Arizona Department of Transportation

Transportation Technology Group

Intelligent Transportation System

Design Guide

May 2015

Arizona Department of Transportation

Transportation Technology Group

Intelligent Transportation System Design Guide

May 2015

Previously Published as "Freeway Management System Design Guidelines"

1989, 1994, 1999, 2002, 2007, and 2009

PAGE INTENTIONALLY LEFT BLANK

CONTRIBUTIONS AND ACKNOWLEDGEMENTS

The 2015 Intelligent Transportation System (ITS) Design Guide is the result of the coordinated efforts of many groups, research organizations, and government agencies. The 2015 ITS Design Guide was prepared for ADOT by a committee representing ADOT stakeholders and the design consultant community.

PAGE INTENTIONALLY LEFT BLANK

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

Intelligent Transportation Systems (ITS) include both rural and urban applications. ITS deployments on urban highways in Arizona are called the Freeway Management System (FMS). In rural and non-freeway areas, deployments may be referred to as ITS for a group of applications, or the specific application such as DMS (Dynamic Message Sign); RWIS (Roadway Weather Information Systems); etc. This ITS Design Guide provides direction to ADOT's ITS designer for both urban and rural deployments.

1.1 Purpose of the ITS Design Guide

This guide is to assist designers to incorporate the basic elements of ITS in their Plans, Specifications, and Engineer's Estimate (PS&E) documents and to facilitate the ongoing implementation of ITS.

This guide is neither a standard nor substitute for engineering experience, skill, knowledge, or judgment. Actual conditions require the use of engineering judgment in using the direction contained in this guide.

The term *designer* refers to anyone, regardless of title and employer, who prepares PS&E for ITS projects for Arizona Department of Transportation. Where the term *Contractor* is mentioned in this guide, it is understood that the role of Contractor is to be viewed from the designer's perspective. The Contractor physically constructs the system. This document is not a substitute for formal documents binding to a Contractor.

ITS projects typically require a planning document, such as:

- Project Assessment (PA) or Scoping Letter;
- FMS Concept Report; or
- If part of a roadway project, a chapter within the Design Concept Report (DCR) or other acknowledgement of ITS needs within the document, during the scoping phase.

The ADOT TTG Project Manager (PM) shall review all ITS planning and design documents during various stages of design. The designer shall consult with various other sections/groups and entities during the design process, including:

- Bridge Group;
- Contracts & Specifications;
- District;
- Engineering Consultants Section;
- Environmental Planning Group;
- Project Resource Office;
- Right-of-Way Group;

- Roadside Development;
- Roadway Engineering Group;
- Traffic Group;
- Urban/Statewide Project Management;
- Utility & Railroad Engineering;
- Federal Highway Administration;
- Adjacent tribal lands;
- National Forest Service;
- State Lands & Parks;
- MPO's; and,
- Counties, towns and cities, or other entities that may have jurisdiction or interest.

1.2 ITS Goals and Objectives

ADOT manages an extensive FMS in two urban areas (Phoenix and Tucson), as well as a vast array of intelligent transportation devices in rural Arizona. With this edition, the name of the document has changed from *FMS Design Guidelines* to *ITS Design Guide* indicating that both rural and urban applications are now addressed. ITS in rural applications has similar objectives and benefits: -maximize the operational safety of the traveling public; -provide motorist with relevant traffic information; -improve safety; and reduce secondary collisions.

There are two types of traffic congestion in urban areas, namely recurring and non-recurring congestion. Congestion occurs when the demand exceeds the capacity, or when capacity is reduced. Recurring congestion commonly occurs during the morning and evening commutes when traffic demand exceeds the available capacity of the freeway lanes. Non-recurring congestion, also found in rural areas, occurs when crashes, disabled vehicles, debris, construction, adverse weather, special events, and other factors reduce the capacity of the freeway to below the traffic demand.

The objectives of both FMS and ITS are intended to:

- Reduce the impacts of congestion;
- Minimize the duration and effects of non-recurring congestion;
- Maximize the operational safety and efficiency of the traveling public;
- Provide motorists with relevant traffic information;
- Provide assistance to motorists; and,
- Operate a system that provides a service and builds credibility with the public.

The benefits of FMS and ITS for the motoring public include:

- Improving safety;
- Improving efficiency of the motoring public;
- Reducing environmental impact;
- Reducing fuel consumption;
- Enhancing productivity;
- Saving lives through emergency response;
- Reducing secondary collisions;
- Integrating regional traffic management systems; and,
- Centralizing management of the freeway system.

1.3 Concept of Communications

In the two largest metropolitan areas of the state, ADOT facilitates the sharing of information between ADOT and local agencies by promoting regional connectivity, as shown in Table 1.1. The ADOT FMS and local cities ITS systems share agreements, which are established through ADOT's Joint Project Agreements Office in the form of a Joint Project Agreement (JPA) or Intergovernmental Agreement (IGA).

Table 1.1 ADOT Regional Connectivity Networks

METRO AREA	ACRONYM	NAME
Phoenix	RCN	Regional Community Network
Tucson	RTDN	Regional Transportation Data Network

For more information, the network documents are available at the respective websites of the Maricopa Association of Governments and Pima Association of Governments.

The designer shall provide communications redundancy for all FMS segments. Preferred redundancy within the segment is accomplished through a physical dual trunkline system. Another redundancy option is a technological alternate path, such as an alternative looped freeway conduit path, using wireless and/or Ethernet Based Internet Protocol (IP) technologies.

If the designer is not versed in communications technologies, including fiber-optics, wireless and Ethernet Based Internet Protocol (IP) technologies, the designer shall add a professional who is, to the design team.

1.4 Using ITS Design Guide with Other Documents

The designer shall follow the PS&E document preparation guidelines as outlined in the Directory of Standardized Work Tasks for the Project Assessment, 60%, 95%, 100% (Stages III, IV, and V), and seal stages.

The designer shall follow this *ITS Design Guide* and the latest version of several ADOT documents, including, but not limited to:

- Predesign Guidelines;
- Design Procedures Manual;
- Roadway Design Guidelines;
- Ramp Metering Design Guide;
- ITS Standard Drawings;
- ITS Standard Specifications;
- Applicable Stored Specifications (all, with emphasis on those related to FMS); and
- ADOT Standard Specifications for Road and Bridge Construction.

Refer to the ADOT website for the latest instructions and to find the respective documents. The designer shall also consult ADOT TTG for recent ITS standards that have not yet been adopted within these published documents.

The ADOT Traffic Group publishes the *Traffic Signals and Lighting Standard Drawings.* These standard drawings contain several standards that may appear to duplicate ITS Standard Drawings. The *ITS Standard Drawings* take precedence over the *Traffic Signals and Lighting Standard Drawings.*

1.5 Acronyms

Table 1.2 is a list of commonly used acronyms that appear throughout this document.

Table 1.2 Acronyms

ACRONYMS	DESCRIPTION
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
APL	Approved Products List
ASTM	American Society for Testing and Materials
AQD	Advance Queue Detector
ATOC	Alternative Traffic Operations Center

ACRONYMS	DESCRIPTION
CCTV	Closed Circuit Television Camera
CLSM	Controlled Low Strength Material
DCR	Design Concept Report
DMS	Dynamic Message Sign
E2C2	Estimated Engineering Construction Cost
FMS	Freeway Management System
GIS	Geographic Information System
HDD	Horizontal Directional Drilling
HDPE	High Density Polyethylene
HVAC	Heating, Ventilation, and Air Conditioning
IMSA	International Municipal Signal Association
IP	Internet Protocol
ITD	ADOT Intermodal Transportation Division (which includes TTG)
ITS	Intelligent Transportation Systems
LED	Light Emitting Diode
MAG	Maricopa Association of Governments
MUTCD	Manual on Uniform Traffic Control Devices
NEC	National Electric Code
Node	Communications hub for termination of trunkline fiber-optic cables, typically housed inside a climate controlled secure building at a SI (system interchange).
NTCIP	National Transportation Communications for ITS Protocol
OSP	Outside Plant
PA	Project Assessment
PAG	Pima Association of Governments
PEP	Product Evaluation Program
PM	Project Manager
PS&E	Plans, Specifications and Estimates
PVC	Polyvinyl Chloride
RCN	Regional Community Network (For Phoenix Metro Region)
RMC	Rigid Metal Conduit
RTDN	Regional Tucson Data Network (For Tucson Metro Region)
SDR	Size Diameter Ratio

ACRONYMS	DESCRIPTION
SI	System Interchange (Freeway to Freeway)
SMFO	Single-Mode Fiber-optic
STOC	Southern Traffic Operations Center
TI	Traffic Interchange (Crossroad)
TOC	Traffic Operations Center
TTG	Transportation Technology Group
UPS	Uninterruptible Power Supply
VAC	Volts – Alternating Current
VDC	Volts – Direct Current

Chapter 2 Freeway Management System Elements

The FMS comprises a number of elements, all interconnected and operating together as a system, in order to accomplish the TTG's goals and objectives.

Key FMS field elements discussed within this guide include:

- Closed-circuit television (CCTV) cameras;
- Communications System, interconnecting devices to the Traffic Operations Center (TOC) and other agencies;
- Detection system;
- Dynamic Message Signs (DMS);
- Ramp meters (See the Ramp Metering Design Guide for additional detail); and
- Traffic Interchange Signals.

2.1 Emerging Technology

The deployment of FMS elements has evolved since the first FMS project. As the FMS has grown and evolved over time, owner experience and technological improvements have driven the need for change. Newer technology must work with existing older *legacy* technology. The need for consistency throughout the system is sometimes challenged by the need to improve it. This Guide attempts to offer the designer a framework that offers consistency and flexibility for improvement. The designer should be familiar with the overall functionality of the FMS, its field elements and their technologies, and the connectivity between the field elements and their users. Continuous input from maintenance, end users, and construction staff have helped determine criteria for design.

Other technologies for FMS infrastructure may be considered in the design provided they have been approved by the ADOT TTG for application in specific cases on specific projects. A listing of current ADOT approved technologies appears on the *Approved Products List* (*APL)* following the *Product Evaluation Program* process. The *Product Evaluation Program* process is administered by the ADOT *Research Center*.

2.2 Mainline System

The FMS contains a mainline detection system covering each traffic lane. Mainline detection occurs at a spacing of approximately one mile. Early FMS deployments utilized mainline detection stations at 1/3-mile spacing; ADOT has removed many of these stations in order to achieve the one-mile spacing standard. Data from these detectors is used to electronically determine travel times and abnormalities in traffic flow, which indicate a potential incident. Once an incident is indicated, the FMS operators at the TOC are able to focus the color CCTV cameras with pan, tilt, and zoom capabilities at the potential incident location to confirm the incident.

A Model 2070 controller-based ramp metering system on the entrance ramps limits the demand on a given section of freeway. Information to be communicated to the motorists is displayed using light emitting diode (LED) DMS.

Field devices are connected to a node building, which is connected to the TOC. Field devices are connected using a fiber-optic communications system.

As new freeways are designed and constructed, it is desirable to incorporate certain FMS features to facilitate future FMS operation. To accomplish this objective, the roadway designer is responsible for the geometric design of on-ramps to accommodate dual lane ramp metering.

The designer is responsible for:

- Layout of detection for the entrance ramp queue loops;
- Trunkline communications conduit and pull boxes on both sides of the freeway; and,
- Design of future DMS median foundation locations.

Unlike new freeway construction, it is common for FMS elements to be *retrofitted* into existing freeway segments, where the existing FMS infrastructure ranges from non-existent to substantial. Retrofit projects require careful evaluation of existing infrastructure, and the available fiber-optic cable strands in the adjacent completed segment of FMS construction.

The design of detection systems, conduits to connect mainline detection systems, ramp meters, CCTV, and DMS is to be initiated in accordance with this document, and the documents listed in Section 1.1.3. The designer is encouraged to be aware of emerging technologies and their effect on FMS design. ADOT is migrating toward National Transportation Communication for ITS Protocol (NTCIP) compliant devices.

Figure 2.1 illustrates typical FMS devices, controller cabinets, and conduit infrastructure for a freeway segment with crossroad interchange.

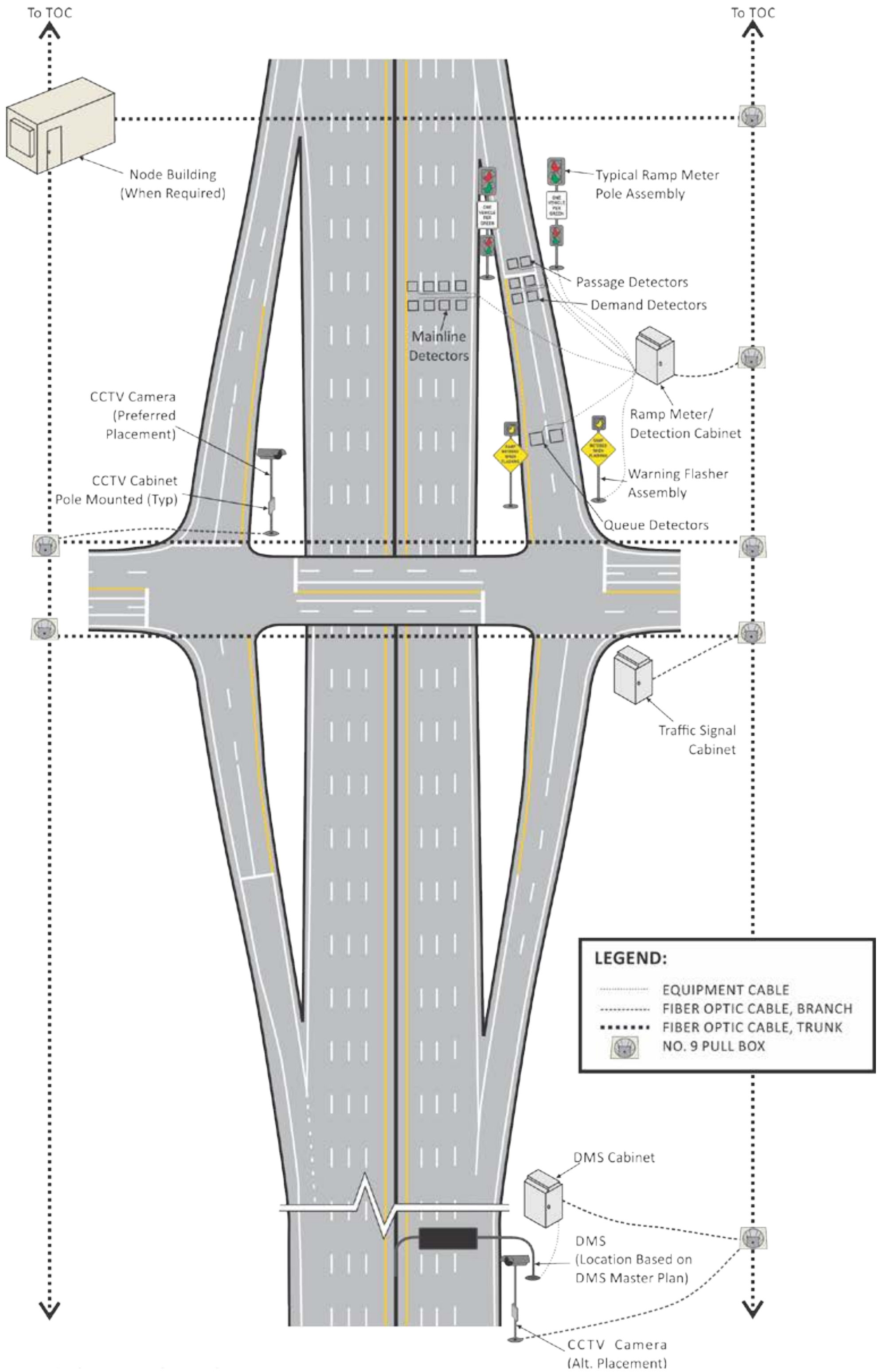

Figure 2.1 - Typical Crossroad Interchange

PAGE INTENTIONALLY LEFT BLANK

Chapter 3 Incorporating Freeway Management System Design

A full FMS project may be implemented either as a *stand-alone* project along an existing section of freeway where no civil improvements are involved or as an *integrated* project with civil improvements, typically a mainline construction or widening. Regardless of stand-alone or integrated status, the design of the full FMS most likely involves every chapter of this Guide. The FMS infrastructure includes the following field elements, with the design of each addressed later within this Guide:

- Communications Trunkline Conduit System – Chapter 4;
- Mainline Detector System – Chapter 5;
- Equipment Cabinets – Chapter 6;
- Dynamic Message Signs (DMS) – Chapter 7;
- Closed-Circuit Television (CCTV) Cameras – Chapter 8;
- Communication Nodes and Node Buildings – Chapter 9; and,
- Fiber Outside Plant (OSP) Design and Modeling – Chapter 10.

In many instances the proposed FMS infrastructure, whether in a roadway project or in a stand-alone project, will border a local jurisdiction. The FMS designer should invite (see Section 1.1) the local jurisdictions to the project kickoff meeting. Coordination with any applicable local jurisdictions should be a standard item on the progress meeting agenda. If applicable, the FMS designer shall coordinate with local jurisdictions and the ADOT IGA/JPA office shortly after receiving the Notice to Proceed.

All submittals shall include plans, specifications and Engineer's estimates (PS&E) for distribution by the designer. Regular progress meetings, as well as comment resolution meetings, shall be held for each project. The designer must submit estimates in the ADOT E2C2 format and provide a schedule detailing the 21 milestones tracked by ADOT (more detailed description of the 21 milestones is available through the ADOT Project Resource Office web site). Requests for utility service drops are typically the responsibility of the designer, and will require on-site meetings with the utility company providing service.

This section outlines basic designer responsibilities and is intended for information, but it is not all-inclusive.

3.1 FMS Infrastructure with a Roadway Project

The FMS infrastructure elements shall be considered an integral part of any new freeway design. As a minimum in each project, the designer should include trunkline conduits and pull boxes. These elements are placed below ground and, as such, should be constructed with the freeway or freeway widening. This constitutes the “plumbing” of the FMS system.

Where new pavement is to be installed, preformed queue loop detectors are required to be placed on each on-ramp, beneath the pavement section. Mainline freeway detection for FMS shall not be placed as part of the initial freeway mainline pavement, unless communications to the FMS is being provided. (The reason for this change in practice is if the mainline lane configuration changes, the mainline detection configuration will need to change).

In some instances, other elements of the FMS design, such as ramp meters, cabinet foundations, DMS foundations, CCTV foundations, or special conduit connections must also be provided within the roadway design. These additional FMS elements are required when elements of the roadway design (such as retaining walls, sound walls, long bridges, median barrier, etc.) make it impractical or excessively costly to complete the necessary installation during a future FMS implementation project. Median blisters for DMS signs, pull box locations, and lateral crossings of the freeway should be strategically placed to accommodate future devices. The designer should consider the criteria presented in this Guide, and other referenced documents (see Chapter 1) for placement of the infrastructure.

In many instances the FMS designers in large-scale roadway projects are required to attend the overall project progress meetings. Although these progress meetings are very productive, the FMS portion of the meeting is small compared to the overall project components. These meetings can also be very time consuming and in many instances the ADOT TTG staff cannot set aside a block of time to attend the entire meeting. The FMS designer shall set up a separate progress review meeting with ADOT TTG, ADOT Phoenix Construction District or other applicable construction district, ITS Maintenance and ADOT VISION field office staff after each project submittal. It is the responsibility of the FMS designer to organize and conduct these additional progress meetings.

3.2 FMS Infrastructure Stand-Alone Projects

When FMS infrastructure is designed as a stand-alone project, the designer bears a greater responsibility for planning documents, clearances, and conformance to the ADOT project management process. Coordination with other agencies, governmental agencies such as tribal governments and local utilities is the responsibility of the designer.

The designer typically starts with a planning document such as a Project Assessment (PA) that takes the project to 30% design, including a detailed estimate and discussion of design alternatives considered. The document will show preliminary device locations in sketch format and identify any special considerations, such as local agency involvement, special clearances needed, and special geographic and access concerns. The document shall include an estimated project schedule for design and construction. Base mapping is generally not required at this stage.

Environmental, utility, and right-of-way clearances are required on all projects, unless specifically noted otherwise by the TTG Project Manager. Projects involving disturbing existing pavements require a Materials Memo from ADOT Materials Group. Where projects occur on or adjacent to Native American lands, special permits may need to be obtained or special requirements met. Special permits or clearances may be needed for crossing or locating facilities within certain bounds beyond railroads, parks, flood control districts, airports and connections to city facilities. The designer must be aware of these items and budget for them in the schedule. A JPA or IGA may be needed to reimburse costs for enhancements desired by outside agencies and/or shared communications infrastructure (i.e., conduit and fiber-optic cabling systems).

Designers shall identify the need for any utility potholing necessary during design to support insuring conflicts are avoided or to determine exact locations of utilities. Potholing needs shall be aggregated, compiled by the designer, and submitted to the TTG Project Manager for evaluation and establishment of the procedure to obtain potholing or determine if another measure is more appropriate in response to each situation.

Designers shall be responsible for determining "prior rights" of any utilities encountered within the project limits and determine appropriate mitigations. The development and issuing of "lock down" plans required by any utility in the course of obtaining utility clearance or new power provisions, shall be the responsibility of the designer.

Prior to the kickoff meeting, the designer should meet with the ADOT TTG PM to discuss stakeholders, statements of work, schedule, scope, and budget. Traffic control for design activities are the responsibility of the designer, including traffic control for bucket truck surveys and field surveys. Special field surveys may be needed for specific devices such as DMS, CCTV, detection systems, and Node buildings. Where unique structural designs are required, the designer shall coordinate with, determine and obtain applicable approvals from the ADOT Bridge Group.

ADOT Phoenix Construction District, ITS Maintenance, Information Technology Group and ADOT VISION Field Office play an important part in plan and specification review, and must be included for each project designed.

Subsequent to completion of the design and final submittal of sealed plans for bid, the designer shall provide the TTG Project Manager with a CD/DVD of all project CADD design files, conforming to the applicable file naming nomenclature and requirements of the ADOT CADD Electronic Files Archiving Process.

The designer's continued involvement through construction, as part of post design services, may be required. In the event post design services are requested of the designer, such activities typically include participation in project Partnering, assisting with equipment submittal review, responding to Requests for Information (RFIs), attending construction meetings, providing alternative designs in response to field conditions, and production of record drawings from Department-furnished redlines, in conformance with the Record Drawings policy of the Statewide Project Management office.

PAGE INTENTIONALLY LEFT BLANK

Chapter 4 Trunkline Conduit System

4.1 Purpose

The preferred FMS communications system consists of two trunkline conduit systems that run parallel to the mainline freeway. These trunkline conduits provide the primary method of distributing fiber-optic communications cabling and power conductors for the system.

FMS conduits that are not part of the trunkline conduit system are typically called *branch* conduits. Branch conduits connect the trunkline network to the various field cabinets and devices. Within this document, branch fiber-optic cables are described as "fiber-optic cables contained within branch conduits".

4.2 Position of Trunkline Within Freeway Right-of-Way

The trunkline conduit system shall be located within the freeway right-of-way. Due to theft concerns, the FMS trunkline conduit should be as close to the right-of-way line as possible, while still being visible from the road, and in front of sound walls or barriers. The designer shall exercise engineering judgment as to the preferred location for the trunkline conduit system, considering factors such as slopes, cross sections, proximity to retaining or sound walls, vulnerability to theft, avoiding utilities, and maintaining landscaping irrigation systems. Maintenance force access to the trunkline conduit system, usually at pull boxes, should be considered. Where feasible, the trunkline conduit system should be positioned to avoid repeated wheel-loads. The following figures are included to illustrate these design concepts.

When the freeway is on an embankment section, considerations must be given to placing field equipment, controller cabinets, etc., at the top of the slope to provide visibility of the FMS equipment from the cabinet. In any case, the trunkline conduit system shall not be placed below the slopes.

4.3 Trunkline Conduit Array & Layout

This section describes several trunkline conduit configurations intended to complete the existing FMS trunkline conduit system and the future expansion of the FMS in a consistent manner. Conduit size, trenching/backfill, directional drilling, etc., are among the most expensive, yet important, elements of the FMS.

4.3.1 Conduit Array: Three-Inch Conduits

The installation of new trunkline conduit along existing urban freeways (Phoenix: Loop 101, Loop 202, Loop 303, SR-24, SR-51, US-60, I-10, and I-17; Tucson: I-10 and I-19) shall be consistent with a three-inch conduit array. This three-inch conduit array has been used extensively in the existing conduit system, and is considered to be the ADOT standard.

Section 4.5.3 provides further discussion of trunkline conduit orientation, including vertical and horizontal configurations.

4.3.2 Conduit Layout

The ADOT FMS in Phoenix is approaching 100% build-out for all freeways interior to Loop 101 and Loop 202. It is ADOT's intention to complete the core FMS by continuing the construction of the three-inch conduit array. If local agencies wish to install fiber optic cable to meet their connectivity goals, they will need to request approval from ADOT TTG.

4.3.2.1 Trunkline on Both Sides of Freeway

Three 3-inch trunkline conduits are required along both sides of the freeway to accommodate communications cables, power cables, and to provide for future expansion of the FMS. Certain segments of the FMS trunkline trench may also include a fourth conduit, for roadway lighting. The conduit path shall be chosen to provide a continuous conduit system as shown in Figures 4.1 and 4.2. Any deviation from the conduit systems, as shown in these figures, shall require ADOT TTG PM approval.

4.3.2.2 Trunkline on One Side of Freeway

A single trunkline, on only one side of a freeway, is not a recommended configuration.

In situations where the design of full FMS encounters an existing freeway segment with trunkline previously installed on only one side of the freeway, the design shall include installation of trunkline conduit on the side without conduit, resulting in trunkline systems on both sides of the freeway, unless specifically directed otherwise by the ADOT TTG PM.

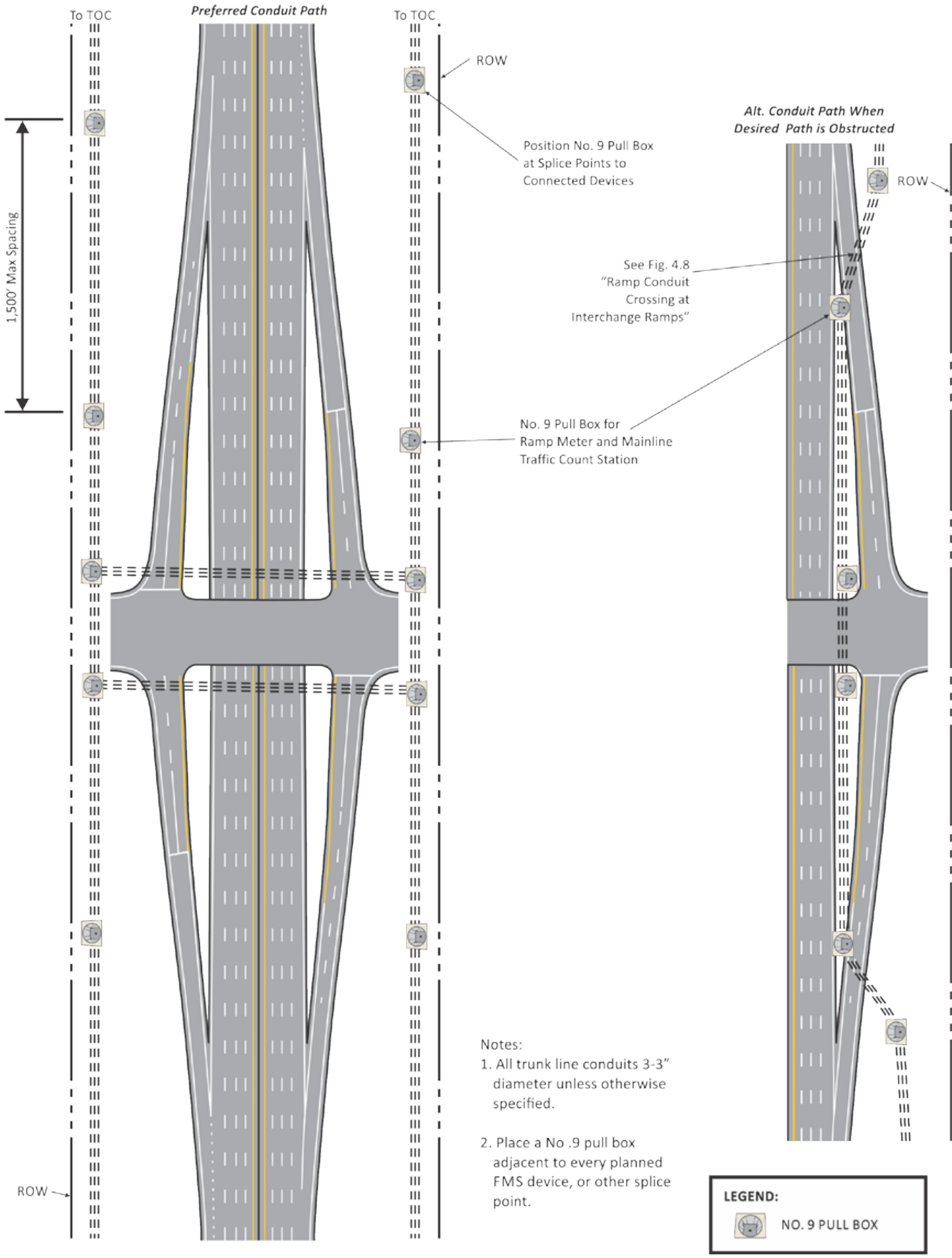

Figure 4.1 - Crossroad Interchange Conduit Installation

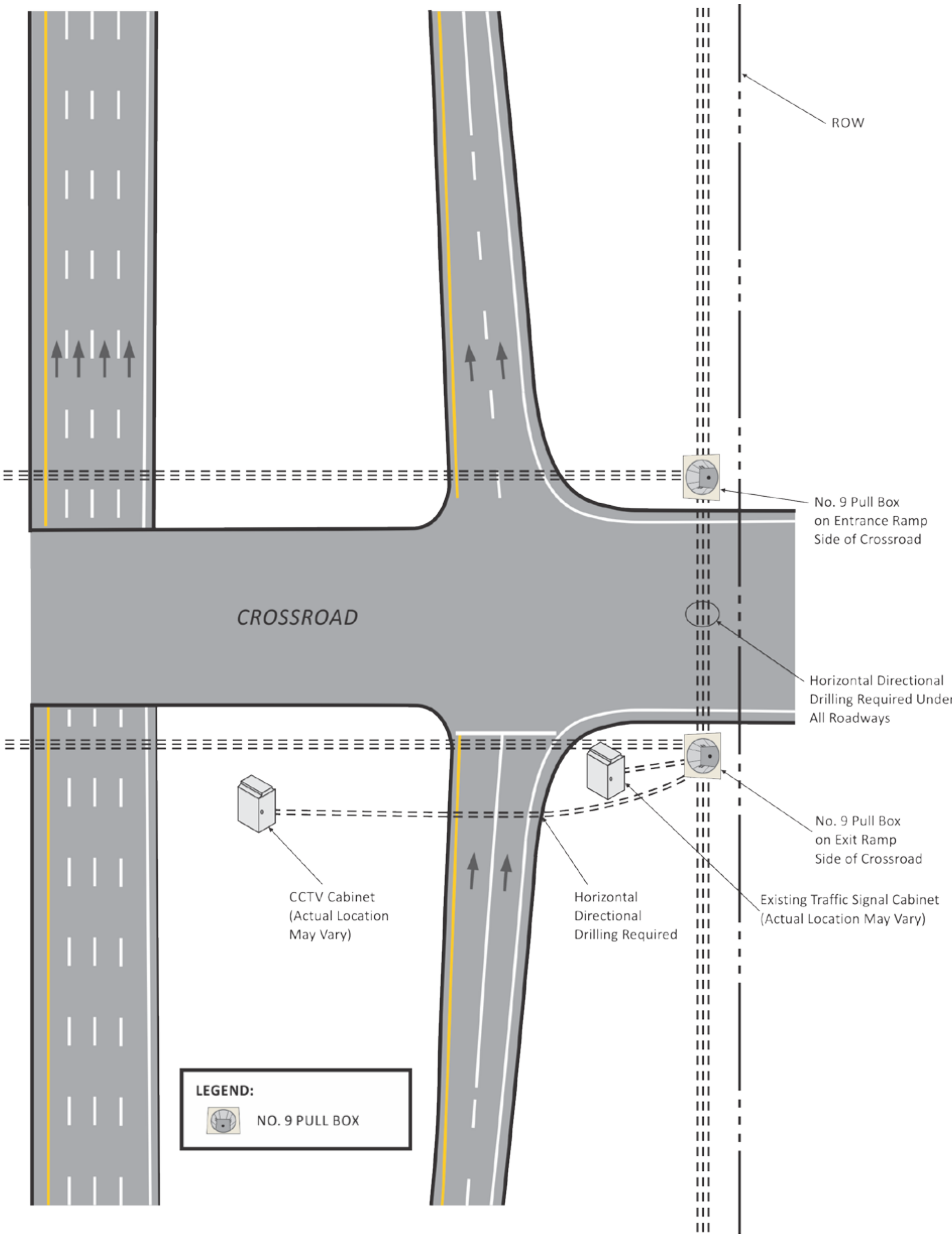

Figure 4.2 - Trunkline Conduit Locations At Crossroad Interchanges

4.4 Trunkline Conduit Co-Location with Lighting Power Conduits

Typically, the trunkline is located adjacent, and in close proximity to the right-of-way line to avoid the impacts of future widening. Unless the available width between the edge of freeway and right-of-way is so constrained that the only way lighting conduit and FMS conduit can coexist is to install in joint trench, co-locating FMS and lighting is discouraged, and is allowed only with the specific approval of the ADOT TTG PM.

In all cases, lighting circuit conductors and the FMS fiber cables and power conductors shall not share the same pull box.

4.5 Conduits

4.5.1 Conduit Connections at Communication Nodes and FMS Trunkline Termination Points

Communication Nodes

At each communication node building, redundant (geographically separated) conduits shall be provided to interconnect the trunkline conduits to the node building. Three-inch diameter conduits should provide interconnectivity between the node building and each of the two trunklines being used, for redundancy. These conduits may be installed in one of several locations, including under the mainline freeway via directional drilling, along the crossroad at a bridge underpass, or attached transversely to overpass bridge structures. The sets of three 3-inch conduits, to each trunkline on either side of the freeway, shall be routed to the node building in such a manner as to not be geographically in close proximity as a means to avoid both sets being severed simultaneously in the event of errant excavations. One 3-inch conduit between the trunkline and the node building, for each trunkline set, shall have two 1-inch corrugated innerducts with detectable pull tape installed.

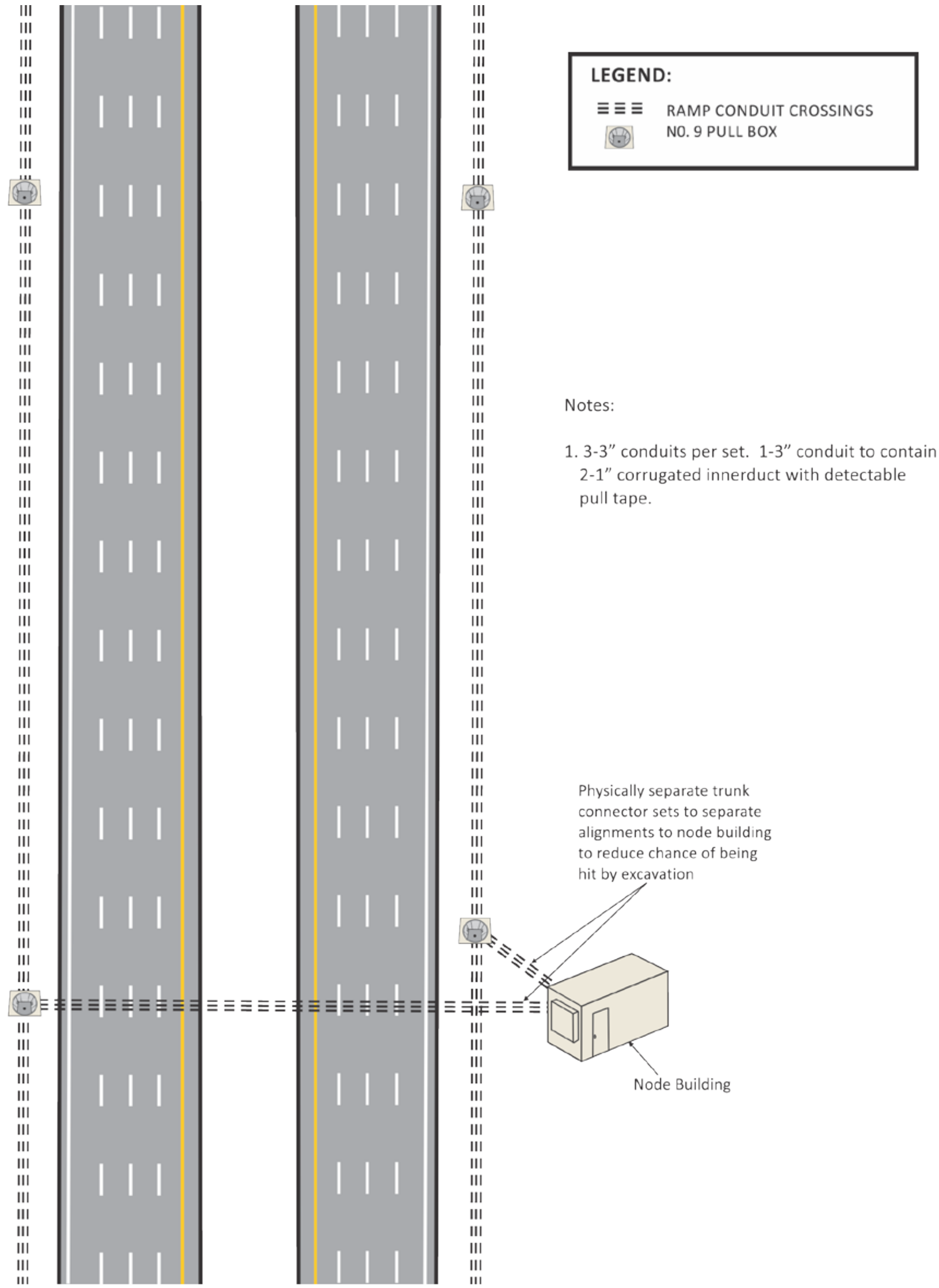

Figure 4.3 - Conduit to Node Building

FMS Trunkline Termination Points

The designer should coordinate the lateral and vertical placement of trunkline conduits at project limits with adjacent design projects to ensure continuity of the conduit system and to ensure separation from other facilities.

In situations where an FMS trunkline, running parallel to, and in close proximity to the right-of-way line needs to connect to an FMS trunkline running parallel to, and closer to the freeway, the preferred method of connection is to terminate each parallel run with a No. 9 pull box, and connect the No. 9 pull boxes with three 3-inch trunkline conduits perpendicular to the freeway.

4.5.2 Conduit Materials and Construction Methods

Underground conduit systems are typically constructed with either PVC or HDPE. All conduits shall have smooth inner and outer walls. PVC conduits are rated by wall thickness and crush resistance. Schedule 40 is typically used for all PVC applications. HDPE conduit is rated for crush resistance and tear resistance. HDPE is subjected to significant pulling tension when installed by directional drilling or boring methods. *Size Diameter Ratio* (SDR) is a term that equates internal diameter and wall thickness to a universal rating. SDR 11 is highly resistant to tear and crush forces for FMS directional drilling or boring applications.

4.5.2.1 Conduit Installation for Fiber Cable - Maximum Pulling Tension

The designer is responsible for designing a conduit system that will facilitate fiber-optic cable installation within and ensuring that the exerted force on the cable will not exceed 600 pounds of pulling tension during installation. Cable pulling programs that calculate pulling tension, or previous design or construction experience, are necessary to meet this requirement. Existing trunkline conduit system alignments shall be evaluated for existing deflection and angle points to determine if the existing alignment is suitable to meet pulling tension limitations, or if alignment adjustments or additional pull boxes are required to mitigate pulling tension challenges.

4.5.2.2 Fiber-optic Conduit Deflection

Conduit deflection should not deviate more than one inch horizontally and/or vertically per 12 inches of running length of conduit (1:12). Long conduit sweeps should be used wherever possible to change conduit direction. The design should strive to stringently adhere to this requirement in order to reduce the pulling tension required during cable installation.

It is recognized that there are complex conduit situations that will have to be addressed during design, such as crossings over canals, tunnels, transitions into structures, etc., where a 1:12 deflection cannot be achieved. Where long conduit sweeps are not possible, standard factory-made conduit elbows of 11 ¼, 22 ½, or 45 degrees with a minimum radius of 24 inches should be specified, or as shown in the ITS Standard Drawings.

90-degree cumulative turns shall be made of individual elbows. Where complex sites leave no other option, such as into and out of structures requiring near 90-degree turns, a minimum radius of 36 inches is required. 90-degree elbows should be avoided, as they require additional labor and equipment for cable installation, even on short runs. The smallest degree of bend possible should be utilized to minimize cable installation challenges. There shall be no more than 360 degrees of cumulative bends between pull points (i.e., pull boxes).

4.5.2.3 Conduit Traceability and Detection – "Blue Stake"

The design of the fiber-optic conduit and cable must strive to avoid both potential damage to the conduit system and damage to the cable. Loss of communications is a critical issue with regard to the FMS.

Requirements for providing magnetic detection for the underground facilities of the FMS have changed throughout the years. The current ADOT policy, with regards to the FMS, is to place continuous detectable pull tape, conforming to the ITS Standard Specifications and ITS Standard Drawings within the conduit system for detectability and to facilitate the future pulling on new conductors and cables.

4.5.3 Conduit Configuration

Several configurations of the trunkline are available to the contractor during construction, as shown in the ITS Standard Drawings. The intent of allowing any of the approved configurations is to adapt to site specific conditions.

The-typical three 3-inch trunkline conduit contents, as shown in the ITS Standard Drawings, are:

1. The conduit closest to the freeway (horizontal array) or on the bottom (vertical array) is designated for ADOT single-mode fiber-optic (SMFO) cable, local agency fiber-optic cables, and other select device communications cables, as approved by the ADOT TTG PM. When multiple fiber cables (ADOT and/or local agency) are installed in the fiber conduit, they shall be segregated by the use of colored innerduct, as specified in the ITS Standard Specifications.
2. The second conduit (center) will be reserved for future FMS purposes and shall contain *detectable pull tape.* This detectable pull tape should be installed in the conduit as part of the initial conduit installation, per the ITS Standard Specifications.
3. The third conduit, furthest from the freeway (horizontal array) or on the top (vertical array) is designated for FMS device electrical power distribution. Other select power cables, where required, such as power to ramp meter poles may also be allowed, within an innerduct array, to separate voltages.

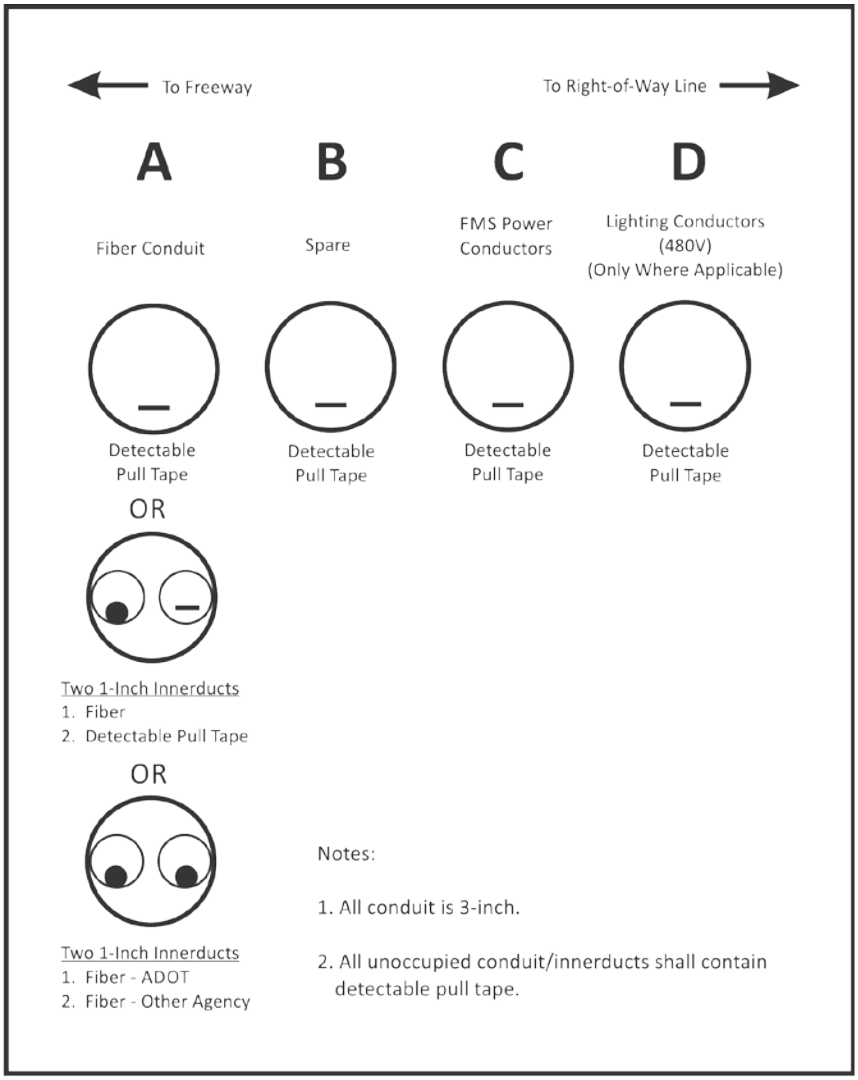

Figure 4.4 - Trunkline Trench Configurations

Corrugated innerduct shall be installed in trunkline and/or branch conduits when ADOT and other agency fiber-optic cables may be installed on the same project, or where one fiber-optic cable is installed with the project, and additional fiber-optic cables to be installed in the future.

Innerduct shall be installed in trunkline and/or branch power conduits to separate 480 volt power conductors from other voltage conductors (power to CCTV, DMS, etc.) when run in the same conduit.

Otherwise, no innerduct is to be installed in the trunkline conduits when they are to remain empty.

Generally, two 1-inch or three ¾-inch innerducts of different colors, conforming to the ITS Standard Specifications, are to be installed in the 3-inch trunkline and/or branch conduits, as required, to establish the appropriate quantity of separate pathways. One innerduct shall contain the ADOT fiber-optic cable. Other innerducts shall contain the other agency fiber-optic cable or pull tape to facilitate future fiber installation.

If a project requires multiple innerducts within a conduit, the designer shall verify the outside diameter of the innerduct such that the desired quantity of innerducts will fit in the designated conduit(s). The specific outside diameter should be referenced in the project plans and Special Provisions.

Fiber-optic cable shall not be installed in any conduit containing innerduct, outside of an innerduct. Any existing conduit containing existing fiber-optic cable or existing electrical conductors or other cables that will have innerduct installed as part of a project, shall provide for the removal and reinstallation of existing contents into the newly installed innerduct. The process of disconnection, removal, and reinstallation and termination shall be clearly indicated in the project plans of Special Provisions, and as approved by the ADOT TTG PM.

4.5.4 Conduit Below Pavement and on Structure

4.5.4.1 Conduit Installation on Structures: Bridges

The designer shall obtain ADOT TTG PM and ADOT Bridge Group approval of any conduit installation within, or attached to, any existing or proposed bridge structure. Attaching conduit and associated hardware to the exposed fascia of new structures should be avoided. Conduit should be incorporated into the structure where possible. Conduits either within or attached to structures shall be rigid metal conduit (RMC). Intermediate Metal Conduit (IMC) shall not be used for any FMS applications. RMC is less likely to be affected by bridge expansion or deflection. Since this conduit is often hidden, it is imperative that the conduit system does not fail. Where required for aesthetic reasons, RMC shall be painted, as approved by the ADOT TTG PM and ADOT Bridge Group, to match the color of the existing bridge structure. Any necessary painting shall have materials and construction requirements spelled out in the project Special Provisions.

For new bridge structures intended to convey the FMS trunkline, the RMC conduit system shall be installed inside the box girder cells or under the bridge deck between the exterior and first interior girders. Details of exact location and method on conduit installation shall be coordinated by the FMS designer with the bridge designer, ADOT TTG PM and ADOT Bridge Group. Designers shall ensure adequate expansion couplings, allowing for conduit movement in all planes. Expansion couple devices should be provided at the same locations of bridge movement points, and conform to the ITS Standard Specifications and ITS Standard Drawings.

No. 9 pull boxes should be placed on either end of every structure where the FMS conduit trunkline is to be installed. The ITS Standard Drawings depict the conduit transition treatment between structures and No. 9 pull boxes. Conduit hanger placement details for I-beam and concrete box girder bridges shall be as shown in the ITS Standard Drawings. The elevation of the conduit through the structure should approximate the elevation of the conduit placement in the trench, in order to avoid sharp directional changes. The use of 90-degree conduit elbows to transition the conduit from the trench to bridge grade is not acceptable.

For bridges over 1,500 feet in length, in addition to the No. 9 pull boxes on each end, one or more intermediate pull boxes shall be detailed into the structure to allow access and to facilitate cable-pulling equipment. Intermediate pull boxes should be equally spaced along the structure at a maximum spacing approved by the ADOT TTG PM in response to the field application. The designer shall evaluate the accessibility of the area under, on, or within the bridge to determine the appropriate location(s) for the intermediate pull boxes.

Although not typically preferred, if directed by the ADOT TTG PM, some bridges may require field devices, such as CCTV and controller cabinets, to be structure-mounted. These devices, along with the pull boxes and associated conduit system, require special design of barriers, platforms, and pull boxes to accommodate the required field equipment.

4.5.4.2 Conduits Crossing Ramps at Traffic Interchanges and System Interchanges

It is preferable to install trunkline conduit as close to the right-of-way line as possible. Hence at traffic interchanges, the trunkline conduits should be installed along the outside of the exit ramp, underneath the crossroad, and along the outside of the entrance ramp. In cases where this routing is not possible, trunkline conduit may cross the exit ramp, run alongside the mainline or inside the entrance and exit ramps (crossing the crossroad either below pavement or on structure, (see Figure 4.1), and finally cross the entrance ramp back to the outside of the entrance ramp (see Figure 4.2).

Alternate ramp conduit-crossing cases are shown on Figure 4.1 and Table 4.1. The *preferred* conduit path should be gradual (1:12 deflection) to avoid use of factory conduit bends.

Table 4.1 Alternate Ramp Conduit Crossing Cases

ALTERNATE RAMP CONDUIT CROSSING OPTIONS		
CASE A	Preferred	No factory conduit bends, maximum deflection of one-inch per foot of conduit.
CASE B	Acceptable	Maximum factory bend of 22½ degrees; 11¼ degrees bend preferred.
CASE C	Acceptable	No factory conduit bends.

4.5.5 Trenchless Conduit Installation Methods

The designer shall be familiar with the requirements of the ADOT Standard Specifications and ITS Standard Specifications regarding where trenchless conduit installations are required, such as under any existing pavements, railroads, graphic slopes and areas specifically called out on the project plans, by the designer, to utilize trenchless installation to minimize damage to existing surface features, or to accommodate grade differentials.

The designer has the option of using customized project-specific bid items that specifically distinguish, measure and pay for trenchless conduit installation separate from other installation methods, or may opt to measure and pay for all conduit based on size and type, regardless of installation method. Factors to be considered by the designer should include the proportion of trenchless conduit versus other methods, difficulty of trenchless installation at the specific project location versus comparable difficulty of other methods, and other project-specific factors that may influence a significant difference in cost for trenchless installation when compared to other methods. The use of such customized project-specific bid items are subject to the approval of the ADOT TTG PM, ADOT Contracts & Specifications and shall supplement the ITS Standard Specifications with project-specific Special

Provisions specifically stating which bid items are applicable, and what deviations from the requirements of the ITS Standard Specifications apply.

Warning tape is not required in conduit segments where HDD methods are used for construction.

The designer may refer to the following HDD reference documents for additional information:

- ASTM F 1962 - Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, including River Crossings;
- Mini Horizontal Directional Drilling Manual - Published by the North American Society of Trenchless Technology (NASTT); and
- Polyethylene Pipe for Horizontal Directional Drilling - Published by the Plastic Pipe Institute (PPI).

4.6 Pull Boxes

FMS pull boxes are used in ground and structure-mounted applications. Two sizes, or types, of FMS ground-based pull boxes are normally used on FMS projects: the “box” sized *No. 7 ITS Pull Box* and the “vault” sized *No. 9 Pull Box*.

Per the ITS Standard Drawings, pull Boxes on slopes should normally be constructed with the lid level, not tilted to be parallel with the slope. Pull Boxes should be designed to avoid exposing any sides of the pull box that might be a hazard to traffic.

Pull boxes should not be installed within the roadway, within any paved area, or future widened roadway footprint unless each location is explicitly approved by the ADOT TTG PM and compliant with additional load and lid requirements, where applicable.

Pull boxes should not be positioned in locations that are known or anticipated paths for vehicles, such as maintenance and landscaping trucks, nor in the roadway shoulder or distressed vehicle pullouts.

Care should be taken in locating pull boxes to avoid drainage swales. Generally, pull boxes should be elevated above the surrounding terrain between one and two inches.

The designer is expected to field verify the proposed pull box locations to avoid any visible conflicts. Designers are required to field check each new proposed pull box location to ensure that it is not in pavement, on a slope, in a drainage swell or area that otherwise may collect standing water, a hazard to traffic or pedestrians, or in a location where it would likely be in the path of vehicle traffic. Where necessary to avoid hazardous conditions, the pull box spacing may be reduced and the number of pull boxes required increased.

Delineators shall not be used to mark new pull box locations. All existing FMS pull box flexible delineators within the project limits, associated with any existing FMS pull boxes, including those that otherwise have no work associated with or in the existing FMS pull box, shall be removed and disposed of by the contractor, per the ITS Standard Specifications.

All FMS pull box lids shall be labeled “ADOT FMS,” consistent with current practice. (Pull box lids used for rural ITS applications, such as rural DMS, RWIS and other TTG systems, shall have lids labeled as directed by the ADOT TTG PM.)

4.6.1 Pull Box Types

Designers are required to run new conduits from No. 9 pull box to No. 9 pull box and minimize the use of No. 7 ITS Pull Boxes, except when approved by the ADOT TTG PM.

All No. 7 ITS Pull Boxes on FMS projects shall be single-unit, 24-inches in depth, conforming to the ITS Standard Drawings and ITS Standard Specifications.

No. 7 ITS Pull Boxes shall be numbered and geo-referenced on the project plans with a unique number that is not duplicated. The pull box numbering scheme should be similar to the ADOT cabinet numbering scheme, e.g., by route, direction, and milepost to the nearest hundredth of a mile. Pull boxes with same milepost, due to close proximity to other pull boxes numbered in the plans, shall utilize an "A, B, C", etc. suffix. In filling out conduit schedules, designers shall indicate an item is a load center with "LC", and cabinet with "C" prefix.

Project record drawing documentation shall be required of the contractor, and conform to the ITS Standard Specifications.

4.6.1.1 No. 9 Pull Boxes - General

No. 9 pull boxes, conforming to the ITS Standard Drawings and ITS Standard Specifications shall be installed in the following instances:

- Typically 1,320 feet, and no more than 1,500 feet along the trunkline to assist installation of fiber-optic cabling within the conduit;
- In the vicinity of each mainline detector station, approximately one mile spacing;
- Locations where parallel trunklines between adjacent projects need to resolve differences in offset alignments;
- Each location where fiber-optic cable splicing occurs or may occur; and/or
- Proposed project or future splice points for branch fiber-optic cable to DMS, CCTV, traffic signal controllers, ramp meters, pump houses, other agency infrastructure, or other field devices; and/or
- Ends of bridge structures and large box culverts.

The designer shall coordinate with the ADOT TTG PM and ITS Maintenance staff when existing cables are present in the existing conduit system to be intercepted. Intercepting conduits may necessitate use of a "split No. 9" pull box, conforming to the ITS Standard Drawings and ITS Standard Specifications, if approved by the ADOT TTG PM.

4.6.1.2 No. 9 Pull Boxes – Loading Requirements

Where No. 9 pull boxes must unavoidably, and approved by the TTG PM, be located within the traveled way, shoulder, other paved surface, or other location where repeated dynamic loads are likely (such as unpaved areas near ramp gores), a special design of a cast iron pull box lid must be conducted by the designer to accommodate the repetitive vehicular loading. The pull box lid design shall incorporate a locking mechanism that will prevent vibration and vehicle traffic from un-seating the lid. This design shall be certified and sealed by an Arizona registered Structural Engineer and approved by the ADOT TTG PM.

4.6.1.3 No. 9 Pull Boxes – Cable Racking

Fiber-optic cable shall be coiled in No. 9 pull boxes, conforming to the ITS Standard Drawings and ITS Standard Specifications. The fiber-optic cables are supported on the sides of the pull box with pre-manufactured vertical cable racks called *cable ladders*. Trunkline conduits typically enter the No. 9 pull box from opposite corners, to facilitate coiling.

4.6.1.4 No. 9 Pull Boxes – Torsion Assist Lid

The diamond-plate steel lid for typical No. 9 pull boxes shall be a square shaped lid, conforming to the ITS Standard Drawings and ITS Standard Specifications.

Projects in areas with existing FMS infrastructure that includes the old design round manhole lids on existing No. 9 pull boxes shall have existing top section, with lid, replaced with the current design of torsion assist square stainless steel lockable lid. The Designer shall replace all such lids on all existing No. 9 pull boxes utilized within the project limits, including any existing No. 9 pull boxes that may otherwise not have any other activity, but contain existing fiber-optic or power cables, or anticipated for future use. The designer shall present the ADOT TTG PM data on where all existing No. 9 pull boxes are located within the project limits, identify those being reused for the project, and obtain direction from the ADOT TTG PM as to which additional existing No. 9 boxes within the project limits are to have top sections with lids replaced.

Designers shall be aware of, and field verify the plan view dimensions and existing ground conditions around each existing No. 9 pull box to get new lids, and develop strategies for dealing with installation challenges, including the existing box being dimensions other than the current lid top section size. The designer shall be responsible to insure that the project plans account for any odd sized lid section dimensions, to avoid improper fit or ability to snugly rest the new top section atop of the existing under field conditions.

Existing No. 9 pull boxes indicated on the project plans to be retrofit with new torsion assist lid, shall have the lid properly grounded to a ground rod driven into the ground through the sump hole in the bottom of the No. 9 pull box. Existing pull boxes found, during the designer's field inventory, to not have a ground rod present, shall have provisions in the project plans and Special Provisions for a new ground rod and ground conductors installed to properly ground the new lid.

4.6.1.5 No. 9 Pull Boxes – Splice Closures

Splice closures for fiber-optic cables shall be appropriate for intended size and quantity of cables and splices, and conform to the ITS Standard Specifications. The designer shall be responsible to identifying and incorporating all splice locations and fiber splice details into the project plans and Special Provisions, including any necessary butt-splice points of all fibers within a cable.

4.6.1.6 Pole Mounted Junction Boxes

All poles intended to support legacy or proposed non-intrusive vehicle detection systems approved by the ADOT TTG PM, shall be accompanied by an adjacent pull box. The pull box may be placed in the ground or, in cases of barrier pole mount sites, a special NEMA junction box mounted on the pole near the base of the pole shall be designed and detailed in the project plans and Special Provisions. Pull boxes in barriers are not preferred, unless directed by the ADOT TTG PM.

4.6.1.7 Bridge Mounted Junction Boxes

Conduit crossings over canals, roadway undercrossings, railroads, etc. that are to be mounted on the exterior of the bridge fascia or abutments shall have secure junction box covers. The junction box covers shall be designed so that special tools are required for the cover plate to be removed to thwart vandalism. The designer shall confirm that the "special tools" is approved by ADOT ITS Maintenance, and if necessary, make provisions in the project plans and Special Provisions to have such tools provided as part of the project, as approved by the ADOT TTG PM.

4.6.2 Co-Locating Lighting No. 7 Pull Boxes with FMS Trunkline Pull Boxes

Lighting power conduit may rarely be co-located in the same trench line or alignment as the FMS trunkline due to specific site space constraints, though this is not the preference of the ADOT Lighting Maintenance staff or ADOT ITS Maintenance.

Co-locating new FMS with new lighting or any other infrastructure, ADOT-owned or otherwise, for contractor convenience is prohibited.

The only situations where co-locating with other new infrastructure will be allowed will be based on the presented justification by the design to the ADOT TTG PM, and explicit approval and direction by the ADOT TTG PM, including any requirements for pull box locations relative to the two facilities.

PAGE INTENTIONALLY LEFT BLANK

Chapter 5 Mainline Detector System

Data from vehicle detection technology is used in real time for FMS applications and is available for planning purposes. The FMS gathers and uses real-time traffic data including speed, occupancy, vehicle identification, and volume. Stored data is also useful for traffic planning purposes such as monitoring traffic trends and generating other traffic related statistics.

The standard vehicle detection system for the ADOT FMS is loop detectors that are either sawcut into the pavement surface or installed beneath the pavement. At certain locations, such as on a bridge where loops cannot be saw cut, non intrusive detection systems may be installed, if agreeable to stakeholders.

Non-intrusive detection technologies may be considered for FMS projects only if approved by the ADOT TTG Project Manager. Where new vehicle detection system technology is being proposed on a project, the designer shall define and document the proposed vehicle detection system technology and communications approach. This documentation shall occur during scoping of the FMS.

At a minimum the vehicle detection system needs to test for vehicle volumes, speed, occupancy, and classification. Mainline detector system components shall conform to the ITS Standard Drawings and ITS Standard Specifications.

5.1 New Installations

Mainline detector stations are required for the entire urban freeway system. One detector loop station is required per mile in each direction, typically near the existing or future entrance ramp detectors, so the mainline detector system and ramp meter can utilize a single control cabinet (refer to the *Ramp Metering Design Guide*). Preformed detector loops shall be embedded in all new concrete pavement on projects where new freeway construction occurs with installation of the full FMS. New freeway construction where fiber is not being installed, will not install mainline detection.

Sawcut loops are allowed in asphalt pavements. Each set of detector loops normally consists of two 6 feet x 6 feet square-shaped preformed detector loops per lane, separated longitudinally by 12 feet. All loops shall terminate in a No. 9 or ITS Pull Box at the shoulder. Median pull boxes shall not be used.

5.2 Retrofit Projects

Saw-cut loops in existing pavement shall be used. If existing loops are being used for a project, it is the designer's responsibility to test the existing loops for continuity and Meg-Ohm readings to ensure the loops are not damaged. These tests do not confirm lateral locations of existing loops, and designer will not conduct field locates to determine lateral loop locations.

Tested loops found to be failed shall be replaced in the project, under Force Account.

If the designer is working on the retrofit of an existing roadway or a restriping project on the roadway, it will be necessary to saw-cut loop detectors in the pavement surface. Typically, when a six-foot, square-shaped loop is centered in the lane, there is approximately three feet to the lane line. In a retrofit or restriping project, if the lane line shifts such that the edge of the buried loop is less than 18 inches from the new lane line, then new saw-cut loop detectors in the pavement surface are required. Each set of detector loops shall consist of two 6-foot, square-shaped loops per lane, separated longitudinally by 12 feet.

Loops are to be centered in the middle of the lane(s). Typical loop placements are shown in the ITS Standard Drawings. Auxiliary lane and high-occupancy-vehicle (HOV) lanes must have loop detectors installed similar to general-purpose lanes.

5.3 Loop Detector Requirements

Loop detector requirements are discussed in the *ITS Standard Drawings, ITS Standard Specifications*, and the *Ramp Metering Design Guide.*

The following procedure is to be utilized for systematic design of the placement of mainline detector stations.

1. Uniformity in loop detector spacing is desired; therefore, divide the project into approximately equal one-mile segments and identify these points as the location(s) of the intermediate stations. If a location falls on a bridge or in a lane taper, the loop location should be adjusted so that it is beyond the nearest bridge abutment or upstream of the start of a lane taper. When an adjustment is required, the loop spacing should be no more than one mile from any adjacent loop detector station.

   The designer should be aware of the difficulties of obtaining accurate mainline count, occupancy, classification, and vehicle length data in the immediate vicinity of entrance and exit ramps due to the number of merging vehicles and lane changes which commonly occur. Where possible, the designer should avoid placing mainline detector stations where merging or extensive weaving occurs.

2. At least one loop detector station should be placed in each one-mile section of freeway, including sections where interchanges are more than a mile apart.
3. Repeat the process for the other direction of travel.
4. The mainline loops should be placed adjacent to the ramp meter stop bar. If there is no ramp meter stop bar, the mainline loops should be placed near the paved gore, before the on-ramp joins the mainline.

Chapter 6 Equipment Cabinets

Equipment cabinets are installed along the freeway as part of a FMS project. Equipment cabinets are typically located adjacent to mainline detector stations, ramp meters, CCTV, and DMS. Ramp meter equipment cabinets are shared with mainline detector stations. When conditions during the initial roadway construction make it difficult or impossible to install an equipment cabinet or foundation at a later time, the provision for the equipment cabinet, or as a minimum, the equipment cabinet foundation, should be made as part of the initial roadway construction. This chapter describes considerations for cabinet location and key provisions for cabinet foundations.

6.1 Equipment Cabinet Location

Design criteria for suitable controller cabinet location include the following:

A. The cabinet is to be placed in the safest possible location, generally along the right shoulder, and to minimize conduit and cable quantities. If no protection (e.g., barrier or guardrail) is proposed for the cabinet location, the cabinet shall be outside the *clear zone* such that no protection is needed. See the *AASHTO Roadside Design Guide* for *clear zone* requirements. If the cabinet must be placed between the mainline and the ramp and an adequate clear zone is not met, protection is to be provided, as required. Consideration should also be given to probable future widening of the mainline and/or ramps, and consequently any opportunity to install cabinets further from the edge of the traveled way should be considered.

B. If a barrier is present along the right edge of the pavement and the installation of a controller cabinet is required, the cabinet is to be located behind a guardrail and behind a concrete barrier as shown in the ITS Standard Drawings.

C. The cabinet is to be located in order to minimize the length of the detector loop lead-in while also considering probable future widening of the mainline and/or ramps. Loops from several different locations may be terminated in the cabinet: the ramp metering stop bar area, the advance queue detector (AQD) area, and adjacent mainline loops. Designer shall refer to the ADOT *Ramp Metering Design Guide*. The detector card supports a maximum distance between cabinets and their respective detector stations. Special provisions shall be developed to identify the anticipated distances and corresponding detector card requirements.

D. Where non-intrusive detection system technology is used instead of loops, the designer shall check with the vendor to determine distance limitations. Visibility from the cabinet to the specific detection system is to be maintained for ease of calibration and maintenance.

E. Modifications in the landscaping plan, or noting the need for grubbing may be required to include a safe maintenance vehicle parking area and to ensure visibility of the FMS equipment served by an equipment cabinet.

F. The position of a combined ramp meter/mainline detector station cabinet is to allow observation of the ramp metering stop bar and at least one ramp meter signal head from the doorway of the cabinet.

6.1.1 Ramp Metering Cabinets

Designers are advised to refer to the *ADOT Ramp Metering Design Guide* for guidance on ramp metering concepts. Where ramp metering equipment is not being installed at the time of roadway design, the future cabinet site shall be located per the *Ramp Metering Design Guide*. Mainline detection may still require placement of a cabinet that would also be used for ramp metering, in the future, when the ramp meets warrants for metering.

6.1.2 Other Equipment Cabinets: CCTV, DMS, Mainline Detection

Locations for cabinets are dependent on the location of each device served, clear zone, and availability of barriers or guardrail. Ideally, positions for CCTV, DMS, and mainline detection stations (besides those associated with ramp meters) are established in the initial design for all FMS projects, including those where only the conduit, pull boxes, and foundations are initially constructed. Device positions then determine cabinet and No. 9 pull box locations. Typically, the No. 9 pull box is positioned laterally from each cabinet.

6.1.2.1 Freeway DMS Cabinet

Designers are advised to refer to the ADOT Statewide DMS Master Plan for guidance on DMS concepts.

Freeway DMS typically utilize a foundation-mounted DMS control cabinet. A foundation-mounted cabinet, and, where required, a transformer enclosure, would be placed downstream of the structure support pole such that the structure support pole provides protection to the cabinet from vehicles.

Freeway DMS for new installations that may, in special cases, as approved by the TTG Project Manager, include a smaller pole-mounted cabinet, a pole-mounted cabinet would be mounted on the right shoulder Freeway DMS structure support pole on the traffic "downstream" side, utilizing the structure's nipples already provided in ADOT Bridge Group Standard Drawing SD 9.20. The designer shall carefully evaluate nipple and cabinet heights to insure the resulting configuration provides a vertical orientation of the cabinet.

6.1.2.2 Legacy Installations

The reinstallation of any existing DMS on new or modified supports shall require the designer to determine the manufacturer, model, existing mounting support vertical tilt and LED angles to insure reinstallation provides equal or improved DMS visibility. The designer shall provide the TTG Project Manager with a visually graphic representation of existing and proposed mounting configurations and resulting LED angles in both the vertical and horizontal planes as evidence of equal or improved visibility. In the event DMS visibility is deteriorated in the proposed configuration, the designer shall propose a mitigation strategy to restore DMS visibility for TTG Project Manager approval.

The designer shall be responsible to identify the correct Standard Drawings series for the tubular support structure and cabinet foundations, based on manufacturer of the legacy DMS to be used.

6.2 Equipment Cabinet Foundation

At construction, the ITS Standard Specifications require the contractor to provide a cabinet foundation field marking for approval by the Engineer prior to construction of each cabinet foundation. The engineer shall verify that the marked foundation location is consistent with the location of the trunkline pull box and the device served by the cabinet, as these locations may have also been adjusted. The engineer shall verify that the location of the cabinet foundation is in a safe position, has acceptable maintenance access, visibility to devices served, and is not in an area susceptible to ponding of water.

The following may need to be added to the Special Provisions:

The contractor shall demonstrate:

1. The marked foundation is consistent with the location of the trunkline pull box and the device served by the cabinet;
2. The location of the cabinet foundation is in a safe position, having acceptable access, and visibility to devices served; and,
3. The area has drainage features to keep the equipment dry.

All equipment cabinet foundations shall be numbered and geo-referenced. Each equipment foundation on each FMS project shall be designated with a unique number that is not duplicated. The numbering scheme should follow the typical ADOT cabinet numbering scheme, e.g., by route, direction, and milepost to the nearest hundredth of a mile. Cabinets with the same milepost, due to close proximity to other cabinets at or near the same location, shall utilize an "A", "B", "C" suffix nomenclature. Load centers shall be labeled with an "LC" prefix, and other cabinets shall use a "C" prefix.

6.2.1 Fiber-Optic Cable Connectivity

Fiber optic branch cables entering FMS control cabinets shall be connected to a patch and splice module unit, mounted on the DIN rail shelf, as shown in Figure 6.1. Special Provisions describing the details of this arrangement will be required on a per project basis, as it is not described in the ITS Standard Specifications. Spider fan-out kits and Dooley sumps are no longer used on new installations.

6.3 Equipment Cabinet Power and Surge Protection

All cabinets shall be grounded in accordance with the ITS Standard Specifications. Surge protectors shall be used, in conformance with the ITS Standard Specifications.

The designer shall size the power conductors to comply with NEC requirements (3% maximum voltage drop for feeder circuits, *NEC 215-2(d) FPN No. 2*; 3% maximum voltage drop for branch circuits, *NEC 210-19(a) FPN No. 4*) and a maximum 5% voltage drop overall for branch circuits and feeders, combined, based upon the design load, actual field distance and voltage. Voltage drop calculations shall be provided to the TTG Project Manager with the 60% design submittal, justifying conductor sizes, and showing design loads and voltages used in the calculations. Shorter runs, utilizing smaller gauge copper conductors are preferred, as a means of deterring copper theft. Situations where utilization of existing

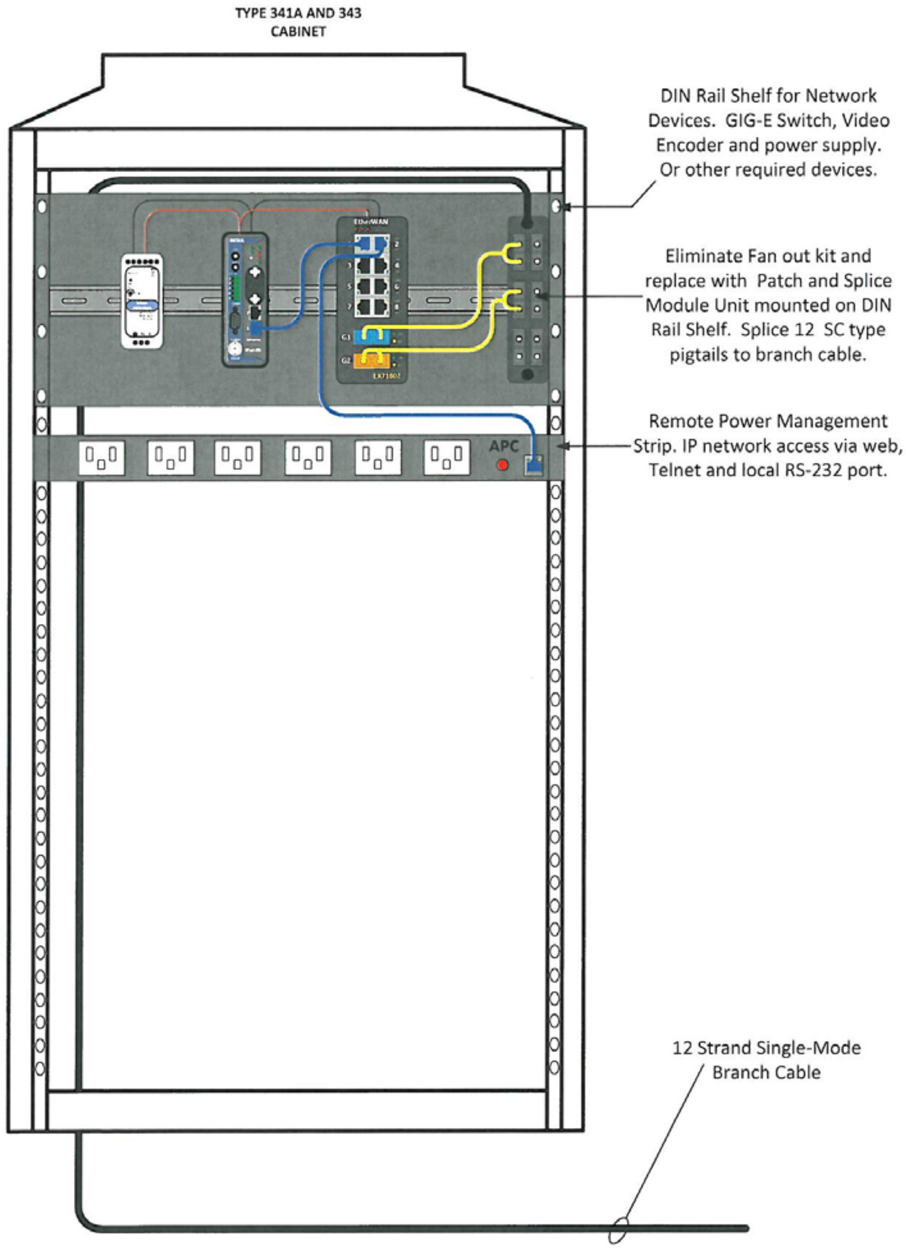

Figure 6.1 Fiber Splice Interface

power sources result in large size copper conductors shall be evaluated by the designer to determine if a line extension by the power provider would mitigate the impact of voltage drop over distance by locating the power source closer to the devices served. The designer shall be responsible for contacting and coordinating this evaluation with the utility, and present the TTG Project Manager with alternatives and associated costs.

For FMS system implementation, 480-volt power is typically distributed from a load center to each equipment cabinet and stepped down from 480-volts to 120-volts with a step-down transformer located adjacent to the cabinet. A type IV load center cabinet is preferred because it offers the opportunity for both voltage types. The designer shall note that a 25kVa transformer will not fit into the standard ground-mounted stand-alone transformer cabinet.

All power services shall be metered. It is preferred that the service voltage be 480 volts, metered, and elimination of the 120 to 480 step-up transformer in the load center. However, if only 120/240 service voltage is available, the modified Type IV load center shown in the ADOT Standard Drawings shall be used. The designer shall confirm with the power provider, any additional cutoff devices required by the power provider and accommodate them in the design as necessary.

In situations where the project calls for additional devices to be added to an existing load center, the designer shall be responsible for confirming adequate capacity of the existing load center and associated service to accommodate the additional load and submit evidence of such analysis to the TTG Project Manger with the 60% design submittal.

Power conductors shall be size #4 or smaller for urban applications, unless otherwise approved by the TTG Project Manager. Long runs of heavy gauge wire should be avoided because they are most vulnerable to theft. The designer shall use the lightest gauge wire that satisfies the voltage drop requirements, and is approved by the TTG Project Manager. Multiple FMS devices should be powered from one load center. Situations where excessive distances imply the use of conductors exceeding #4 size should consider whether a line extension by the power provider would be a more economical approach - especially since it shifts the burden of some of the voltage drop impact to the power provider. Conductor size #3 shall not be used.

Service addresses for new power services shall be obtained by the designer from the local municipality responsible for address assignments, and show the power service address on the project plans and in all correspondence with the power provider. Copies of any and all design sketches from the power provider shall be copied to the TTG Project Manager. Any situations requiring line extensions or power provider work or equipment with a cost to the Department shall be immediately brought to the attention of the TTG Project manager for guidance on whether such costs will require a separate utility agreement and funding or whether they should be covered in the project under the power service bid items.

The design shall ascertain whether the power provider located within or near a project will require "lock-down" plans, specific elements of the lock-down plans, and shall be responsible for generating and submitting such plans to the utility for approval.

6.3.1 Transformer Cabinet Power Disconnect

All transformer cabinets shall be equipped with an external power disconnect as shown in the ITS Standard Drawings and conforming to the ITS Standard Specifications.

Chapter 7 Freeway Dynamic Message Signs

The ADOT Statewide DMS Master Plan is not only a plan of where DMS should be placed on Arizona highways and freeways but also a design guide for DMS.

The FMS designer is to determine if any Freeway DMS locations were previously planned for the mainline corridor that is under design by consulting the Statewide DMS Master Plan and Errata. Criteria for placing Freeway DMS are stated in the Statewide DMS Master Plan. Any deviations shall only be with the approval of the TTG Project Manager.

Freeway DMS provide key route guidance and diversion information to the freeway driver; therefore, the proper placement of the signs is essential. Individual DMS locations may be tied to specific diversion routes and their associated exit ramp. DMS sign placements are considered the highest priority and may necessitate the designer to coordinate and arrange for moving other signs, such as guide/destination signs and logo signs.

PAGE INTENTIONALLY LEFT BLANK

Chapter 8 Closed-Circuit Television (CCTV)

CCTV cameras are to be located at intervals of no more than one mile on the freeway. It is not unusual to have more than one camera per mile. The proper position of cameras and provision for the required conduit and foundations will be accomplished at the time the FMS is designed.

CCTV placement shall insure the following:

- Ability to view and read text posted on DMS;
- Ability to view all of the freeway mainline and traffic interchange ramps and gores;
- Ability to view all system interchange ramps from termini to termini;
- Ability to view all interchange ramp junctions with crossing arterials, typically signalized intersections:
- Ability for ADOT maintenance staff to access.

Camera locations shall be carefully selected by the designer to accomplish the above requirements. One typical location is to place a CCTV camera in close vicinity of the interchange. In this position, visibility of the arterial roadway (especially regionally significant roadways), ramps, and the mainline freeway can be accomplished. Another typical location is at the midpoint location between interchanges. This midpoint location is desirable to observe the mainline where the interchange CCTV view is blocked by the arterial overcrossing or in cases where roadway geometrics or viewing of DMS messages dictate the need for additional cameras.

The ability to read messages posted on DMS is a priority for placement of CCTV cameras, and may require:

- Mounting a camera at a lower height
- Installing a camera on the same side of the freeway as the DMS to be within the optics of the DMS.

Freeway widening projects with existing FMS shall add additional CCTV if necessary, to provide the capability of reading DMS messages.

The designer shall identify the manufacturer, model and optics of any DMS (new or existing) to be viewed by the CCTV, and determine the horizontal and vertical spread of the optical system for that model, vertical tilt angle, and horizontal angle of the DMS relative to the roadway, height and characteristics of the base elevation of the proposed CCTV location and develop a graphic documenting that the proposed location and elevation of the CCTV falls within the visibility aspects of the specific DMS unit being viewed.

Possible roadway conditions that shall require additional cameras for mitigation:

- Near the point of intersection (PI) of horizontal curves that restrict visibility to less than ½ mile;
- At locations with recurring congestion, and other high interest areas;
- On the crests of vertical curves;

- Freeway sections where vertical walls restrict visibility, especially around horizontal curves;
- Sight lines obstructed by guide signs, lighting and traffic signal poles;

Any CCTV poles proposed near any airfields, public, private or military, are required to be reviewed by the Federal Aviation Authority (FAA) to determine any height limitations and the need for pole-top illumination. Designers shall contact the FAA to complete Form 7460, and provide pole location coordinates and height, and provide documentation to the TTG Project Manager, at the scoping stage, to determine design requirements and any mitigation strategies.

The designer shall be responsible for conducting a field verification of the visual images expected from each new CCTV, based on the specific location and camera mounting height. The purpose of the field verification is to visually document the anticipated views developed by the designer based on an engineered solution to satisfying the "ability to view" requirements, by providing the TTG Project Manager with images of the freeway, ramps, DMS (existing or proposed) and impacts of items that may impact or obstruct sight lines, such as walls, lighting poles and fixtures, sign structures, and any possible future obstructions, such as new overcrossings or pedestrian crossings. Such field verifications shall be conducted with the use of a bucket truck or other means approved by the TTG Project Manager, capable of reaching the proposed CCTV mounting heights at the proposed CCTV locations.

The designer shall be responsible for coordinating the field verification exercise with all applicable stakeholders, such as the TTG Project Manager, ITS Maintenance, and the District Permits office. The designer shall provide all equipment, vehicles, devices and any necessary traffic control used in facilitating field verification. When scheduling field verification the designer shall mitigate impacts to traffic and identify availability of stakeholders required by TTG.

The designer shall recommend camera sites based on review of field verification images meeting camera criteria. If all the camera criteria can not be met, alternate sites shall be proposed and field verified. Rejected camera locations may require additional field verification efforts by the designer to be conducted, to refine the selection of the optimum site.

The CCTV pole should be located so that a maintenance vehicle can park within reasonable proximity without necessitating a lane closure or blocking traffic. Where crossroads go over the freeway, the area near the bridge abutment may be a level accessible area well suited for a CCTV pole. A maintenance vehicle can often be positioned partially on the sidewalk if the area behind the walk is clear of landscaping. The area immediately adjacent to the CCTV pole, an approximately 10 foot radius around the pole, should be clear of obstructions and landscaping that may inhibit accessibility to the pole, pole-mounted cabinet, transformer pad or operation of the camera lowering device.

CCTV cabinets shall be mounted on the pole supporting the camera with necessary transformer cabinets located using the same criteria as “Equipment Cabinet Location” in Chapter 6.

Typically, an approximately 10 foot radius, shall be leveled and covered with compacted decomposed granite or decorative rock, matching the surrounding area. When leveling is not possible, the designer shall retain uphill soils and landscape materials from intruding into the level area around the pole. Locations of CCTV poles with ground materials other than decomposed gravel shall be discussed with the TTG Project Manager for direction specific to those sites. The designer shall make provisions in the project documents for leveling and sufficient preparation and treatment of the area around the CCTV pole, including repair of any disturbed irrigation infrastructure.

The designer shall coordinate with the TTG Project Manager to determine the type (barrel, dome) and mount of the contractor-furnished camera planned for each particular location. Unless specifically directed by the TTG Project Manager, all new CCTV installations shall use lowering devices integral to the pole. Existing CCTV installations within the limits of a project shall require direction from the TTG Project Manager.

The ITS Standard specifications require that the CCTV pole location be marked in the field and approved by the engineer prior to construction. Designers shall see the ITS Standard Drawings for typical CCTV pole and cabinet configuration.

PAGE INTENTIONALLY LEFT BLANK

Chapter 9 Communication Nodes and Node Buildings

Communication node buildings should be considered at 15-mile interval locations on the FMS network. A node building is an environmentally controlled secure structure at a field site where information is accumulated and transmitted along fiber-optic cables to the TOC. Communication nodes that collect all device information from a geographic area may be located in the field or at the TOC.

New node buildings are modular pre-cast buildings. The building size is based upon the number of racks and communications equipment that are planned to eventually reside in the building. Node buildings contain several racks of electronic equipment for node to field and node to TOC communications. This equipment supports multiplexing video and data signals as well as switching equipment to provide redundant paths of communications for the transmission of field device data and images to the TOC.

Each potential site should be evaluated to ensure it is clear of any future expansion (auxiliary lanes, connector-distributor roadways, frontage roads, etc.).

New node buildings shall include the design of the Access Control System and Building Automation System. The FMS designer shall coordinate the Access Control System design and the Building Automation System design with the ADOT TTG Project Manager.

Considerations for node buildings include:

- Floodplain elevation;
- Maintenance access;
- Security;
- Distance exceeding clear zone from roadway;
- Foundation site shall be on level, firm, compacted material;
- Level and accessible all-weather drive, for maintenance vehicle access;
- Reinforced Portland cement concrete base, with edge footings on all four sides, designed and sealed by an Arizona Registered Structural Engineer;
- Conduits through foundation and floor of modular building, no wall penetrations;
- Exterior texture and color — coordinate with District Roadside Maintenance Group;
- Heating, ventilation and air conditioning controls;
- False floor designed for 250 pounds per square foot total load; and,
- Rack-mounted UPS & power disconnects.

PAGE INTENTIONALLY LEFT BLANK

Chapter 10 Fiber Outside Plant Design and Modeling

New projects are required to build trunkline fiber-optic outside plant (OSP) infrastructure. The central core Phoenix FMS fiber-optic cable network has already been constructed to the TOC. The STOC node in Tucson may require additional connectivity to the fiber-optic OSP infrastructure. New FMS devices coming on-line will require connectivity to the TOC via new and existing fiber-optic cable and node buildings, creating many challenges for the designer such as:

- Where future trunkline fiber is to be spliced to existing trunkline fiber, each existing spare dark fiber strand proposed for use needs to have its source and destination verified, beginning at the TOC, through every intermediate node building, and ending at the new trunkline connection. The FMS designer shall account for any dB loss when splicing to dissimilar fibers, all splices and all connectors. These requirements need to be added to the project Special Provisions once analyzed.
- The ITS Standard Specifications require that the completion of new FMS projects will require a rigorous record drawing documentation process, where contractors must document all splice and path loss data. OTDR/power meter testing of all fiber strands in new cables is required to determine the path loss and proper installation of the fiber-optic OSP infrastructure.
- Existing fiber-optic OSP infrastructure within the project limits shall be documented on the project plans. The design shall require documenting how fiber-optic OSP infrastructure within the project limits are to be extended beyond the project limits (beyond existing fiber-optic OSP infrastructure) to achieve connectivity to existing node buildings and-the TOC.

10.1 OSP Architecture Model

Ideally, an architecture model of the fiber-optic OSP infrastructure (i.e., origination points, cables, splice closures, hubs, nodes, and devices) would accurately depict the following:

- Geographic Information System (GIS) based model of the OSP;
- Splice data at every splice point; and
- Capability to trace a fiber path from the origination point to every FMS device.

This OSP architecture model involves two types of data: GIS and tabular:

- GIS data is needed to track the physical location of the OSP. GIS data aids in locating OSP infrastructure quickly when there is a failure on the network. Tabular data tracks the lengths of fiber runs to ensure that fiber losses are accounted for in the design.

- Tabular data describes every fiber strand splice or termination at each node point, i.e., termination point (TOC, node building, or FMS device) or splice closure (No. 9 pull box), including cable foot markings etc.

10.2 Fiber Splice Tables

Table 10.1 and Figure 10.1 through 10.5 depict examples of five levels of detail used to describe the OSP architecture model. Designers shall review the FMS Communications Master Plan, latest revision, for current details.

Table 10.1 OSP Model Description

LEVEL	MACRO TO MICRO	DESCRIPTION OF COVERAGE	EXAMPLE – SEE FIGURE:
1	Macro	Overall FMS Communications Diagram	Fig. 10.1
2		Access Point-to-Access Point	Fig. 10.2
3		Splice Point-to-Splice Point	Fig. 10.3
4		Splice Detail	Fig. 10.4
5	Micro	Individual Splice Table	Fig. 10.5

Fiber-optic splice information is the foundation of the OSP database. This information is useful in different forms to different users:

- Designers and System Managers typically need network information, at a macro level view. They concentrate on connecting individual devices to the TOC via the overall network. Details from the macro to the micro level are necessary to design and manage the system. Figure 10.1 through Figure 10.4 illustrate the typical design progression from system, nodes, freeway segments, down to cable segments.
- Contractors and FMS Maintenance staff typically need information focused on one specific problem area, usually a splice closure or termination point, hence a micro level view. Finding a specific problem area typically involves a search of documents starting at the macro level and moving to the micro level to "zero in" on the problem.
- The smallest level of interest is a single splice closure point. An example of a single splice detail, showing the splices before and after construction, is shown in Figure 10.5.

Fiber assignments, per 12-fiber tube, within a typical 144 strand fiber cable shall be:

- 1 - 2 ITS Devices, DMS, CCTV, Ramp Meters
- 3 Node backbone
- 4 Traffic Signals, Pump Houses, ADOT Misc.
- 5 - 9 Future Use
- 10 - 12 Inter-Agency, Cities, RCN, etc.

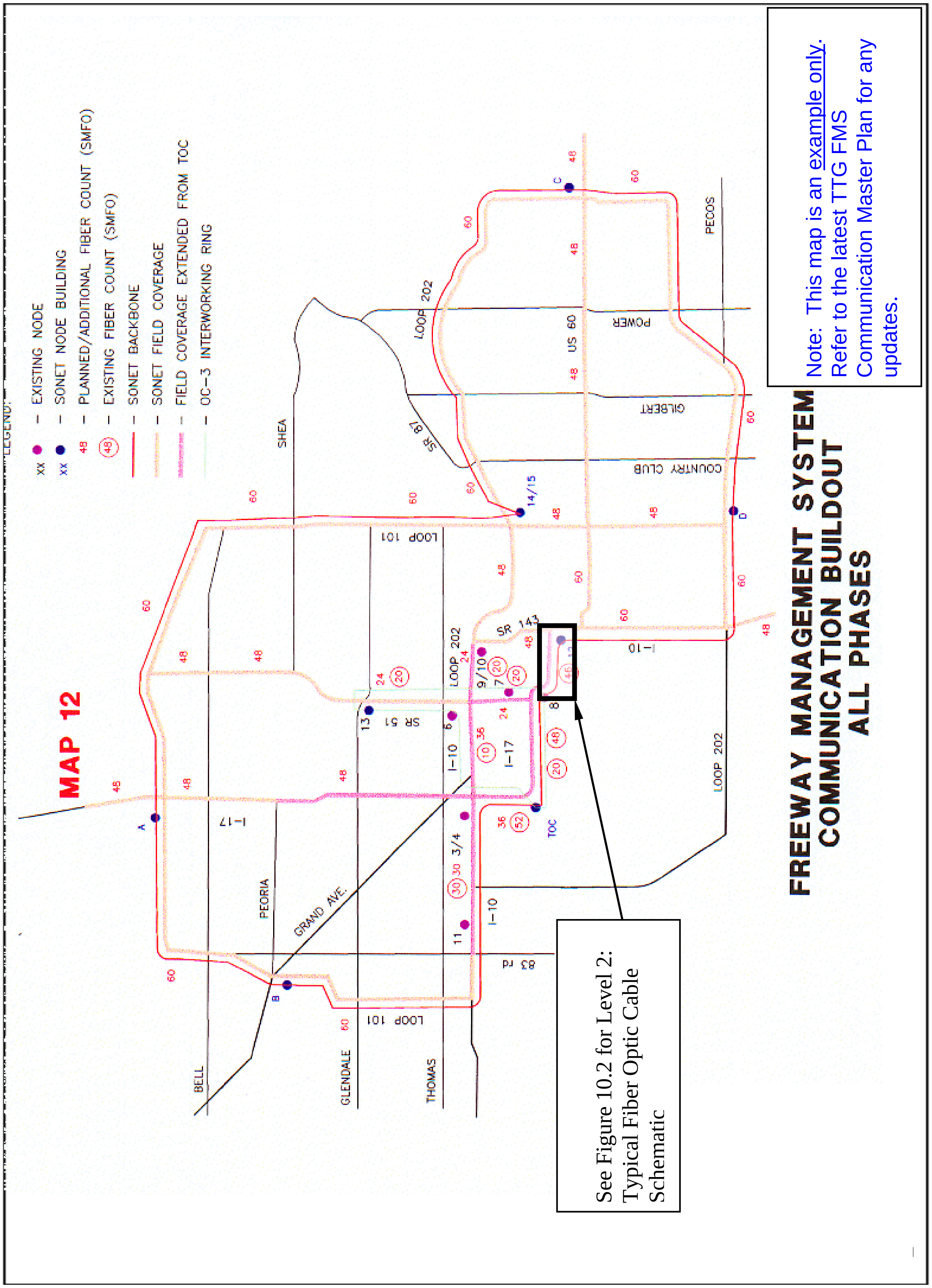

Figure 10.1 Level 1 Typical Fiber Optic System-wide Schematic

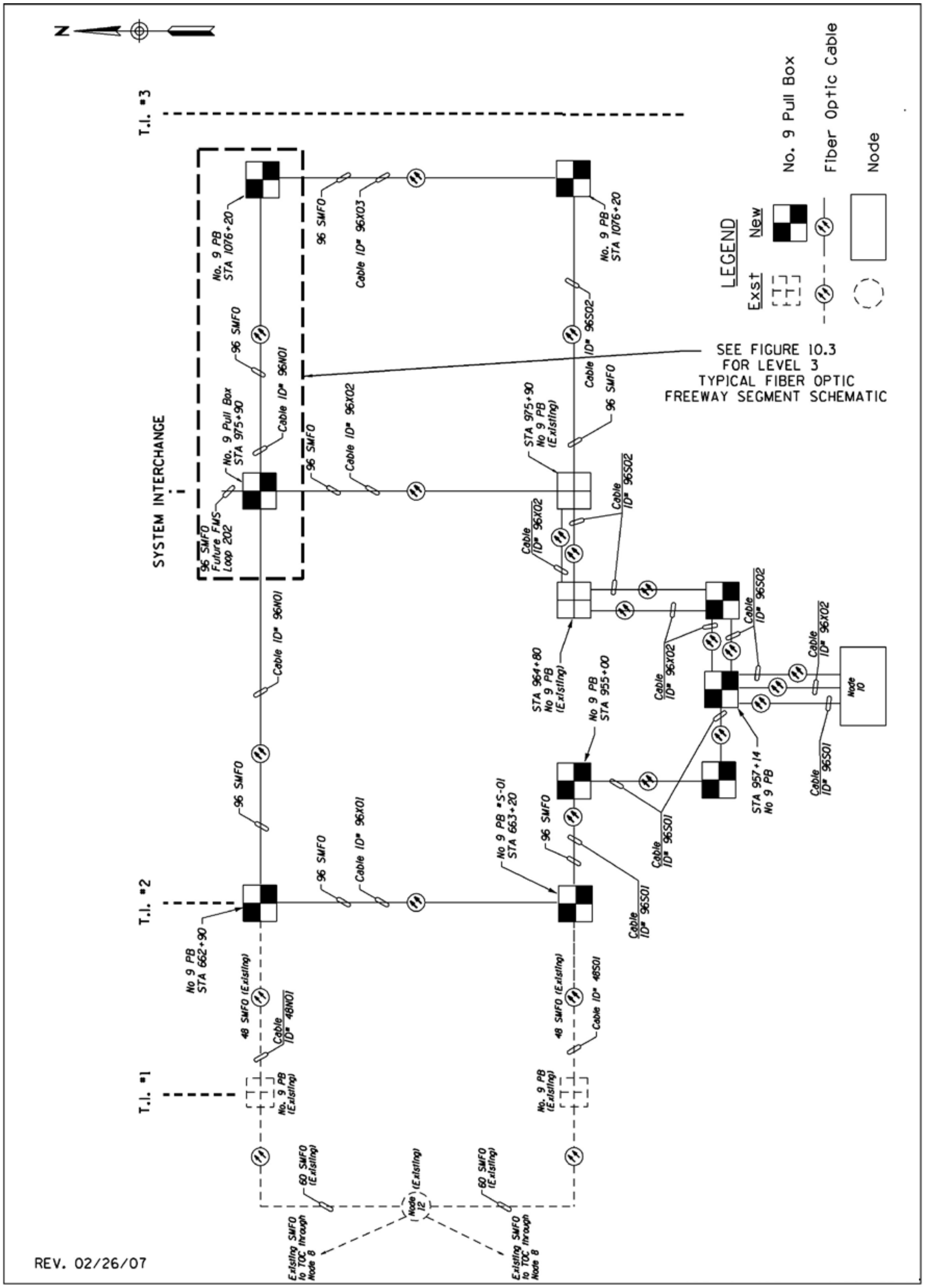

Figure 10.2 Level 2 Typical Fiber Optic Cable Schematic

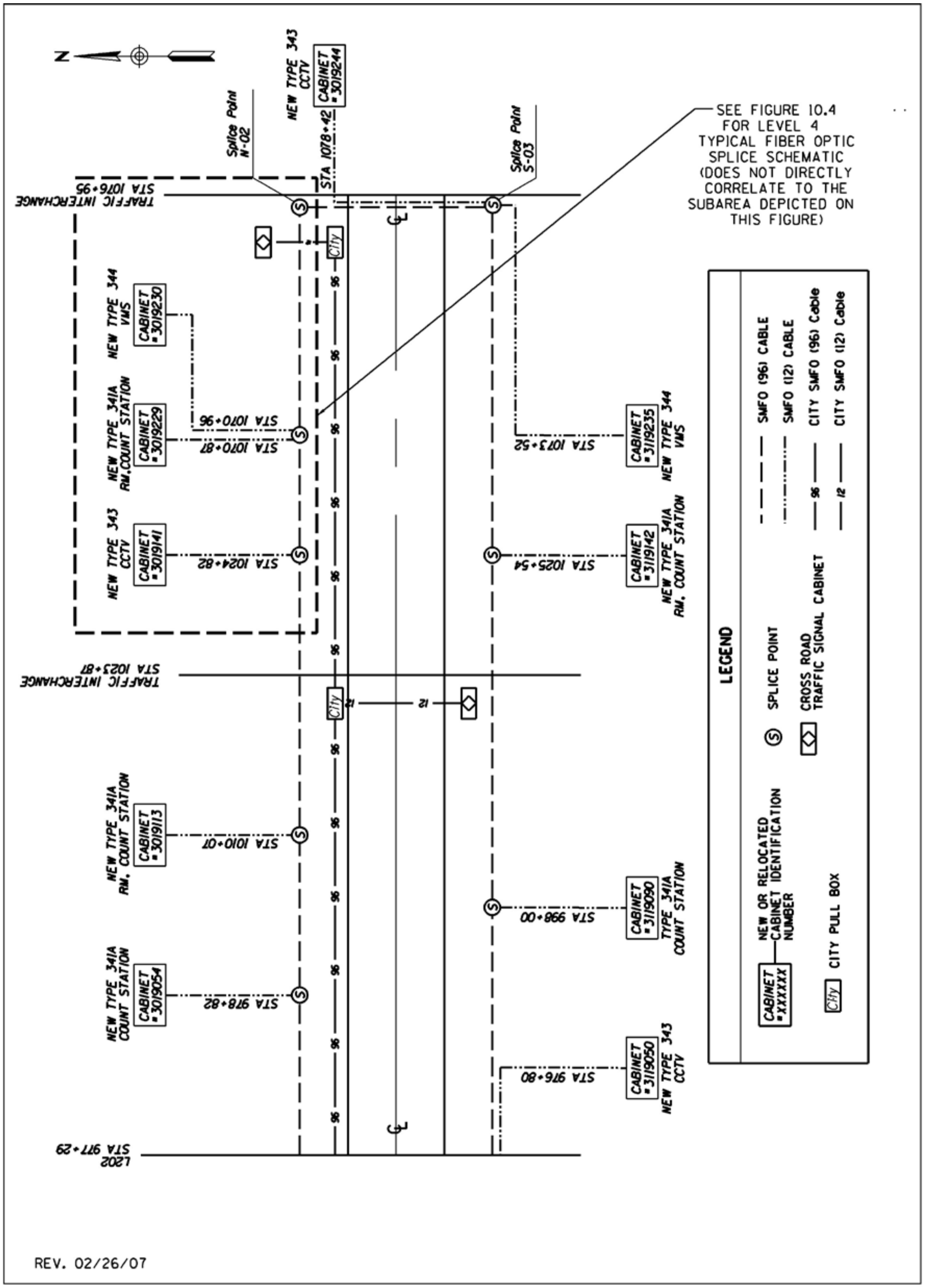

Figure 10.3 Level 3 Typical Fiber Optic Freeway Segment Schematic

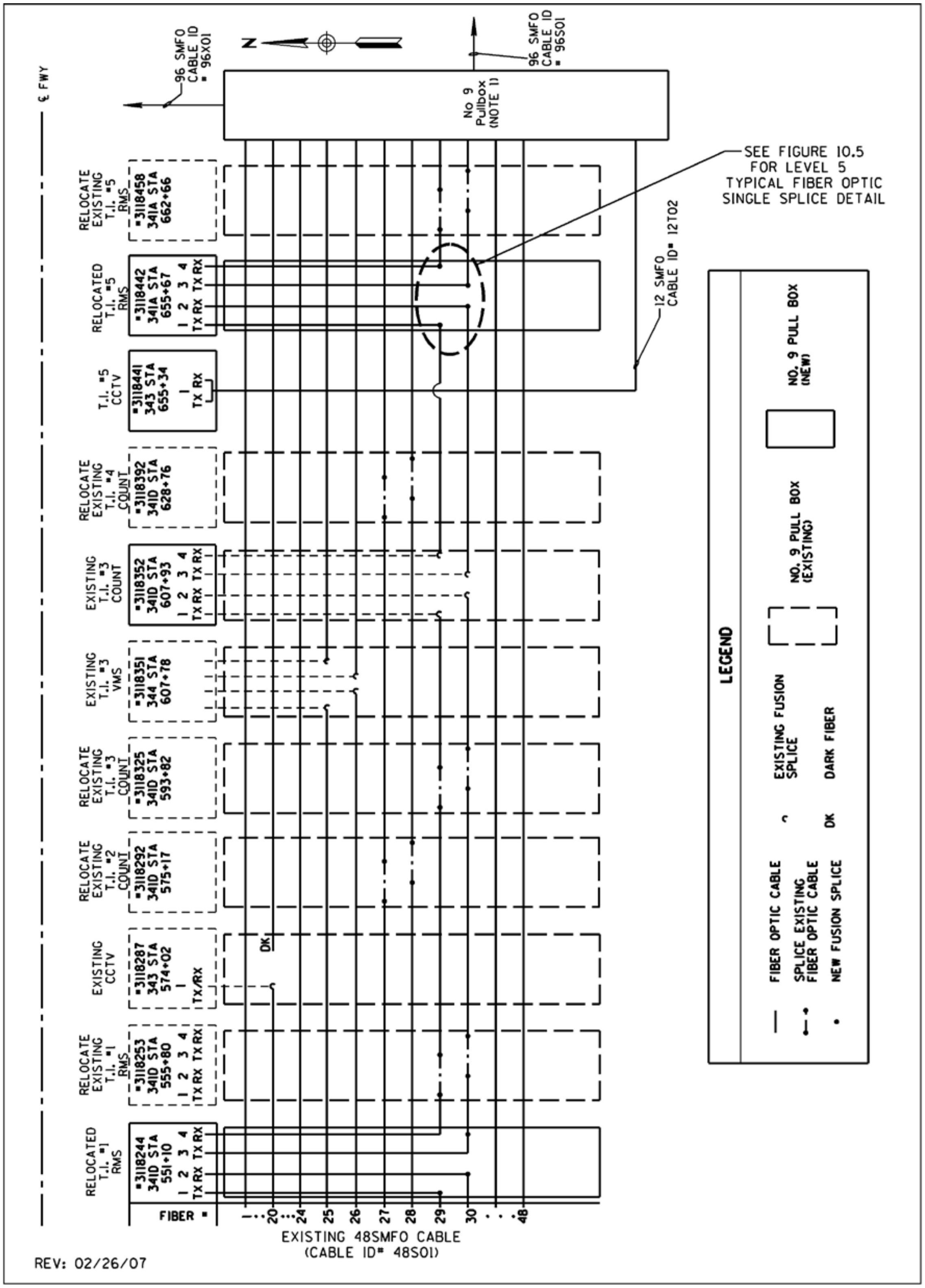

Figure 10.4 Level 4 Typical Fiber Optic Splice Schematic

Typical Field Work Order for Splicing at a Single Location

CABINET 3118442		
SPLICE DETAILS		
SPLICE LOCATION STA 655+67-WB		
Cable #4 Cable ID 48 SO1 From No. 9 @ 628+76	8SMFO To Cabinet 3118442	Cable #4 Cable ID 48 SO1 To No. 9 @ 662+66
Fiber	Fiber	Fiber
	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	11	
	12	
29		29
30		30

Before Construction

CABINET 3118442					
SPLICE DETAILS					
SPLICE LOCATION STA 655+67-WB					
Cable #4 Cable ID 48 SO1 From No. 9 @ 628+76		8SMFO To Cabinet 3118442		Cable #4 Cable ID 48 SO1 To No. 9 @ 662+66	
Cable Ft Marking		Cable Ft Marking		Cable Ft Marking	
In	Out	In	Out	In	Out
5300	N/A	100	183	N/A	5400
Fiber		Fiber		Fiber	
29		1			
30		2			
		3		29	
		4		30	
		5			
		6			
		7			
		8			
		9			
		10			
		11			
		12			

After Construction

Figure 10.5 Level 5 Typical Fiber Optic Single Splice Detail

PAGE INTENTIONALLY LEFT BLANK

Chapter 11 Testing

FMS construction culminates with a series of tests that confirm the full functionality of each component, subsystem, and the overall FMS. The designer must understand the rationale for these tests, the actual test requirements and procedures, the required test equipment and how the tests are reported in a written document to the Engineer.

11.1 Required FMS Testing in Current Practice

FMS tests are crucial to the successful completion of the FMS construction. ADOT has gained considerable experience with the testing and results of these key tests. The designer shall refer to the ITS Standard Specifications for specific testing requirements, and pass/fail criteria. Items not covered under the ITS Standard Specifications shall have a project specific Special Provision developed by the designer to specify testing procedures and criteria, and approved by the ADOT TTG Project Manager. Starting at Stage II (60%), project submittals must include all the test procedures required for the project. It will be the designer's responsibility to coordinate with the ADOT TTG PM to confirm the test procedures. Project Special Provisions may be necessary if test requirements for a project are required to deviate from those indicated in the ITS Standard Specifications.

11.1.1 Stand Alone Test

The Stand Alone Test is intended to verify that the functionality of each FMS device (one by one) is fully compliant with the FMS standards. This test is conducted in the field at each individual FMS device location. The device must be proven to operate per specification, independent of interconnection to the FMS software through the communication network. This test does not usually involve TTG personnel.

11.1.2 Subsystem Acceptance Test (SST)

The SST verifies the communications system and device firmware with the respective FMS equipment for each subsystem (CCTV cameras, DMS, ramp meters/detection stations, etc.). Databases for each device type are typically updated and communications circuits are integrated at the TOC by ADOT. Communications with each device in the network is then monitored from the TOC by ADOT for a 72 hour test period, using test software specifically for the ADOT FMS databases.

11.1.3 System Acceptance Test (SAT)

The final test is a 30-day full System Acceptance Test, comprising of the proper operation of the overall system. This test is typically conducted by the operators at the TOC to verify the system operates as expected in day-to-day operations.

PAGE INTENTIONALLY LEFT BLANK

Chapter 12 Rural Applications

There are a variety of rural ITS applications such as:

- Rural Dynamic Message Signs (Rural DMS)
- Remote Weather Information Systems (RWIS)
- Truck Escape Ramps Detection and Warning Systems

Each has various stages of maturity and development. The following sections address those which have a mature evolution, suitable for providing specific direction. The others should be considered "in development" and subject to eventual evolution to a suitable level for direction. In the meantime, those applications are subject strictly to the direction of the TTG Project Manager to the designer.

12.1 Rural Dynamic Message Signs

Rural dynamic message sign (Rural DMS) differ from the urban freeway applications in several ways:

- Size and Type of DMS
- Support Structures
- CCTV Provisions
- Communications Provisions
- Power Provisions

Rural Dynamic Message Sign design guidance is found in the Statewide DMS Master Plan. Siting of the rural DMS shall include inviting all stakeholders to a field meeting at each proposed site to determine suitability of the site and the need for adjustment due to the availability of power, ability to communicate to the TOC, visibility to traffic and the location maximizing the purpose of the DMS. The District in which the DMS is to be located shall have input and any concerns, suggestions or requests by District shall be respected, noted and accommodated as directed by the TTG Project Manager.

The designer shall make observations, conduct field measurements, take site photos and other documentation, as necessary in support of evaluating and documenting the site characteristics. It is advantageous to obtain and have any available records or plans from Engineering Records in hand during the siting field reviews, to have some knowledge of existing features and right-of-way locations.

Siting of rural DMS is influenced by other factors, such as aesthetics, environmental restrictions related to cultural sites, proximity to other features such as other signs, and requires that the users (District) and other stakeholders all agree on the site.

Rural DMS shall be accessible for maintenance, and may require maintenance pads adjacent to the paved shoulder, for sign access, depending on Type and support arrangement. All rural DMS shall be safely accessible for Department maintenance personnel working on the DMS, support structure, cabinet and power facilities.

The designer shall identify all stakeholders specific to the DMS site, such as State Parks, Federal Parks, and various Native American governments.

12.1.1 Size and Type of DMS

Rural DMS applications may utilize any of the current types of DMS procured by ADOT, and as specified by TTG at project initiation. The DMS contract offer a variety of DMS sizes.

In some cases, the decision as to which type of DMS depends on roadway classification, or whether use of an existing support structure influences DMS size due to structural limitations. For example, Interstate highways and certain wide or high speed state highways may utilize the overhead Type 1 Freeway walk-in DMS, similar to those used in the metropolitan area FMS application. The next smaller size, Type 3 Intermediate front access may be directed for use on overhead supports where the speeds may be lower or the highway of less width, or as a roadside application. Types 5 and 6 Large Arterial may be used overhead or roadside, but are limited in character size - a consideration when associating message recognition with traffic speed. The Type 7 and 8 DMS Small Arterial are scaled for arterial street applications, with limited message size.

The selection of DMS Type, outside of FMS applications, shall be as directed the TTG Project Manager.

12.1.2 Support Structures

Rural DMS applications have utilized a variety of support structures, including the typical 2-legged "tubular" DMS support structure familiar to the urban FMS system. Support structures shall be evaluated and certified by an Arizona registered Structural Engineer when deviating from the use of standard drawings for structures.

The 2-legged tubular structures are designed to support a single Type 1 or Type 2 DMS. Use of those structures for variations, such as for the support of more than one DMS, or the attempted use of an existing tubular structure for a different or additional DMS from the original rural installation shall be evaluated and certified by an Arizona registered Structural Engineer. Existing legacy support structures were designed and used for specific manufacturers and models of DMS, and all DMS have unique weight, wind loading and vertical mounting angle characteristics that generally prohibit the transferable use of an existing structure for a subsequent different DMS support situation without structural verification. Any structural verification of any existing structure shall start by obtaining and evaluating the shop drawings from the original installation. The designer shall, in no case, assume the installed support conforms to any issued standard drawing at the time of design, or project plans, as they do not represent subsequent field adjustments or other potential allowed variations.

Any application requiring use of a support system other than the standard tubular support structure for the specific manufacturer and model of DMS shall be designed as part of the project, and structurally certified by an Arizona registered Structural Engineer, with all calculations submitted to the TTG Project Manager for approval prior to field use.

Designers shall be aware that a variety of combinations of rural DMS types and support structures other than the overhead tubular support have been deployed, and use of same or similar support structures pose a maintenance and replacement advantage to the Department, if the support system is proven structurally suitable for the application. Prior installations have used roadside 2-legged supports for Type 3, 4, 5 and 6 DMS, and overhead support applications of multiple Type 3 DMS.

The designer shall consider and evaluate position of the support structure, relative to the LED aspects of the specific subject DMS, and account for sufficient visibility to approaching traffic in terms of angle of the support relative to the roadway alignment.

Support structures that cannot be placed outside of the clear zone applicable for the field situation at hand shall be provided with sufficient protection in the form of barrier, guard rail or crash barrels.

12.1.3 CCTV Provisions

Rural DMS typically employ fixed-view CCTV for the purpose of viewing the roadway and for viewing the face of the DMS to confirm the message has been properly displayed. Over the years, various forms of CCTV mounting, placement, interface equipment and connections have been utilized. Recognizing the dynamic nature of the CCTV concept for rural DMS, the design shall confer with the TTG Project Manager at project initiation to determine the type and approach to CCTV to be deployed on a project, and to determine which components are to be contractor furnished and installed.

12.1.4 Communications Provisions

Rural DMS communications, over the years, has utilized telephone lines, cellular and radio technologies to various levels of success for the DMS and CCTV connections. The current approach to communications to rural DMS is to utilize the DPS radio system for communications between the TOC Operator and the DMS in the field, and cellular carriers for the CCTV images. The use of multiple technologies is a result of variations in bandwidth needs between the two applications, and is subject to revision as new technologies and capabilities are deployed.

The designer, at project initiation, shall determine from the TTG Project Manager, in concert with the ITS Communications Engineer, which technologies are to be used at which locations and in which manner, determine designer responsibilities during field siting of the rural DMS, and take responsibility for conducting any field analyses or observations required by TTG. Field activities may include confirmation of line of site to a specific mountain top defined by TTG, noting signal strength of a specific cellular carrier at a field site, obtaining GPS coordinates of a rural DMS site and other such activities as defined by TTG.

Wireless communications requirements are presented in more detail in Chapter 13, Wireless Communications.

12.1.5 Power Provisions

Rural DMS final locations are influenced by the availability or the ability to provide power. The designer shall make a preliminary evaluation of the proposed rural DMS site based on the original milepost location provided by TTG at project initiation, to determine if power is observed in the field in the vicinity of the desired location.

The preference is to locate rural DMS near a suitable power source, considering the ability to provide the desired level of load and voltage as determined by the specific quantity, type and model of DMS to be operated. The siting process may require compromise with stakeholders based on the ability to provide power at a desired location versus adjusting the location to satisfy power provisions. In some cases, a utility company can provide a "line extension", extending their power infrastructure to the DMS, at a cost paid by the Department. Designers shall recognize that the cost of line extensions can cause a project to become disproportionately costly, favoring the compromise in location to be closer to a power source.

All rural DMS site selections shall include field confirmation between the designer and an authorized representative of the power utility to both physically be present and agree to the location and method of power provision (conduit size, overhead or underground, conduit contents, responsibilities of Department versus utility, etc.). Some rural locations require dealing with power entities that may require fees to meet, review plans or evaluate and design service provisions. Such situations require the designer to coordinate activities with the TTG Project Manager and the ADOT Utilities and Railroad URR) representative assigned to the project. The ADOT URR representative shall assist the designer in determining what utility entity applies in a specific location, who the contact person is, and will be copied on all dealings with any utility.

Any situations that imply the need for acquisition of easement outside of established ADOT right-of-way shall be immediately brought to the attention of the TTG Project Manager for direction. It is preferable that such situations be avoided, and acknowledged that easements require environmental evaluation and documentation and represent additional "environmental footprint", possibly adding delay and costs to the design process.

The designer shall determine any and all costs for the provision of power at all rural DMS sites, and provide such information to the TTG Project Manager. Costly power arrangements, as determined by the TTG Project Manager, may require a separate execution of a Utility Agreement to compensate the utility outside of the bid items for the project's construction. Typical power provisions, those not involving easements or costly arrangements, are covered under the bid items as Force Account items reimbursable to the contractor during construction.

Service addresses shall be obtained by the designer from the entity responsible for address assignments in the geographic area of the DMS. This may be the county, town/city or other authority. In some case, typically along Interstate highways, a milepost designation will be used. In all cases, the designer shall be responsible to verify with the power utility the acceptability of the address format (milepost, street address, GPS coordinates, etc.) to avoid delays in power company dealings during construction.

The designer shall confirm with the TTG Project Manager the form of power service and load center type. Most rural DMS have used Type II Load Centers to allow for additional future circuits for other ITS features, others have used meter pedestals and some have used transformers to boost or reduce voltages, as site conditions require. The designer shall be familiar with multiple forms of power provision, conduct voltage drop analyses and size conductors and power equipment accordingly.

The designer shall acknowledge that other utilities may exist in even the most rural of environments, and is responsible for identifying, locating and showing all utilities on the plans. Utility logs are available on-line from ADOT URR, and shall be supplemented by Design Blue Stake research. Ultimately, this information is necessary to obtain utility clearance from ADOT URR prior to bid.

12.2 Other Rural Applications

12.2.1 Truck Escape Ramp Detection and Warning Systems

ADOT has deployed detection and fixed frame cameras at some truck escape ramps.

12.2.2 Remote Weather Information Systems (RWIS)

Remote weather information systems (RWIS) are deployed around the state on various rural and Interstate highways to collect data on air and roadway surface temperatures and conditions. Most are solar powered and also provide fixed-view cameras for observation of weather conditions.

At present, deployment of RWIS is through a procurement contract from which a selected vendor furnishes and installs a turnkey RWIS system for the Department, separate from the traditional design-bid process.

PAGE INTENTIONALLY LEFT BLANK

Chapter 13 Wireless Communications

Wireless ITS communications are necessary when the project does not have the ability to utilize the installation of fiber optic trunk line or other suitable hard-wire cable solution. Typical wireless project considerations are:

- High cost of right-of-way or easement acquisition;
- Lack of right-of-way;
- Environmentally sensitive areas;
- Temporary installations; and
- Construction zone applications.

It is important to note that wireless solutions may apply in urban environments, especially for difficult to connect or temporary applications. Wireless communications can be described in terms of low bandwidth, point to multi-point systems, and high bandwidth, point-to-point systems. Point-to-multipoint systems have the ability to communicate with multiple locations/devices from a single access point radio.

For reliable radio transmission, most systems require direct line of sight between antennas. The distance is limited by power, frequency and free space loss. Line of sight is required and becomes more critical as the frequency increases.

13.1 Licensed vs. Unlicensed Wireless

Licensed radio systems are the preferred type of radio system to be used on ITS projects and will minimize problems with radio emissions or interference from other systems. Licensed frequencies can be acquired by using a contractor that is familiar with the process of frequency coordination and will do all the paperwork to obtain the FCC license.

Unlicensed systems may also be used for short range links that are designed to take into account that some interference may be present from other wireless devices. The use of spread spectrum, directional antennas and enough system gain may work well since spread spectrum is designed for tolerating interference. An RF engineer, assisting the designer as a component of the design team, should be able to provide more guidance on this topic.

13.2 Site Survey

All design projects involving wireless communications shall require a detailed site survey to analyze the terrain, line of sight, frequency in use, and RF requirements. The survey will also identify and locate sources of interference that can degrade performance. The survey shall measure signal strength, signal quality and noise levels. A site survey report shall be developed by the designer to detail the communication links and bandwidth performance. The RF budget shall provide greater than 20 dB of fade margin per link. The report shall detail survey results with "heat" and coverage maps. The report shall be provided to the TTG ITS Communications Engineer at Stage II (60%), for review and approval. Deficiencies in the procedures or results shall require mitigation as directed by the ITS Communications Engineer.

The designer shall develop project Special Provisions for the contractor to use an Ethernet bit rate tester with the RFC 2544 option to test for throughput and frame loss, latency, packet jitter, and burst ability. A radio link stress test will be performed to verify that the radios will pass payload traffic within project specifications determined by the designer's RF engineer.

13.3 Installation

The designer's project documents plans and Special Provisions shall require that contractor shall perform a line of sight survey prior to installation, and inform the ITS Communications Engineer of any obstructions or other factors that would affect the RF communications. The contractor shall be required to perform a RF test prior to permanently installing the RF links to verify each link and test to verify it meets the project performance specifications provided by the designer before installing others, to prevent the installation of radios that do not perform to specifications.

13.4 Wireless Designer Qualifications

The designer of wireless subsystems for ADOT TTG projects shall be a Radio Frequency Engineer and have experience in designing wireless communications systems, including radio propagation modeling and prediction, microwave path analysis, interference analysis, frequency coordination. Wireless designers shall have to provide supporting qualifications and references of existing jobs and projects, upon request of the TTG Project manager and/or ITS Communications Engineer.

13.5 Contractor Qualifications

The designer shall develop project Special Provisions that require that the contractor shall provide a Communications Technician and have experience in deployment of RF communications systems and test equipment. Minimum specified qualifications shall be two years of progressively responsible experience in the Radio Frequency (RF) technology including installation, maintenance, and repair of electronic and radio communications systems and programming, tuning, and aligning mobile, portable and fixed radio equipment. Project Special Provisions shall require supporting qualifications and references of existing jobs and projects, upon request of the TTG Project Manager and/or ITS Communications Engineer.