method approved by the Engineer.

660-2.4.1.3 Calculation of AVI Detection System Speed and Travel Time Accuracy: Calculate speed and travel time accuracy by comparing the speeds and travel times reported by the system against ground truth collected through human observation or another method approved by the Engineer.

660-2.5 Environmental Requirements for all Detectors: Meet the environmental requirements of NEMA TS-2-2003.

660-3 Installation Requirements.

660-3.1 Installation Requirements for all detectors: Install, configure, and demonstrate a fully functional vehicle detection system, as shown in the Plans. Connect all field equipment to the existing communication network, and provide all materials specified in the Contract Documents. Install all equipment according to the manufacturer's recommendations.

Ensure that above-ground detectors can be mounted on existing poles or sign structures, or on new poles, as shown in the Plans. Furnish all equipment with the appropriate power and communication cables. Install the power cable and the communication cables according to the manufacturer's recommendation. Ensure that the cables comply with NEC sizing requirements and meet all other applicable standards, specifications, and local code requirements.

Do not install communication cables in the same conduit or pull boxes as power cables carrying voltage greater than 24 V_{DC}/V_{AC} or current in excess of 1.5 amps.

Cut all wires to their proper length before assembly. Do not double back any wire to take up slack. Neatly lace wires into cables with nylon lacing or plastic straps. Secure cables with clamps and provide service loops at all connections.

In the event that power to the vehicle detection system or a subcomponent thereof is interrupted, ensure that the equipment automatically recovers after power is restored. Ensure that all programmable system settings return to their previous configurations and the system resumes proper operation.

660-3.2 Inductive Loop Detector Installation: Install vehicle loops in accordance with the manufacturer's instructions and the Design Standards, Index No. 17781.

660-3.2.1 Inductive Loop-Detector Units: Adjust the operating frequency of each detector unit, if required, to prevent crosstalk of the units.

660-3.2.2 Saw Cuts: Use a chalk line or equivalent method to outline the perimeter of the loop on the pavement and routes for lead-in cables. Do not allow the saw cut in the pavement to deviate by more than 1 inch from the chalked line. Ensure that all saw cuts are free of any dust, dirt, or other debris and completely dry prior to installation of the loop wire, loop wire twisted pair lead, or lead-in cable.

Ensure that the top conductor of the loop wire or lead-in cable is a minimum of 1 inch below the final surface of the roadway.

660-3.2.3 Loop Wire: Ensure that all loops are wound in a clockwise manner and the first turn of the loop wire is placed in the bottom of the saw cut, with each subsequent turn placed on top of the preceding turn. Push the loop wire to the bottom of the saw cut with a non-metallic tool which will not damage the insulation.

Tag and identify the clockwise "lead" of each loop.

Use alternate polarity on adjacent loops.

Ensure that the hold down material is non-metallic, is placed in the saw slot using segments 1 to 2 inches long, spaced 12 inches apart, and that the distance from the top of the hold down material to the final surface of the roadway is not less than 1-1/2 inches.

660-3.2.4 Loop Wire Twisted Pair Lead: Create a loop wire twisted pair lead by twisting the loop wire pair a minimum of 10 turns per foot to form a loop wire twisted pair lead from the edge of the loop to the pull box located adjacent to the roadway. Place only one loop wire twisted pair lead in a saw cut. Ensure that the distance between a twisted loop wire pair lead within the roadway is a minimum of 6 inches from any other twisted loop wire pair lead or loop, until they are within 1 foot of the edge of pavement or curb, at which point they may be placed closer together.

Provide a minimum of 3 feet of twisted loop wire pair lead in the pull box located adjacent to the roadway. Do not route twisted loop wire pair lead directly through conduits to the cabinet, unless otherwise shown in the Plans.

660-3.2.5 Loop Sealant: Prepare and apply loop sealant in accordance with the manufacturer's instructions. Ensure that the loop sealant has cured completely before allowing vehicular traffic to travel over the sealant.

660-3.2.6 Shielded Lead-in Cable: Place the lead-in cable in the bottom of the saw cut. Do not damage the insulation.

Install no more than four lead-in cables in a saw cut. Ensure that the hold down material is not longer than 1 inch and that the distance from the top of the hold down material to the final surface of the roadway is not less than 1-1/2 inches.

660-3.2.7 Splicing: Perform the splicing in a pull box located off the roadway, not in the roadway itself.

Splice the black conductor of the lead-in cable to the clockwise "lead" of the loop.

Ensure that the ends of the cable jackets, twisted pair, and lead-in are encased in the loop splice material.

Ensure that each loop has an individual return to the cabinet and series splicing is performed on a separate terminal block in the cabinet.

660-3.2.8 Terminations: Using insulated terminal lugs, terminate lead-in cables or twisted pair loop wire on a terminal strip, which is located in the controller or detector cabinet. Use a calibrated ratchet type crimping tool to attach the lugs to the conductors of the lead-in cable or twisted loop wire.

660-3.2.9 Loop Assembly Identification: Identify and tag each loop assembly in the controller or detector cabinet by lane and movement number.

660-3.2.10 Inductive Loop Detector Testing and Turn-on:

660-3.2.10.1 Series Resistance: Obtain Department of Transportation Traffic Signal Resistance Measurement Data Sheets from the Engineer. Measure and record the series resistance of each loop assembly on these data sheets. Leave a copy in the controller cabinet.

If the series resistance of a loop assembly is greater than 10 Ω, inspect the loop assembly to find the cause of the excessive resistance. Correct the cause of the excessive resistance at no additional cost to the Department.

660-3.2.10.2 Insulation Resistance: Measure and record the insulation resistance of each loop assembly and verify that the resistance is greater than 100 MΩ. Use a 500 V_{DC} insulation tester to measure the resistance. Reference all measurements to a good earth ground (ground rod, metallic water pipe, etc.). Disconnect the transient suppression devices from the loop assemblies before taking any measurements. If the insulation resistance is less than 100 MΩ, determine if the lead-in cable or the loop wire is causing the problem, and replace the defective cable or loop wire at no additional cost to the Department.

660-3.2.10.3 Loop Detector Turn-on: Connect the loop assemblies to the appropriate inductive loop vehicle detectors and tune the detectors in accordance with the manufacturer's instructions. Separate the operating frequencies of vehicle detectors, in adjacent lanes, by at least 2 kHz. Verify operation proper operation in accordance with 660-2.2.1.2.

660-3.3 Video Detector Installation: Install cameras and configure detection zones and settings in accordance with the Contract Documents, manufacturer's recommendations, and as directed by the Engineer. Submit configuration settings (including, but not limited to detector names, communication settings, and output assignments) and configuration file backups to the Engineer. Submit a graphical depiction of each camera site, its pole location, mounting height, the ratio of distance away from the camera versus the mounting height, the camera's mounting type (i.e., pole or structure), camera aiming procedures, and the placement of the proposed detection zone for each lane.

Do not use coaxial cable runs in excess of 500 feet. Mount and aim cameras in a manner that eliminates as much environmentally generated glare as possible.

660-3.4 Microwave Detector Installation: Install detector and configure detection zones and settings in accordance with the Contract Documents, manufacturer's recommendations, and as directed by the Engineer. Submit configuration settings (including, but not limited to detector names, communication settings, and output assignments) and configuration file backups to the Engineer.

660-3.5 Wireless Magnetometer Installation: Install in accordance with the Contract Documents, manufacturer's recommendations, and as directed by the Engineer. Ensure that materials used for the installation of magnetometers in the road surface have cured completely before allowing vehicular traffic to travel over them.

660-3.6 AVI Detection System Installation: Install in accordance with the Contract Documents, manufacturer's recommendations, and as directed by the Engineer.

660-4 Warranty.

Ensure that vehicle detection and data collection systems have a manufacturer's warranty covering defects for a minimum of 5 years from the date of final acceptance by the Engineer in accordance with 5-11 and Section 608. Ensure the warranty includes providing replacements, within 10 calendar days of notification, for defective parts and equipment during the warranty period at no cost to the Department or the maintaining agency.

660-5 Method of Measurement.

660-5.1 Furnish and Install: The Contract unit price for each inductive loop detector and per assembly for loop assembly, furnished and installed, will include all equipment, materials as specified in the Contract Documents, and all labor, equipment, and miscellaneous materials necessary for a complete and accepted installation.

The Contract unit price for each component of an MVDS, VVDS, WMDS, or AVI detection system , furnished and installed, will include furnishing, placement, and testing of all materials and equipment, and for all tools, labor, equipment, hardware, operational software packages and firmwares, supplies, support, personnel training, shop drawings, warranty documentation, and incidentals necessary to complete the work.

660-5.2 Furnish: The Contract unit price for each inductive loop detector, per assembly for loop assembly, per gallon for loop sealant, and per foot for cable, furnished, will include all equipment and materials as specified in the Contract Documents, plus all shipping and handling costs involved in delivery as specified in the Contract Documents.

The Contract unit price for each component of an MVDS, VVDS, WMDS, or AVI detection system, furnished, will include providing all equipment specified in the Contract Documents, plus all shipping and handling costs involved in delivery as specified in the Contract Documents.

660-5.3 Install: The Contract unit price for each inductive loop detector and per assembly for loop assembly, installed, will include all loop sealant, miscellaneous materials, labor, and equipment necessary for a complete and accepted installation. The Engineer will supply the inductive loop detector, harness, lead-in cable, and loop wire.

The Contract unit price for each component of an MVDS, VVDS, WMDS, or AVI detection system, installed, will include placement and testing of all materials and equipment, and for all tools, labor, equipment, hardware, operational software packages and firmwares, supplies, support, personnel training, shop drawings, warranty documentation, and incidentals necessary to complete the work. The Engineer will supply the equipment specified in the Contract Documents.

660-5.4 Modify: The Contract unit price per assembly for loop assembly, modified, will include all lead-in cable, saw cuts, miscellaneous materials as specified in the Contract Documents, connecting new lead-in cable to an existing loop and installing and terminating the lead-in cable to the location designated in the Contract Documents, and all labor and equipment necessary for a complete and accepted installation.

The Contract unit price for each component of an MVDS, VVDS, WMDS, or AVI detection system, modified, will include adjustment, relocation, placement, and testing of all materials and equipment, and for all tools, labor, equipment, hardware, operational software packages and firmwares, supplies, support, personnel training, shop drawings, warranty documentation, and incidentals necessary to complete the work.

660-6 Basis of Payment.

Price and payment will be full compensation for all work specified in this Section. Payment will be made under:

Item No. 660-1	Inductive Loop Detector – each.
Item No. 660-2	Loop Assembly – per assembly.
Item No. 660-3	Vehicle Detection System - Microwave – each.
Item No. 660-4	Vehicle Detection System – Video – each.
Item No. 660-5	Vehicle Detection System – Wireless Magnetometer – each.
Item No. 660-6	Vehicle Detection System - AVI – each.