DEPARTMENT OF TRANSPORTATION

Intelligent Transportation Systems (ITS) Design Manual

October 2021

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1. Introduction

1.1. What are Intelligent Transportation Systems (ITS)?

The United States Department of Transportation (USDOT) Federal Highway Administration (FHWA) defines Intelligent Transportation Systems, or ITS, as the integration of advanced communications technologies into the transportation infrastructure and within vehicles to improve transportation safety and mobility and enhance American productivity. ITS encompasses a broad range of wireless and wire line communications-based information and electronics technologies.

The Minnesota Department of Transportation (MnDOT) further defines ITS as electronics, communications, or information processing systems or services used to improve the efficiency and safety of the surface transportation system. MnDOT utilizes ITS to help deliver on the Department's overall vision of creating a multimodal transportation system that maximizes the health of people, the environment, and the state's economy. MnDOT strives to implement new technologies and systems into Minnesota's transportation system to achieve a safer, more accessible, efficient, and reliable multimodal transportation system that connects people to destinations and markets throughout the state, regionally, and around the world. Through ITS infrastructure implementation, MnDOT targets a goal of providing real-time traffic conditions to the public to provide them with tools to make informed decisions about their planned routes, prior to and during their trips.

1.2. Purpose and Use

The purpose of the MnDOT ITS Design Manual is to provide individuals familiar with ITS an overview of the MnDOT project development process and information to assist in the design of ITS infrastructure for MnDOT. While ITS technologies share many similarities with traffic signal and roadway lighting elements, they are unique and require their own set of design criteria and have many unique qualities and considerations. This manual is focused on agency and consultant personnel who are engaged in ITS design and project management with MnDOT.

This manual is intended to be a living document and may be periodically updated. Users should periodically check the MnDOT website for updates to this manual. A current version of the ITS Design Manual can be accessed using the link below.

MnDOT ITS Design Manual: http://www.dot.state.mn.us/its/design.html

MnDOT has published other manuals such as signal design, maintenance, etc. The website below houses links to other MnDOT manuals.

MnDOT Manuals: http://www.dot.state.mn.us/manuals/

1.3. Acronyms and Definitions

The table below includes a list of ITS acronyms and definitions used throughout this document.

Table 1-1: Acronyms and Definitions

Term	Definition
511 Traveler Information System (TIS)	The State of Minnesota's 511 Traveler Information System (https://hb.511mn.org) provides real-time travel information including traffic speeds, video camera snapshots, DMS messages, road weather information, and traffic alerts.
Absorbed Gas Mat (AGM)	A type of battery that is designed for delivering powerful bursts of starting amps and running electronics for a long time.
American Association of State Highway Transportation Officials (AASHTO)	A nonprofit, nonpartisan association representing highway and transportation departments in the United States. It serves all transportation modes and its goal is to foster the development, operation, and maintenance of the integrated national transportation system.
Architecture	The organizational structure of a system, identifying its components, their interfaces, and a concept of execution among them.
Advanced Transportation Management System (ATMS)	Systems of detection, communication, and software technologies that are aimed to reduce traffic congestion.
American Wire Gauge (AWG)	US standard used by MnDOT to measure wire conductor sizes.
Video Camera	A camera that transmits video to a monitor screen that is used to provide traffic monitoring by the facility operator along the length of the facility and particularly at points of entry and tolling locations.
Components	Components are the named "pieces" of design and/or actual entities [sub-systems, hardware units, software units] of the system/sub-system. In system/sub-system architectures, components consist of sub-systems [or other variations], hardware units, software units, and manual operations.
Concept of Operations (ConOps)	A foundation document that frames an overall proposed system and sets the technical course for a project.
Connected Vehicle (CV)	A vehicle that uses devices and networks to communicate with other vehicles and field devices.
Dedicated Short-Range Communication (DSRC)	A type of communication used in Connected Vehicle technology to communicate between vehicles and roadside devices.
Department of Transportation (DOT)	A government agency, federal, statewide, or local, dedicated maintaining and developing transportation systems and infrastructure.
Design	Those characteristics of a system or components that are selected by the developer in response to the requirements.
Detector Loops	Consists of one or more turns of insulated loop wire installed in a shallow slot sawed in the pavement surface

Term	Definition
	or installed in the subgrade that are can be used to determine traffic characteristic such as: count vehicles, measure traffic speed, and detect the presence of vehicles.
Django	A content management system created in Python that creates reports from IRIS and other databases. The system is used by MnDOT designers for a variety of reasons. A few examples are to review fiber schematics, search for past projects in an area, and identify MnDOT staff assigned to a particular project.
Dynamic Message Sign (DMS)	An electronic sign deployed on roadways to inform travelers of specific warnings including but not limited to congestion, special events, traffic incidents, and other emergency alerts. Most DMS can display one or more predefined messages automatically without user intervention. MnDOT most often uses the term DMS in ITS design although some use the term Variable Message Sign (VMS) and Changeable Message Sign (CMS) interchangeably. Portable Changeable Message Signs are trailer mounted signs that are used in work zones and as an incident management tool. Blank-Out Sign (BOS) are a specific type of DMS that have the capability to show a blank message or a fixed message(s).
Express Lanes	A lane or set of lanes physically separated or barriered from the general-purpose lane capacity provided within major roadway corridors. Express lane access is managed by limiting the number of entrance and exit points to the facility. Express lanes may be operated as reversible flow facilities or bi-directional facilities. These can include High-Occupancy Toll lanes.
Federal Aviation Administration (FAA)	A division of the USDOT that is responsible for the regulation and oversight of civil aviation within the United States.
Federal Communications Commission (FCC)	An independent agency of the United States government created by statute to regulate interstate communications by radio, television, wire, satellite, and cable.
Federal Highway Administration (FHWA)	A division of the USDOT that specializes in highway transportation.
Freeway Incident Response Safety Team (FIRST)	The FIRST program, formerly known as Highway Helper program, is tasked with minimizing congestion and preventing secondary crashes through the quick response and removal of incidents. The FIRST program is a key component of the Twin Cities Metropolitan Area Incident Management Program.
Georilla	Georilla is an internal MnDOT web-map application that is currently being used by approximately 700 unique visitors

Term	Definition
	per month to match-up asset, project, and activity information to make better data-driven decisions. The Asset Management Project Office Supports the development and direction of Georilla.
Global Positioning System (GPS)	A satellite-based navigation system that provides geolocation and time information to a GPS receiver.
Hardware	Articles made of material, such as tools, computers, vehicles, fittings, and their components [mechanical, electrical, electronic, hydraulic, and pneumatic]. Computer software and technical documentation are excluded.
High Density Polyethylene (HDPE)	A thermoplastic polymer used for many applications. In ITS design it us used for underground conduit systems.
High-Occupancy Toll (HOT) Lane	Managed, limited-access, highway lanes that provide free access to HOVs, and make excess capacity available to other vehicles not meeting occupancy requirements at a market price.
High-Occupancy Vehicle (HOV)	A passenger vehicle carrying more than a specified minimum number of passengers, such as an automobile carrying more than one or more than two people. HOVs include carpools and vanpools, as well as buses.
HOV Lane	An exclusive traffic lane or facility limited to carrying HOVs and certain other qualified vehicles.
Institute of Electrical and Electronics Engineers (IEEE)	A professional organization focused on advancing technology, comprised of electrical and electronics engineers.
Incident Management	Managing forms of non-recurring congestion, such as spills, collisions, immobile vehicles, or any other impediment to smooth, continuous flow of traffic on freeways.
Infrastructure	Fixed facilities, such as roadway or railroad tracks; permanent structures.
Intelligent Transportation Systems (ITS)	A broad range of diverse technologies which, when applied to our current transportation system, can help improve safety, reduce congestion, enhance mobility, minimize environmental impacts, save energy, and promote economic productivity. ITS technologies are varied and include information processing, communications, control, and electronics. Intelligent Transportation Systems facilitate providing real-time information on traffic conditions to travelers on roadways for which the technologies are deployed on.
Interface	The functional and physical characteristics required to exist at a common boundary - in development, a relationship among two or more entities [such as software-software, hardware-hardware, hardware-software, hardware-user, or software-user].

Term	Definition
Internet Protocol (IP)	The method by which data is communicated between devices on the Internet
Intelligent Roadway Information System (IRIS)	MnDOT's Freeway Management System control software. IRIS is an open-source ATMS software project developed by MnDOT.
Legacy System	The existing system to which the upgrade or change will be applied.
Life-Cycle Maintenance	Concept of keeping a facility or system useable at least through its design life by conducting scheduled maintenance.
Light Emitting Diode (LED)	A type of light source illuminated by the movement of electrons.
Manual on Uniform Traffic Control Devices (MUTCD)	A document published by the Federal Highway Administration setting standards and providing guidance to ensure uniformity of traffic control devices across the United States.
Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD)	A document published by MnDOT setting standards and providing guidance to ensure uniformity of traffic control devices across the state of Minnesota.
National Electrical Code (NEC)	A standard for the installation of electrical wiring and equipment that ensures safety, also known as NFPA 70.
National Electrical Manufacturers Association (NEMA)	A trade organization comprised of electrical equipment and medical imaging manufacturers that make safe, reliable, and efficient products and systems in seven markets, including transportation systems.
National Electrical Safety Code (NESC)	A standard that outlines methods for the safety of electric supply and public and private communication utility systems.
National Transportation Communications for ITS Protocol (NTCIP)	A group of standards that provides both protocols and vocabulary necessary to ensure consistency between ITS device manufacturers.
Non-Intrusive Detector (NID)	A vehicle detector that is not installed into the pavement. MnDOT currently utilizes side-fire, FMCW microwave vehicle detection to detect vehicles traveling along freeway mainlines.
Plans, Specifications, and Estimates (PS&E)	A package for a project that includes the plans, specifications, and cost estimate for the project that is ready to be bid on by contractors.
Polyvinyl Chloride (PVC)	A solid plastic that is often used to make pipes, including to construct underground conduit.
Radio Frequency (RF)	The rate of oscillation or range of rates of electromagnetic radio waves used in telecommunications.
Ramp Metering	The electronically regulated flow of vehicles on highway entrance ramps and loops to reduce crashes, reduce congestion, and provide more reliable travel times.

Term	Definition
Regional ITS Architecture	A specific regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects in a particular region.
Remote Weather Information System/Roadway Weather Information system (RWIS)	A system of sensors, communications, and data collection technologies to measure specific weather conditions including atmospheric, pavement and/or water level conditions.
Roadside Unit (RSU)	A device on a roadway that communicates with on-board units in connected vehicles and sends information back to a traffic management center.
Small Form-Factor Pluggable (SFP)	A compact, hot-pluggable network interface module used for both telecommunication and data communications applications.
Source of Power (SOP)	Electric utility transformer that provides power to a device or infrastructure.
Specification	A document that describes the essential technical requirements for items, materials or services including the procedures for determining whether the requirements have been met.
Single-Occupancy Vehicle (SOV)	A passenger vehicle containing only a single occupant.
System	An integrated composite of people, products, and processes, which provide a capability to satisfy a stated need or objective.
Systems Engineering	An interdisciplinary approach and a means to enable the realization of successful systems. Systems engineering requires a broad knowledge, a mindset that keeps the big picture in mind, a facilitator, and a skilled conductor of a team.
Traffic Management Center (TMC)	A location to collect real-time data on the surrounding transportation system to monitor conditions, manage the systems in the field, and provide traveler information.
Traffic Management System (TMS)	The development and application of network-wide data collection and sharing of traffic information system. The system can integrate data and control systems from freeways, arterials, and city streets to provide real-time proactive traffic information and control. Implementation of the system would facilitate congestion management over the entire network across multijurisdictional boundaries. The system could provide incident detection, transit and emergency vehicle priority, and advance traveler information.
Uninterruptible Power Supply (UPS)	A device that is used as emergency power when there's an interruption to the standard power.
Volts - Alternating Current (VAC)	A measure of circuit power pressure for alternating current.
Volts - Direct Current (VDC)	A measure of circuit power pressure for direct current.

1.4. References

The ITS Design Manual is intended to be used as a resource for MnDOT agency and consultant personnel performing ITS project management and design services for the department. This manual incorporates information from multiple MnDOT resources, and individuals managing ITS projects or performing ITS design services are encouraged to familiarize themselves with these documents and their contents. A list of key MnDOT resources have been detailed below along with a web link to access the current version of the document. Please note that reference material is updated often, and users should periodically check for new or updated versions of these documents.

The MnDOT Office of Traffic Engineering website includes a wide array of traffic engineering and ITS topics. The website can be accessed using the link below.

MnDOT Office of Traffic Engineering: http://www.dot.state.mn.us/trafficeng/

The MnDOT Regional Traffic Management Center (RTMC) handles coordination between State Patrol and MnDOT Maintenance and Freeway Operations. The center's website is an excellent source for information on the Freeway Incident Response Safety Team (FIRST), as well as other traffic operations and traveler information. In addition, the RTMC website includes information on traffic operations and system design. The website can be accessed using the link below.

MnDOT RTMC: http://www.dot.state.mn.us/rtmc/trafficoperations.html

Information on MnDOT's activities and policies related on Connected and Automated Vehicles (CAV) can be found on MnDOT's CAV-X website. This website contains links to the report published by the Minnesota governor's advisory council on CAV, as well as information on the state's CAV challenge.

MnDOT CAV-X: http://www.dot.state.mn.us/automated/

In addition to the MnDOT resources detailed above, several additional resources were used in the development of the ITS Design Manual and should be referenced for additional information. Additional ITS resources have been detailed below.

Additional ITS Resources:

- USDOT A Guide for HOT Lane Development (https://www.ibtta.org/sites/default/files/A%20Guide%20for%20HOT%20Lane%20Development%20FHWA.pdf)
- FHWA Systems Engineering Guidebook for ITS (www.fhwa.dot.gov/cadiv/segb/index.htm)
- Enterprise Warrants for the Installation and Use of Technology Devices for Transportation Operations and Maintenance (http://enterprise.prog.org/itswarrants/)
- FHWA Traffic Detector Handbook: Third Edition—Volume I (https://www.fhwa.dot.gov/publications/research/operations/its/06108/06108.pdf)
- Wisconsin Department of Transportation – Intelligent Transportation Systems (ITS) Design and Operations Guide, October 2009 (https://wisconsindot.gov/dtsdManuals/traffic-ops/manuals-and-standards/its/01/01-01.pdf)
- FHWA Office of Operations - Traffic Control Systems Handbook (http://ops.fhwa.dot.gov/publications/fhwahop06006/index.htm)

- MnDOT Evaluation of Non-Intrusive Technologies for Traffic Detection (http://www.dot.state.mn.us/guidestar/2006_2010/nit_phaseIII/FINAL%20REPORT.pdf)
- Pennsylvania Department of Transportation – Publication 646 – Intelligent Transportation Systems Design Guide, April 2011 (https://www.dot.state.pa.us/public/pubsforms/publications/pub%20646.pdf)

1.5. Manual Organization

The ITS Design Manual includes four chapters and is generally organized as described below.

- Chapter 1: Introduction – Overview of the manual and its contents, list of ITS acronyms and definitions, MnDOT organizational structure and contact information, and general document disclaimer
- Chapter 2: Project Development Process – Overview of the MnDOT ITS project development process
- Chapter 3: Supporting Infrastructure Design – Design guidance for supporting ITS infrastructure including power service, communications, conduit, conduit access, and cabinets/shelters
- Chapter 4: Plans, Specifications, and Estimate (PS&E) Design Steps – Typical ITS plans, specifications, engineer's estimate, and design guidance for common MnDOT ITS elements

1.6. MnDOT Organization

Address and contact information for MnDOT headquarters has been included below along with a link to the current version of MnDOT's organizational chart.

Minnesota Department of Transportation
395 John Ireland Blvd.
St. Paul, MN 55155-1800
Phone: (651) 296-3000
Toll-free: (800) 657-3774

MnDOT Organization Chart:
https://www.dot.state.mn.us/information/orgchart/index.html

1.6.1. Regional Transportation Management Center (Metro District)

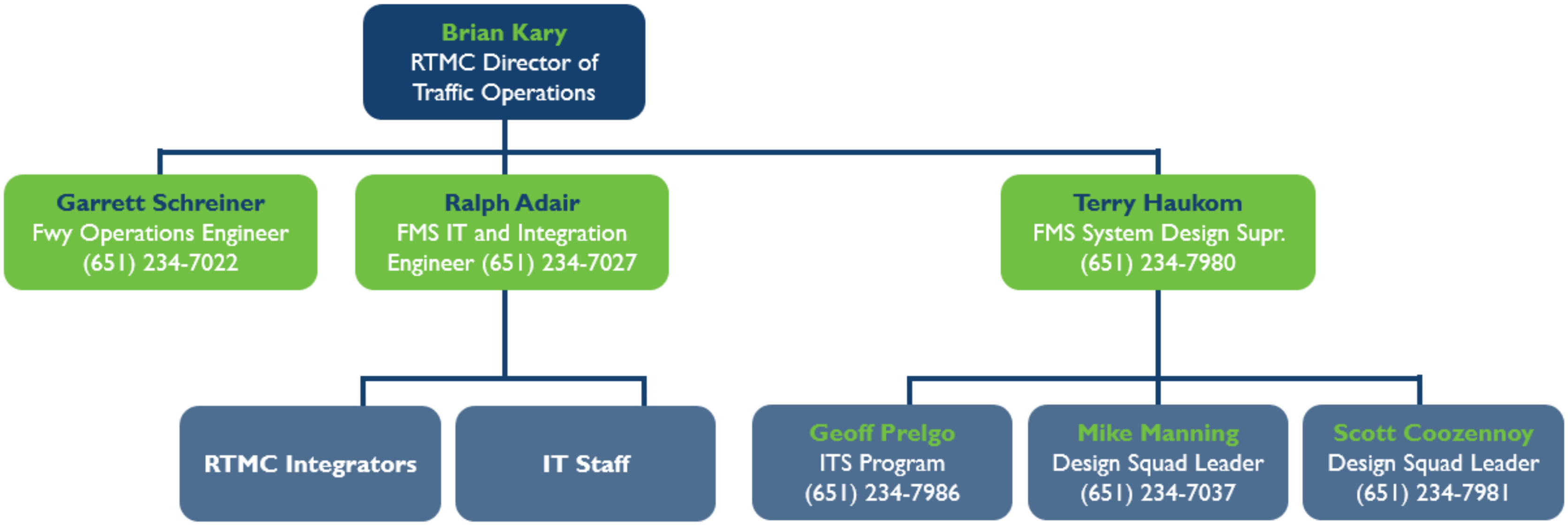
The RTMC houses MnDOT Freeway Operations personnel, MnDOT Maintenance staff, and Minnesota State Patrol officers all working together to quickly detect, respond to, and remove incidents from the transportation system with the goal of improving safety and enhancing mobility across the state. The RTMC address and contact information has been included below along with a link to the RTMC website.

MnDOT RTMC (Metro District)
Water's Edge Building
1500 West County Road B2
Roseville, MN 55113
Phone: (651) 234-7001

http://www.dot.state.mn.us/rtmc

An organization chart with current primary contacts related to ITS design is included in Figure 1-1.

Figure 1-1: RTMC Organization Chart



1.6.2. Shared Services

MnDOT has issued a memo that documents how shared services are used to complete ITS Design. All ITS projects are to be completed by the RTMC as a shared service due to the specialty nature of the work and to ensure consistency in ITS systems across the state. Only minimal impact ITS design projects such as fiber signal interconnect and sole video camera installation may be completed by the District/Office and those still required review and approval by the RTMC.

1.6.3. Connected and Automated Vehicles Office

The Connected and Automated Vehicles (CAV-X) Office within MnDOT is dedicated to furthering the state in the field of CAV. A link to MnDOT's CAV program website as well as information on Minnesota Executive Order 19-18, the Governor's CAV Advisory Council, Minnesota's CAV Challenge, and some of the benefits associated with CAV technology has been provided below.

MnDOT CAV Website and Contact Information:

http://www.dot.state.mn.us/automated/index.html

1.6.4. Office of Traffic Engineering

MnDOT's Office of Traffic Engineering (OTE) establishes statewide guidelines and procedures designed to consistently implement traffic engineering principles across the state. The address for MnDOT OTE has been included below along with a link to their website and an organizational chart.

MnDOT OTE
1500 W. County Rd B2
Mailstop 725
Roseville, MN 55113
Phone: (651) 234-7000

MnDOT OTE Website:
http://www.dot.state.mn.us/trafficeng/

MnDOT OTE Organization Chart:
http://www.dot.state.mn.us/information/orgchart/co/ote.pdf

1.6.5. Bridges and Structures

MnDOT's bridges and structures group provides structural guidance and oversight of the state's bridges and structures. The address and contact information for MnDOT's bridges and structures group has been included below along with a link to the Bridges and Structures website.

MnDOT Bridges and Structures
Mail Stop 610
3485 Hadley Avenue North
Oakdale, MN 55128
Phone: (651) 366-4500

MnDOT Bridges and Structures Website:
https://www.dot.state.mn.us/bridge/index.html

1.7. Minnesota Information Technology Services

Minnesota Information Technology Services (MNIT) is the central IT organization for the State of Minnesota and is responsible for establishing IT strategy, direction, policies, and standards for enterprise IT leadership and planning. MNIT is responsible for the State's IT infrastructure, applications, projects, and services. The address and contact information for MNIT has been included below along with a link to the MNIT website.

MNIT
658 Cedar St
St. Paul, MN 55155
Phone: (651) 201-1118

MNIT Website:
https://mn.gov/mnit/

1.8. Written Communication Policy

To request this document in an alternative format, please contact the Office of Equity and Diversity at 651-366-4720 or 1-800-657-3774 (Greater Minnesota); 711 or 1-800-627-3529 (Minnesota Relay). You may also send an e-mail to ADArequest.dot@state.mn.us. (Please request at least one week in advance).

1.9. Disclaimer

This manual is disseminated under the sponsorship of the MnDOT CAV-X Office. Standards change rapidly in the field of ITS so portions of the manual may become out of date between updates. MnDOT and Kimley-Horn and Associates, Inc. assume no liability for its contents or use thereof. All MnDOT ITS plans, specifications, and engineer's construction estimates should be prepared by or under the direct supervision of a professional engineer licensed to provide engineering services in the State of Minnesota.

MnDOT does not endorse products or manufacturers. Trademarks of manufacturers' names appear herein only because they are considered essential to the object of this manual. The contents do not necessarily reflect the official policy of MnDOT.

2. Project Development Process

2.1. ITS Project Types

2.1.1. Stand-alone ITS Projects

Stand-alone ITS projects are led by the RTMC, who is responsible for all management tasks that would be handled by the roadway group on a roadway construction project. Significant coordination with other functional groups will be required as a part of design (survey, design, geotechnical, signals & lighting, structures, signing, etc.). The designer will also need to obtain required input from other groups for items including the submittal memo, which may require environmental documentation, right-of-way acquisition, and many other considerations. The designer will need to coordinate reviews with other functional groups at various milestones throughout the project and is responsible for the final submittal to Central Office. Since development of the ITS plans are not tied to a larger project, there is more flexibility in when the milestone submittals need to happen and in the ITS components that are included in the final design based on project budget considerations.

2.1.2. ITS as Part of Larger Project

For ITS design as part of a larger project, the designer is responsible for the ITS plans and coordination with other functional groups as needed. All management tasks are handled by the roadway group, who will need to coordinate with all the other functional groups. The development of the ITS plans will be more prescribed in following the overall project schedule, where ITS design is typically not started until after the 30% design.

2.2. Project Delivery Methods

2.2.1. Design-Bid-Build

Design-Bid-Build is the traditional project delivery method in which MnDOT designs, or retains a designer to furnish complete design services, and then advertises and awards a separate construction contract based on the designer's completed construction documents. In Design-Bid-Build, MnDOT "owns" the details of design during construction and as a result, is responsible for the cost of any errors or omissions encountered in construction. ITS design is completed as part of the overall plan set and follows the traditional review process. RTMC staff are more consistently involved throughout the entire design development of a Design-Bid-Build project. The ITS design on a Design-Bid-Build project may be completed either by MnDOT or by a consultant.

2.2.2. Design-Build

Design-Build is a project delivery method in which MnDOT procures both design and construction services in the same contract from a single, legal entity referred to as the design-builder. The method typically uses Request for Qualifications (RFQ)/Request for Proposals (RFP) procedures rather than the Design-Bid-Build invitation for bids procedures. The design-builder controls the details of design and is responsible for the cost of any errors or omissions encountered in construction. On Design-Build projects, each functional group design is typically developed and approved as a separate design package. There may be separate design packages for signing, traffic signals, pavement markings, maintenance of traffic, ITS, roadway, drainage, and many others. There may also be multiple ITS design packages that are constructed at different times according to the overall construction staging. MnDOT RTMC staff are heavily involved early in the project developing the ITS related components of the RFP for a Design-Build project. Once the Design-Build project is awarded, the ITS design is completed by a consultant, so MnDOT provides an oversight role on these projects and conducts more Over-The-Shoulder (OTS) reviews throughout the design process. The development of design packages on Design-Build projects is accelerated compared to Design-Bid-Build projects, so OTS reviews are utilized more than traditional 30%/60%/95%/100% submittal reviews.

2.2.3. Construction Manager/General Contractor

Construction Manager/General Contractor (CMGC) is a project delivery method in which MnDOT contracts separately with a designer and a construction manager. MnDOT can perform the design or contract with an engineering firm to provide a facility design. MnDOT selects a construction manager to perform construction management services and construction works. The significant characteristic of this delivery method is a contract between MnDOT and a construction manager who will be at risk for the final cost and time of construction. Unlike Design-Bid-Build, Construction Manager/General Contractor brings the builder into the design process at a stage where definitive input can have a positive impact on the project. Construction Manager/General Contractor is particularly valuable for new non-standard types of designs where it is difficult for MnDOT to develop the technical requirements that would be necessary for Design-Build procurement without industry input. The development of ITS design on a CMGC project is more similar to Design-Bid-Build, with a difference being that a construction contractor will complete constructability reviews in order to provide a better final product.

2.3. Systems Engineering Approach

To use federal funds, the project must be compatible with the Regional ITS Architecture and utilize the appropriate Systems Engineering Checklist(s) that are described below.

2.3.1. Regional ITS Architecture

The Minnesota Statewide Regional Intelligent Transportation Systems (ITS) Architecture Version 2018 is an update of the previous version that was developed in 2014. The purpose of this update is to: 1) foster integration of the deployment of regional ITS systems; 2) facilitate stakeholder coordination in ITS planning, deployment and operations; 3) reflect the current state of ITS planning and deployment; 4) provide high-level planning for enhancing the state transportation systems using current and future ITS technologies; and 5) conform with the National ITS Architecture (the Architecture Reference for Cooperative and Intelligent Transportation, or ARC-IT, Version 8.2) and the Federal Highway Administration (FHWA) Final Rule 940 and Federal Transit Administration (FTA) Final Policy on ITS Architecture and Standards.

The Final Rule and the Final Policy provide policies and procedures for implementing Section 5206(e) of the Transportation Equity Act for the 21st Century (TEA–21), pertaining to conformance with the National ITS Architecture and Standards. The Final Rule and the Final Policy ensure that ITS projects carried out using funds from the Highway Trust Fund, including the Mass Transit Account, conform to the National ITS Architecture and applicable ITS standards.

Regional ITS architectures help guide the planning, implementation, and integration of ITS components and systems. ARC-IT is a tool to guide the development of regional ITS architectures. It is a common framework that guides agencies in establishing ITS interoperability and helps them choose the most appropriate strategies for processing transportation information, implementing and integrating ITS components and systems, and improving operations. The Minnesota Statewide Regional ITS Architecture is a specific application of the framework specified in ARC-IT, tailored to the needs of the transportation stakeholders in Minnesota.

The Minnesota Statewide Regional ITS Architecture geographically covers the entire state of Minnesota, encompassing local, regional and state transportation agencies and transportation stakeholders. It represents a shared vision of how each agency's systems work together by sharing information and resources to enhance transportation safety, efficiency, capacity, mobility, reliability, and security. During the development of the Minnesota Statewide Regional ITS Architecture, agencies that own and operate transportation systems collaboratively consider current and future needs to ensure that the current systems, projects and processes are compatible with future ITS projects in Minnesota. The collaboration and information sharing among transportation stakeholders helps illustrate integration options and gain consensus on systematic and cost-effective implementation of ITS technologies and systems.

The Minnesota Statewide Regional ITS Architecture is a living document and will evolve as needs, technology, stakeholders, and funding streams change.

The Minnesota Statewide Regional ITS Architecture, Version 2018 is available at the following link:

http://www.dot.state.mn.us/its/projects/2016-2020/itsarchitecture.html

2.3.2. Systems Engineering Checklist

The Highway Project Development Process (HPDP) includes the following link that provides guidance on Intelligent Transportation Systems (ITS) and Systems Engineering (SE) Requirements:

http://www.dot.state.mn.us/its/projects/2016-2020/systemsengineering/hpdp.pdf

The purpose of the guidance is to ensure that 23 CFR Section 940 (Rule 940) is implemented on applicable Trunk Highway projects. FHWA has established Rule 940 based on FTA policy. The intent of the FTA Policy and Rule 940 is to foster integration of regional ITS systems, which includes the integration of the deployment of regional ITS systems.

Where applicable, Rule 940 requires that all ITS systems or components be developed based on a Systems Engineering (SE) process, and that the scale of the SE process be on a scale commensurate with the project.

- Implementing the ITS SE Process for Rule 940 compliance is required for all ITS projects funded (in whole or in part) with the highway trust fund (includes National Highway System (NHS) and non-NHS facilities).
- In addition, MnDOT requires that the ITS SE Process for Rule 940 compliance is followed on all State Funded ITS projects in which ITS component(s) will be connected/integrated to another ITS component, project or system.

The ITS SE Process applies to all ITS Class A-1, A-2, B-1, B-2 and C projects that are defined below:

- Class A-1: Programmatic ITS Applications for Standard Traffic Signals, Road Weather Information Systems, Weigh-in-Motion Systems, and Railroad-Highway Grade Crossings
- Class A-2: Programmatic ITS Applications for Dynamic Message Signs, Traffic Detection, Video, Ramp Metering, Communications, Flood Warning Systems, and Slippery, Visibility, and Curve Warning Systems.
- Class B-1: Freeway Traffic Management
- Class B-2: Arterial Traffic Management
- Class C: Large Scale/Complex ITS Projects

The guidance describes responsibilities and steps that must be followed by the project manager and district traffic engineer including checklists and SE process that must be followed for various project types and submittal process.

2.4. Planning and Pre-Design

2.4.1. Concept of Operations

The Concept of Operations:

- Documents the total environment and use of the system to be developed in a non-technical and easy to understand manner
- Presents this information from multiple viewpoints
- Provides a bridge from the problem space and stakeholder needs to the system level requirements

2.4.2. Systems Requirements

System requirements are the foundation for building Intelligent Transportation Systems. They determine what the system must do and drive the system development. System requirements are used to determine if the project team built the system correctly. The system requirements development process identifies the activities needed to produce a set of complete and verifiable requirements.

2.4.3. Planning Guidance and Warrants

ITS warrants were developed by the ENTERPRISE pooled fund study. Details can be found at the following link:

http://enterprise.prog.org/itswarrants/

2.4.4. Statewide ITS Plan Location Criteria

Last published in 2015, MnDOT produces a Statewide ITS Plan which focuses on planning, funding, policy issues, investment scenarios, future possibilities, and next steps. Within the plan are location criteria for ITS devices, including video cameras and sensors. The criteria are dependent on the purpose of the device, the spacing requirements, and the system requirements. The current version of the MnDOT Statewide ITS Plan is available here:

https://www.dot.state.mn.us/its/projects/2006-2010/mnitsarchitecture/statewideitsplan.pdf

2.4.5. Pre-Design ITS Device Placement

Once it has been determined which location criteria from the Statewide ITS Plan are met (see Section 2.4.4), the designer will start laying out preliminary locations for the proposed ITS devices. Included below are important components for developing the pre-design ITS device locations.

AERIALS

At the initial planning stage for determining placement of proposed ITS devices, the designer should review aerial imagery to identify possible conflict areas and desired placement locations. These factors may include sight lines, bridges, and other geographical characteristics.

PRELIMINARY LAYOUT

The designer should create a roll plot with an aerial background and inplace utilities and ITS infrastructure to start pencil-sketching proposed ITS device locations, possible fiber optic trunk line routing, possible source of power locations, and any other required elements.

FIELD VISIT

After completing the initial draft of the preliminary layout, the designer should perform a field visit to collect photos and review proposed ITS device locations. For example, a proposed cabinet may be shown on a steep slope while there is a flatter area nearby that would work better.

2.5. General Design Guidance

2.5.1. Clear Zone Requirements

The AASHTO Roadside Design Guide defines clear zone as the "total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area." The MnDOT Road Design Manual states that “The roadside clear zone is the distance from the edge of the travel lane which should be free of any non-traversable hazard such as steep slopes or fixed objects. The clear zone distances are targeted towards allowing approximately 80 to 85 percent of all run-off-the-road vehicles to recover or come to a safe stop.”

The width of a clear zone along the horizontal alignment is dependent on roadside geometry, design speed, radius of any horizontal curve, and the ADT. As an example, a roadway tangent section with 3000 vehicles per day, a posted speed limit of 55 mph and a 1:4 (V:H) fill section would have a calculated clear zone of 36 feet, per Table 4-6.04A; MnDOT Road Design Manual.

The MnDOT Road Design Manual states that “The designer should not apply rigid adherence to the calculated clear zone distance. The designer should not use the clear zone distances as boundaries for introducing roadside hazards such as bridge piers, non-breakaway sign supports, or trees. These should be placed as far from the roadway as practical.” ITS devices should be placed outside the clear zone whenever possible, and in cases that it is not possible or feasible the ITS devices must be placed behind guardrail.

MnDOT State Aid requirements may differ from those described above, so if the designer is working on a State Aid Project they need to review the MnDOT State Aid documentation on clear zone best practices, available at the link below.

https://www.dot.state.mn.us/stateaid/clear-zone.html

2.5.2. Survey and Boring Request

Whenever survey and soil borings are required, the designer will need to submit formal requests to the appropriate groups. Soil borings are required for every footing for a proposed overhead sign structure, and the materials group will complete those requests and provide a report that recommends whether a special foundation be used or if the standard design is adequate. Additional geotechnical review is also required in areas where shallow bedrock is anticipated as a part of I-Beam sign design because special post footings may be required, or the sign location may be moved to avoid the bedrock. Additional geotechnical review may include a review of historic soil borings in the area, ground penetrating radar, or additional soil borings. Resources for soil borings in the Metro District are available at the link below. For all Greater Minnesota districts, the designer should coordinate with that district to determine their process for requesting soil borings.

http://www.dot.state.mn.us/metro/materials/soils.html

If current surveys are not available, they need to be completed in order for the designer to create cross sections for overhead and roadside ITS devices and design guardrail and grading for those ITS devices. The designer will need to coordinate with the district survey group to obtain survey information for the required locations.

2.5.3. MnDOT Utility Coordination Process

The MnDOT utility coordination process is designed to help reduce the time that designers spend on utility coordination. By identifying early milestones for utility coordination meetings and follow up, project managers and designers can avoid time-consuming efforts to resolve utility issues that often occur later in the process. Many MnDOT staff members contribute to successful utility accommodation and coordination, and each of them plays an important role. The Utility Accommodation and Coordination Manual details the roles and responsibilities of MnDOT staff members who are involved with utility coordination for each step of the utility coordination process. The process encourages early and ongoing communication with utility owners. MnDOT often collaborates with consulting engineers on the design of highway transportation projects. As a result, consulting engineers are involved with many aspects of utility coordination, including project management. Resources for the utility coordination process are available at the following link:

https://www.dot.state.mn.us/utility/projectdelivery.html

On ITS projects, the full utility coordination process is not typically followed. Most inplace public or private utilities will not be impacted, and under that scenario the utility listings in the plan set will note all inplace utilities as “LEAVE AS IS”. The designer will need to submit a design locate through Gopher State One Call to obtain a list of all utility owners in the project area. If source of power modifications or new sources of power will be required as part of the ITS design, the designer and the MnDOT RTMC service coordinator will need to coordinate with the power company designer to determine the final design.

2.5.4. Environmental Process

All MnDOT projects are required to complete an Early Notification Memo (ENM). The ENM is used to provide notification of a project and/or request information that may affect project scoping, layout, or design. Instructions and links to ENM forms are available on the Highway Project Development Process (HPDP) website at the following link:

http://www.dot.state.mn.us/planning/hpdp/index.html

As part of the ENM, MnDOT's Environmental Document Decision Tree must be reviewed to determine what type of environmental documentation is needed for the project under both state and federal rules.

2.5.5. Functionality

The proposed ITS device(s) should be designed to adequately address the existing problems that have been identified to be addressed. For example, if a series of video cameras are proposed to be added the designer needs to ensure that the proposed camera locations do not include or minimize blind spots (assuming they cannot be avoided), or for a proposed DMS the designer needs to ensure that the DMS is located optimally to facilitate major traffic diversions due to a crash downstream of the DMS.

2.5.6. Constructability

The designer needs to consider the constructability of ITS devices when determining proposed ITS device locations. For example, all ITS infrastructure and construction equipment should have a minimum clearance to overhead power lines per Rural Utility Service standards. The designer needs to consider common construction methods that contractors use to construct the ITS devices that have been designed and make sure that the design is realistic and practical.

2.5.7. Maintainability

The designer also needs to consider the maintainability of ITS devices when determining proposed ITS device locations. The two most important considerations are access and safety, and if possible, the designer should use standard MnDOT approved components so there is consistency in ITS devices throughout the entire system. The designer needs to consider whether an ITS device will need to be accessed via a ladder or a bucket truck, whether a lane closure is needed, if there is adequate shoulder to pull off to access the site, and any other site-specific characteristics that may affect access or safety. Another consideration regarding ITS device locations is the ease and complexity of underground utility locating.

2.5.8. Device Collocation

If multiple different ITS devices (video camera, DMS, NID, etc.) are proposed for a certain area, the designer should evaluate whether it would make sense to place them at the same site. This could reduce the number if SOP locations, the number of control cabinets, and the number of folding poles. This could also simplify maintenance operations such as mowing.

2.6. Typical Design Review Process

The TMS sample plan is located at the link below and provides general information about the design of TMS plans.

http://www.dot.state.mn.us/metro/finaldesign/pdf/sampleplan/tms.pdf

2.6.1. Conceptual Design (30% Design)

TMS plans are not typically included as part of a larger roadway project plan set for the 30% submittal and are more of a high-level layout that determines which devices are required and where they are located. No conduit runs, pull vaults, or sources of power are designed at this point. The RTMC will review the conceptual ITS design to ensure that all required devices are included as needed.

2.6.2. Detailed Design (60% Design)

Detailed design typically includes all TMS plans except fiber schematics and DMS cross sections, and the TMS construction plans should be fully annotated. At 60%, the RTMC will review the plans but no other functional groups will be involved in the project yet.

2.6.3. Integrator Review & Input

After the 60% review and the 60% RTMC design comments have been addressed, the TMS plans should be provided to an RTMC integrator for their review and input. An integrator will provide input based on their field experience, and the designer will incorporate comments from the integrator.

2.6.4. Final Design (95% Design)

The 95% submittal will include the Plans, Special Provisions, and Estimate (PS&E) and will be reviewed by other functional groups as required. Depending on the scope of the TMS construction plans, the PS&E should be provided to MnDOT Construction, Traffic, Structures, Safety, Drainage, Utilities, and others as necessary. The MnDOT traffic and/or construction group will complete the Time & Traffic Special Provisions. This submittal should be distributed to the other groups a minimum of six weeks prior to plan turn-in. This allows for the four weeks other groups often required to review and provide comments and two weeks for changes to be incorporated prior to turn-in. The 95% design must be treated as if it is being issued for construction, there should not be any significant changes between 95% and 100% design.

2.6.5. Issued for Construction (100% Design)

The 100% PS&E submittal will go to the RTMC and MnDOT Central Office for final approval, and the vellum title sheet will be routed for signatures. Any comments from the Central Office must be incorporated prior to bidding. If other changes are made in addition to or that differ from the Central Office comments, the revised sheets must be resubmitted along with a copy of the same sheets that highlights those differences.

The RTMC has a state-wide Public Information Finding (PIF) that addresses State-provided materials on ITS projects. A memo, signed by Central Office, that refers to this PIF and references the applicable sections of the PIF based on the particular State-provided materials that will be utilized on the project is required prior to of plan turn-in.

2.6.6. Additional Input & Reviews

If there are structures as part of the project or if there are any right-of-way concerns, additional input & reviews may be required by the relevant functional groups. As soon as the designer has determined that there are components that will require involvement from other functional groups, the designer should coordinate with the relevant functional groups early in the design process, so they have adequate time to provide design input. There is more information on this in Chapter 3 and Chapter 4.

TRAFFIC

If signing or pavement markings are required as part of the project, the traffic group should review the plans at the 95% and 100% submittals. In Metro District, for every project the traffic group also provides input on the traffic portion of Time & Traffic within Division S. For all other districts this may vary. Special Provisions are discussed in Section 4.3.

CONSTRUCTION

The construction group should review the plans at the 95% and 100% submittals for all projects. In Metro District, for every project, the construction group is also responsible for writing the Time & Traffic portion of Division S with input from the traffic group. For all other districts this may vary. Special Provisions are discussed in Section 4.3.

SURVEY

If right-of-way information is not available and needs to be obtained, or if there are any other concerns that may require surveying, the survey group will need to review the plans. The survey group should review the plans earlier in their development, preferably at the 95% submittal.

FOUNDATIONS

If soil borings are required for overhead sign structures and the geotechnical report recommends that a special foundation design is required, the foundation group will need to review the plans. This review should occur with the 95% submittal.

STRUCTURES

If there are any new bridge-mounted structures, such as a DMS installation, the structures group should review the plans at the 60%, 95%, and 100% submittals.

METAL FABRICATIONS

If there is any proposed structural steel work on any existing or proposed structures, the metal fabrications group should review the plans at the 60%, 95%, and 100% submittals.

2.6.7. Coordination with Other Disciplines

When the ITS design is being done as part of a larger project, the designer will need to coordinate with other disciplines including drainage and utilities. This coordination needs to occur so the proposed ITS design does not conflict with wetland areas, proposed ponds, drainage structures, and other utilities.

The designer needs to ensure that early in the design process all disciplines are aware of each other's proposed design and that regular coordination happens throughout. Any groups that need to be coordinated with should also participate in the review process described above.

2.6.8. Coordination with Other Projects

The designer must be aware of other projects that are being designed by others that may affect their own project, so any items that may require coordination during design or construction are addressed and incorporated into the plans and Special Provisions. For example, plan notes may specify that certain components shown on the plan are installed under a different SP number. In the Division S Special Provisions, Section 1505 COOPERATION BY CONTRACTORS should list all projects that the contractor needs to be aware of and coordinate with. In some cases, it may make sense for separate projects to be tied and bid on as one package for one contractor to construct both projects, such as if there is an overhead signing project that will affect some of the same inplace overhead sign structures that the ITS project is impacting.

2.7. Bid and Construction Support

2.7.1. As-Built Plans

Information about the GPS As-Built Deliverable is available at the link below that describes all requirements for each asset class. The TMS tab provides information on all the features that need to be documented for TMS plans.

http://www.dot.state.mn.us/gisspec/index.html

Section 2011 AS BUILTS in Division S describes the requirements for as-built plans, the contractor is required to provide GPS as-built information for TMS. TMS as-builts typically require Method (2) and mark-up drawings. Method (2) requires that all coordinates be sub-meter accurate x and y, where Method (1) requires that all coordinates be sub-foot accurate x, y, and one-tenth-foot accurate z. Mark-up drawings require that the contractor submits an "As-Built" plan set that includes mark-ups showing additions, deletions, and other changes made during construction."

RTMC design staff take the GPS as-built data and mark-up drawings and perform all CAD updates in MicroStation. All updated CAD linework is viewable in Georilla and the master file is regularly exported to MicroStation to be used as existing conditions on new ITS projects. Django tracks when as-built data is received by the contractor, uploaded into Georilla, and other relevant information.

2.8. Operations and Maintenance

It is important that the ITS design addresses the needs of operations and that the ITS system is ultimately able to be maintained in a safe and efficient manner.

2.9. Project Timelines

There are multiple timelines that need to be considered throughout all projects, including letting schedules, construction timeframes, and lead times for materials such as steel or fiber optic cable. When a project is initially setup in the project scheduling software, a customized turn-in date is assigned. There are minimum time periods that are required to provide for project letting, so if the project turn-in falls behind schedule it could have significant impacts on the project letting and award dates, procurement of materials, and when construction of the project occurs. Additional information about the bid letting process is available at: https://www.dot.state.mn.us/bidlet/.

3. Supporting Infrastructure Design

3.1. Power Distribution

3.1.1. Overview

The purpose of this section is to familiarize the designer with the National Electric Code (NEC), the National Electric Safety Code (NESC), and current MnDOT standards and design guidelines for power distribution systems associated with ITS infrastructure. Electric services must be located within MnDOT right-of-way.

The four basic physical characteristics of electricity, noted below, are voltage, current, resistance, and power. Voltage is the difference in electrical potential between two points of an electrical circuit, expressed in volts. Voltage measures the potential energy of an electric field to cause an electric current in an electrical conductor. Current is the rate of flow of electricity through an electrical conductor and is measured in amperes, or amps. Resistance, measured in ohms, is the resistance of an electrical conductor to the flow of electricity. Power is the rate at which work is done or energy is transferred. Work can be measured using many different units but is most often measured in watts when used in calculations for ITS infrastructure.

Electrical current can be characterized as alternating current (AC) or direct current (DC). Power supplied by an electric company is typically AC while power provided by a battery is DC. Power can be converted from AC to DC using a rectifier and from DC to AC using an inverter. A majority of the ITS cabinets, and subsequently ITS devices, used by the State are supplied by an AC power source. A smaller number of State ITS cabinets and ITS devices are supplied by low voltage DC power sources that may include batteries and a solar array.

3.1.2. Compliance with Electric Codes and Standards

The design of all MnDOT electrical systems, including all power infrastructure for ITS elements, should adhere to the standards and requirements included in the current version of the NEC and the NESC. The NEC is typically updated every three years, and the NESC is updated every five years. Prior to beginning any MnDOT ITS design project, the designer should verify they are using the latest versions of the NEC and NESC. A variance committee has been established to review special cases where it is not practical to meet all of the requirements in the NEC and the NESC. The designer should notify the MnDOT project manager and RTMC of all variances to the NEC and NESC, which must be reviewed and approved by the committee.

The NEC and NESC include standards for:

- Conductor properties
- Conductor insulation
- Maximum recommended voltage drops
- Maximum conduit fill
- Junction box sizing

For additional information refer to the links below:

- NEC: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70
- NESC: https://standards.ieee.org/products-services/nesc/index.html

3.1.3. Electric Service Providers

Power for ITS infrastructure across the state is provided by many electric service providers, and the electric service provider for each ITS device location will depend on the electric service provider that covers the specific area in which that device is located. The link below includes an interactive map of electric service utility providers within the state of Minnesota.

Minnesota Electric Utility Service Provider Map:
http://minnesota.maps.arcgis.com/apps/webappviewer/index.html?id=95ae13000e0b4d53a793423df1176514/

In some instances, new ITS devices may be located near or adjacent to the dividing line between two electric service provider service areas. There are several factors that may impact which of the two electric service providers is preferred, including service provider reliability, rates, policies, service levels, and existing service agreements with MnDOT. When multiple service providers are available, the designer should contact the MnDOT project manager to determine the preferred electric service provider. In addition to the service provider, the designer should consider a number of different factors when selecting which of multiple available power sources to utilize including the location of the existing power source, the difficulty in connecting to each power source, the voltage available from the power source, the difficulty and timeline for obtaining service from the electrical service provider.

3.1.4. Distribution versus Transmission

Electric service providers deliver electricity to consumers in two separate phases: transmission and distribution. The transmission phase includes the bulk movement of electrical energy from the power generation facility to a power substation. Electrical transmission lines typically carry three-phase alternating current at very high voltages (greater than or equal to 69 kilovolts (KV)). The distribution phase includes delivery of that electrical energy from the power substation to individual consumers at lower voltages (less than or equal to 34.5KV). Power for all MnDOT ITS devices is obtained from electric services that are installed off an overhead or underground electric distribution line.

3.1.5. Power Supply

The designer may consider several different options to provide power to an ITS device. The following power source options can be utilized:

- Existing Electric Service: When available and evaluated for condition (rust, enclosure's structural integrity, space for additional circuit breakers), the designer may obtain power from an existing MnDOT ITS electric service. All MnDOT Districts, except for Metro District, allow sharing service meters between functional groups (lighting, signals, ITS), but the designer should still check with each District on a by-project basis. The designer will be required to verify that the existing service has sufficient capacity to provide power to the new ITS infrastructure without negatively impacting the power being supplied to any of the existing infrastructure currently supplied by the service. The engineer should consider the distance between the proposed ITS infrastructure and the existing service to determine if use of the existing service will be more cost effective and maintainable than the installation of a new electric service located closer to the proposed ITS infrastructure. Every attempt to obtain power from the electric service provider should occur during the design process; the use of a MnDOT-owned step-down transformer is not preferred but may be required in some situations. Power runs over 1000 feet are discouraged and require prior MnDOT approval.

- New Electric Service: If an existing MnDOT ITS power service is not available, power can be obtained from a new electric service. The service transformer should be located as close to the ITS device as possible to minimize the length and size of the electric conductors.
- Alternative Power Source: When power service is unavailable in the immediate vicinity of the proposed ITS infrastructure and installing a long electric cable run is not feasible, the designer may consider alternate power sources including solar and, in some cases, wind. Use of an alternate power source will require installation of batteries to store electricity for use when the solar or wind equipment is unable to provide sufficient power. The use of an alternate power sources is strongly discouraged.

3.1.6. Obtaining Power Service

Power for ITS infrastructure is obtained by the power coordinator while coordinating with the RTMC service coordinator. A standard format spreadsheet is used by the RTMC to document all utility coordination items, including what the power company is responsible for and what the contractor is responsible for. See Figure 3-1 for a screenshot of the spreadsheet. A copy of the spreadsheet can be requested from the RTMC. Once the spreadsheet has been completed for the project, it must be provided to the MnDOT RTMC service coordinator.

MNDOT TMS ELECTRIC SERVICE COORDINATION PROCESS

The individuals involved in the coordination process and their roles are as follows:

- Power Coordinator – MnDOT, County, City, or consultant designer/engineer completing the TMS design
- RTMC Service Coordinator – MnDOT RTMC design staff responsible for power coordination/tracking/records
- RTMC Design Supervisor – MnDOT RTMC design staff or project manager
- RTMC Integration – MnDOT RTMC field personnel
- Power Company Designer – designer/field representative for power company

The MnDOT TMS Electric Service Coordination Process is as follows:

1. Project power coordination is initiated at approximately the 60% plan development milestone.
2. Power Coordinator creates the MnDOT RTMC Utility Coordination Spreadsheet and starts populating information as it is determined.
3. Power Coordinator determines the electric service provider and follows the service provider's standard process for obtaining the Power Company Designer's information and initiating the service coordination process with the service provider. Contact the Power Company Designer and provide them a copy of the 60% plan sheet(s) and fill out any necessary load sheets or other forms that the service provider requires.

4. Power Coordinator coordinates a field meet with the Power Company Designer and the RTMC Service Coordinator and discuss the following:
    a. Discuss the project turn-in date, letting date, and start date with the Power Company Designer. Discuss milestones for when Power Company Designer needs to provide information (plan for 1-2 months for Power Company Designer to determine and provide costs, easements, and design information)
    b. Discuss the availability of 120/240V electric service. The MnDOT RTMC requires 120/240V power from the service point (pad mounted transformer or service pedestal)
    c. Determine proposed usage based on main circuit breaker size (30 Amps, 60 Amps, 100 Amps, etc.)
    d. Determine access requirements to meter (gate in fence may be needed for power company access)
    e. Discuss that MnDOT will provide a foundation and metered service cabinet for the service connection point.
    f. Discuss that no stepdown transformers are allowed, unless approved by the RTMC Service Coordinator and RTMC Design Supervisor.
    g. Discuss that MnDOT no longer installs a riser on power company poles. The power company will install a U-channel on the pole to a service pedestal or pad mounted transformer within MnDOT right-of-way. The service pedestal must have a red marking stake installed next to it to ensure its visibility when in long grass or deep snow. MnDOT infrastructure cannot go outside of MnDOT right-of-way to get to the service point.
    h. In situations where an electric service isn't reasonably close and the power company will not work within MnDOT right-of-way, the MnDOT contractor will provide a 3" non-metallic conduit with a pull tape within MnDOT right-of-way for the power company to pull their power cables through. For longer conduit runs, pull vaults will be installed at 500 foot intervals. This infrastructure then becomes the property of the power company and is their responsibility to locate.
    i. In situations where there is a noise wall between the transformer and the meter, the designer will need to install an access door into the noise wall so the power company can access the meter.
        i. If an access door cannot be installed in the noise wall, there is adequate space between the noise wall and MnDOT right-of-way, and there is reasonable access from outside MnDOT right-of-way, the designer will need to install the metered service cabinet between the noise wall and MnDOT right-of-way and a service cabinet type special on the highway side of the noise wall.
5. Power Coordinator obtains meter address, account number, and premise number from the Power Company Designer.
6. Power Coordinator updates RTMC Utility Coordination Spreadsheet with all information determined up to this point and provides a copy of it to the RTMC Service Coordinator, RTMC Design Supervisor, RTMC Integration, Power Company Designer, etc.
7. Designer determines all TMS equipment loads to calculate voltage drop and determine appropriate conductor sizes.
8. Power Coordinator updates RTMC Utility Coordination Spreadsheet with costs provided by Power Company Designer.

9. Power Coordinator provides 100% plans and RTMC Utility Coordination Spreadsheet to Power Company Designer for final written approval. At this point, all information in the spreadsheet should be filled out except which contractor was awarded the electrical work.
10. Power Company Designer provides a service contract with costs and scope of work that will be signed by the RTMC Service Coordinator.
11. After the project has been let and awarded, MnDOT's construction contractor will need to contact the power company and provide the project start date so the power company can get their portion of the work scheduled and coordinated. The construction contractor must pay the power company in order to get the project onto the power company's construction schedule.
12. Any electric service work performed by the power company on MnDOT right-of-way will need a permit. The power company is responsible for acquiring such permit from MnDOT.
13. Send all permits for RTMC service work to the RTMC Service Coordinator for review.
14. The service address, account number, and premise numbers have already been determined and are included in the Division SZ special provisions for the project. The construction contractor does not need to submit new applications for service. See the Electrical Service section of Division SZ for more information.

Figure 3-1: MnDOT RTMC Utility Coordination Spreadsheet

S.P. XXXX-XX SERVICE REQUEST LOCATION	ADDRESS & CITY	ACCOUNT	PREMISE	METER	MnDOT COMMENTS	EQUIP	COST FOR INSTALL	TURN IN DATE	LETTING DATE	START DATE	REQ COMP END DATE	ELEC. FIRM	STATE PROJECT NUMBER DESIGNER/ INTEGRATOR	Power Company Designer
TH 35E-211 @ NORTH OF WAGON WHEEL TR	2130 TIMMY LN MENDOTA HEIGHTS, 55120				**DMS LOCATION # 3** XCEL WILL: Remove meter from Service Installation Type B. CONTRACTOR WILL: Remove Service Installation Type B from wood pole.	DMS TH 35E-211 DMS CAB 35E-100.6 INSTALL 334MP CAB 35E-100.6							XXXX-XX XXXX XXXX	Name Phone Email
TH 35E-211 @ NORTH OF WAGON WHEEL TR	2132 TIMMY LN MENDOTA HEIGHTS, 55120				**DMS LOCATION # 3** XCEL WILL: Install new meter in new service cabinet. CONTRACTOR WILL: Install Service Installation Type A on wood pole. Install conduit and power cables from inplace wood pole to new foundation and metered service cabinet inside ROW fence.	DMS TH 35E-211 DMS CAB 35E-100.6 INSTALL 334MP CAB 35E-100.6							XXXX-XX XXXX XXXX	Name Phone Email

3.1.7. Placement of ITS Elements

In addition to the device-specific location criteria identified for each ITS device, the designer also needs to consider all available options to obtain electric service. When possible, the ITS device should be located as close to source of power as possible to minimize the length and size of power cables required to supply that device with power. Power cable runs from the metered service cabinet to the ITS device that are longer than 400 feet must include a service cabinet type special at the ITS device. Power cable runs that are shorter than 400 feet but do not have a clear line of sight to the ITS device or safe walking access should also include a service cabinet type special at the ITS device. If more than one potential option exists to obtain electric service, the designer should consider the voltage available at each location as a part of the design process.

The following four figures detail typical service cabinet placement under various power service installation scenarios.

Figure 3-2: Typical Power Service - Pole-Mounted Transformer

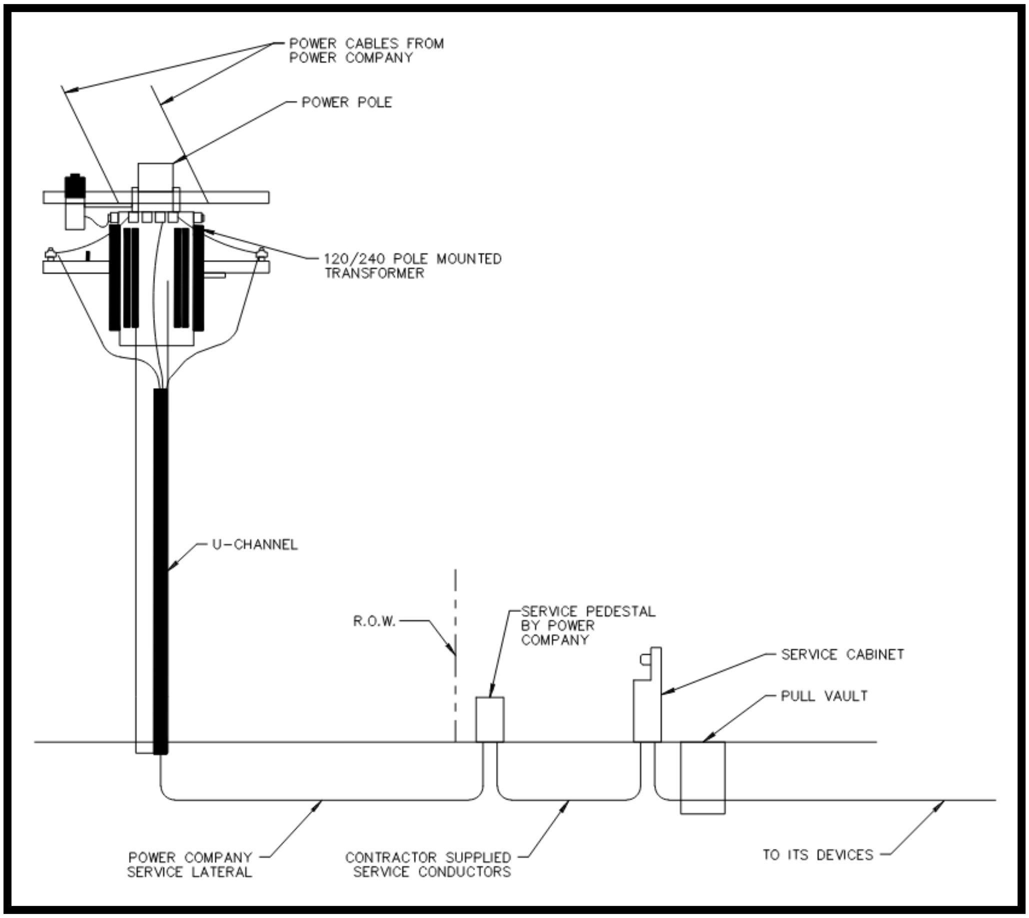


Figure 3-3: Typical Power Service - Pole-Mounted Transformer behind Noise Wall

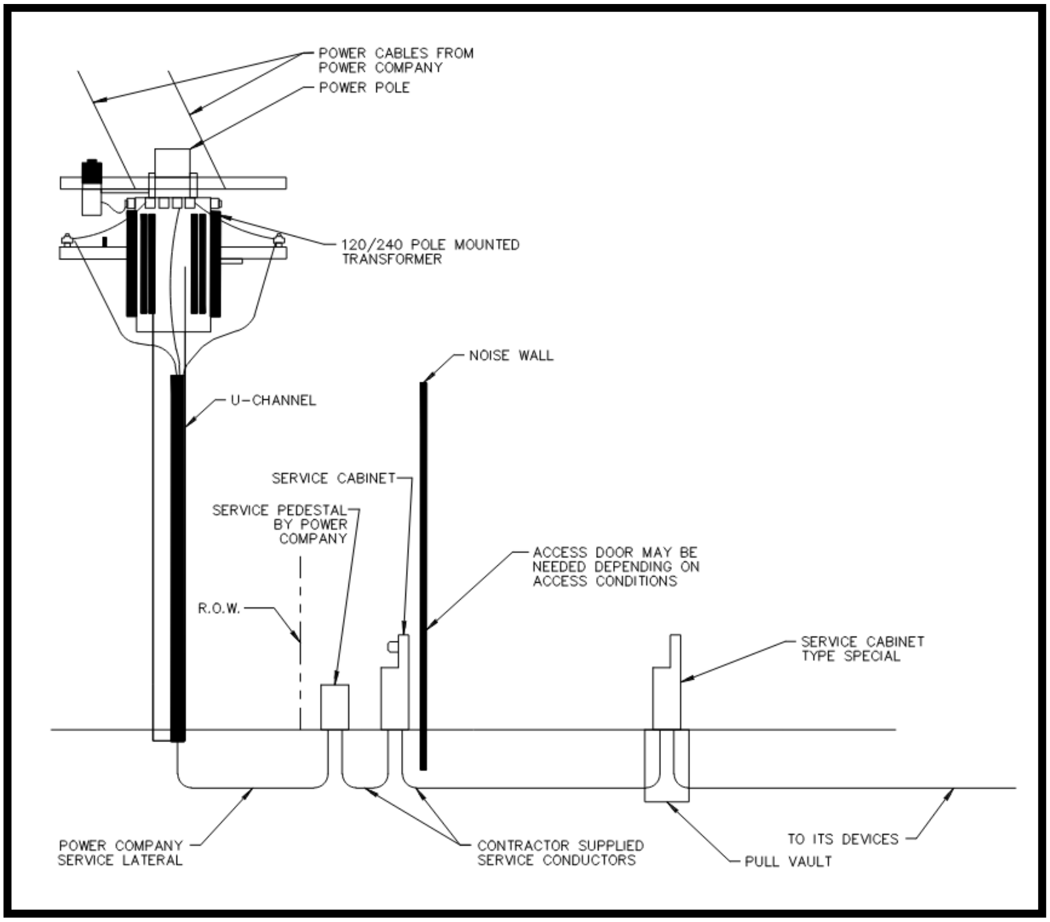


Figure 3-4: Typical Power Service - Ground-Mounted Transformer within MnDOT R.O.W.

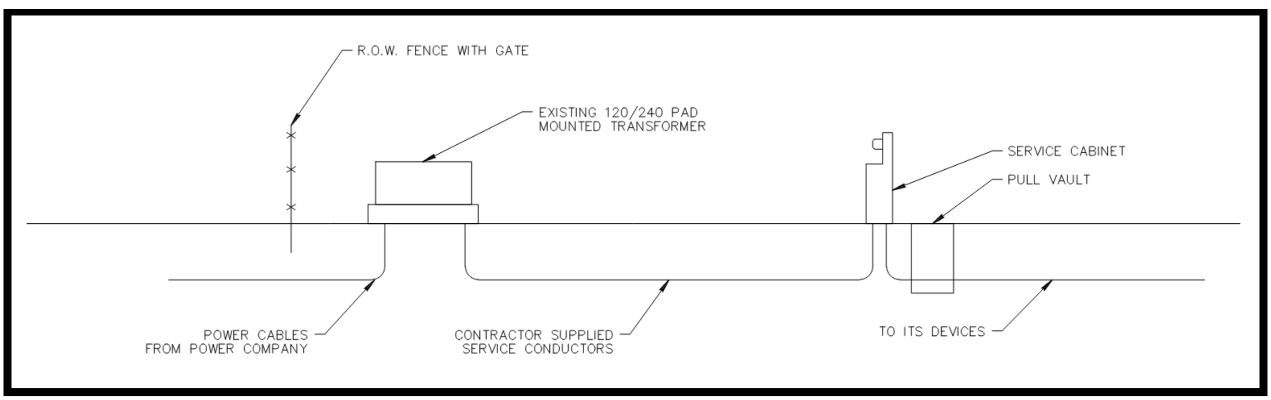
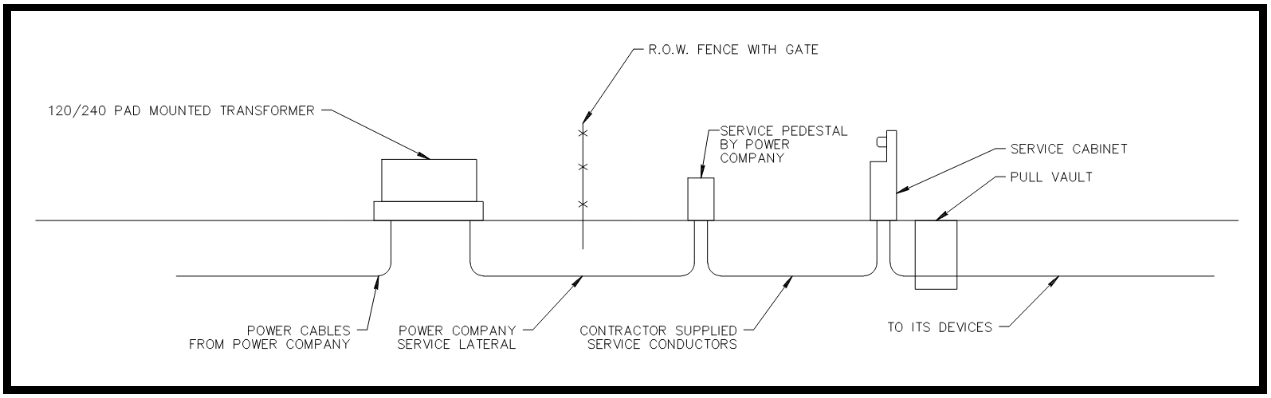


Figure 3-5: Typical Power Service - Ground-Mounted Transformer outside MnDOT R.O.W. with Service Pedestal within MnDOT R.O.W.



Most power companies no longer allow MnDOT equipment on their power poles and many are using service pedestals. It is important to note that most power companies prefer the meter to be less than 15 feet from the service pedestal or pad mounted transformer.

3.1.8. Design Considerations

There are several principles that need to be understood when determining conductor size and the required circuit breakers for the circuits included in an ITS design. Below is a description of several electrical principles followed by an example problem.

WIRE GAUGE

American wire gauge (AWG) is a standardized wire gauge system used in the United States and other countries, especially for nonferrous, electrically conducting wire. Increasing gauge numbers give decreasing wire diameters, which is similar to many other non-metric gauging systems. This seemingly-counterintuitive numbering is derived from the fact that the gauge number is related to the number of drawing operations that must be used to produce a given gauge of wire; very fine 30-gauge wire requires far more passes through the drawing dies than does a 0-gauge wire. Note that for gauges 5 through about 14, the wire gauge is effectively the number of bare solid wires that, when placed side by side, span 1 inch. That is, 8-gauge wire is about 1/8 inch in diameter. An AWG of 14 is the minimum size used by MnDOT for ITS applications.

The following minimum conductor sizes need to be incorporated into the design:

- Service conductor from service pedestal to metered service cabinet: #6 or larger
- Feeder circuit serving standard service cabinet type special: #6 or larger
- Branch circuit serving NID or camera pole cabinet: #14 or larger for circuits less than 400' and #8 or larger for circuits over 400'
- Branch circuit serving 334 series cabinet: #8 or larger
- Branch circuit serving 334 series cabinet that shares the same foundation with the service cabinet: #10 conductors or larger
- Branch circuit serving 18’ wide Ledstar DMS: #8 or larger
- Branch circuit serving 30’ wide Ledstar DMS: #6 or larger
- Branch circuit serving 40’ wide Ledstar DMS: #2 or larger

- Branch circuit serving shelter: #2 or larger

The designer must also verify that the breakers specified can accommodate the wire sizes specified.

AMPACITY

Ampacity is defined as the maximum amount of electric current a conductor or device can carry before sustaining immediate or progressive deterioration. The circuit breaker must not be rated for a larger current than the ampacity of the conductors used in the circuit. Ampacities are listed in Table 3-1.

Table 3-1: Electrical Wire Characteristics

Wire Size (AWG) Copper	Ampacity (Amps)	Resistance of Copper Wire (Ohm / 1000 Ft)
14	15	2.57
12	20	1.62
10	30	1.02
8	45	0.64
6	65	0.41
4	85	0.26
3	100	0.21
2	115	0.16
1	130	0.13
0	150	0.10
00	175	0.08
000	200	0.06

CIRCUIT TYPES

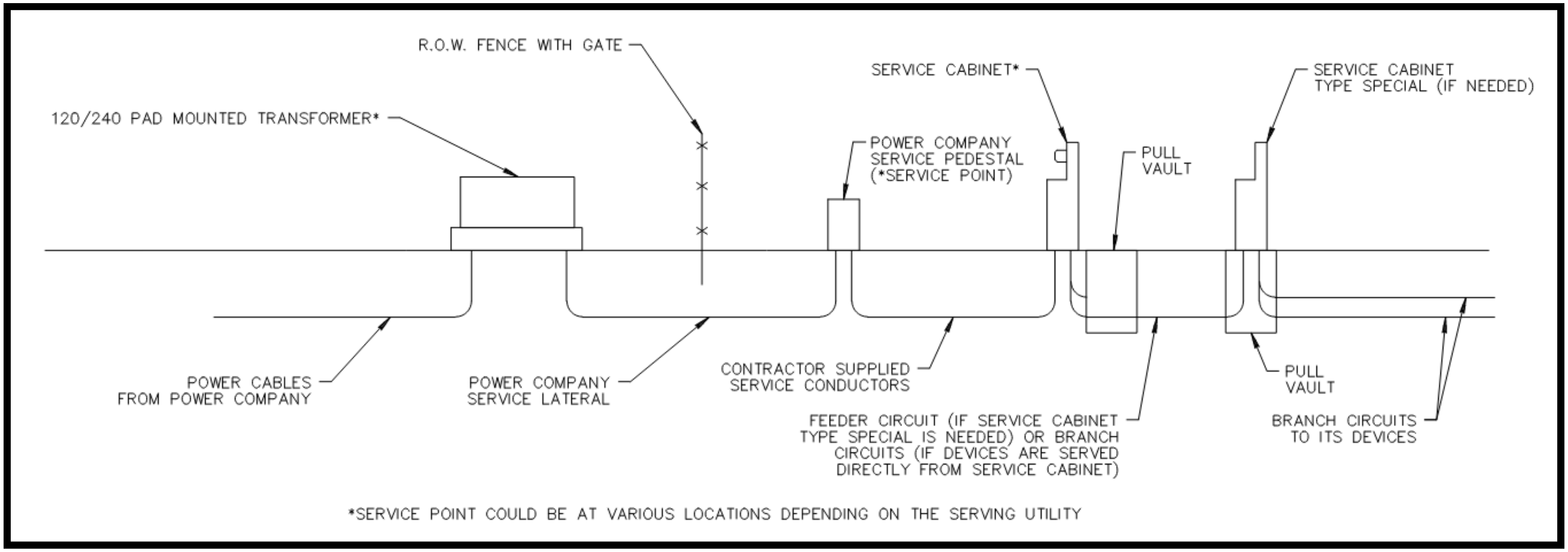
Below is the definition for service conductors and the two types of circuits:

- Service point – The transformer, or service pedestal (if present)
- Service lateral – The power company supplied conductors from the transformer to the service pedestal (if present)
- Service conductors - The contractor supplied conductors from the service point to the metered service cabinet.
- Feeder circuit – All circuit conductors between the service equipment, the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device.
- Branch circuit – The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).

The power company is responsible for conductors on the power company side of the service point. MnDOT is responsible for service conductors between the service point and the metered service cabinet. The power company may provide conductors all the way to the service cabinet meter. In that case, the service cabinet is the service point and there are no service conductors. It is important that the utility coordination spreadsheet (see Figure 3-1) is completed because not all power companies provide power in the same fashion.

- Some power companies provide service conductors to a service pedestal and the service pedestal becomes the point of service. Under this scenario MnDOT is responsible to install the conductors between the service pedestal and service cabinet.
- Other power companies provide service conductors to the service side of the service cabinet. In this case the point of service is the service cabinet meter.

Figure 3-6: Circuit Types Exhibit



In terms of TMS design: The service conductors are the circuits from the service cabinet to the connection with the power company (service point). The branch circuit(s) are the circuits from a service cabinet or service cabinet type special to the various ITS devices. The feeder circuit is circuit between the service cabinet and service cabinet type special. Service conductors are located on the service side of the service pedestal. Figure 3-6 shows the circuit types.

CURRENT REQUIREMENTS

The total current required for an ITS application for a branch or feeder circuit is the sum of the following:

- Current requirements for all ITS device(s) (e.g., shelter, DMS, video camera, vehicle detection, controller cabinet, etc.) on each leg of every branch or feeder circuit

Power cables and the circuit breakers should be sized based on the total current required for all ITS devices and cabinet components being served. The current required for various ITS devices can be found in Table 3-2. When determining the total current required, do not factor-in both devices when those devices perform opposing functions and are not expected to operate simultaneously (e.g., heater and air-conditioner). The current value used for sizing the conductors and circuit breakers considers continuous loads and non-continuous loads (see the section on Breaker Sizing). The conductors must have sufficient ampacity to carry the current rating of the circuit breaker, unless the conductor ampacity is not a standard circuit breaker size, then the circuit breaker can be the next biggest standard size. The distinction of continuous and non-continuous loads only applies for determining minimum wire and circuit breaker sizes and is not considered for calculating voltage drops.

Note that a larger conductor size may be required in order to keep the voltage drop over longer lengths below the recommended maximums. Current load requirements for individual ITS devices should be obtained from the Table 3-2 and, if not identified or the devices are from a different vendor/manufacturer, from the manufacturer/vendor of that specific ITS device.

VOLTAGE DROP

In order to properly size the electrical conductors in a feeder circuit that will supply power to a service cabinet type special, and subsequently each ITS device connected to the cabinet via branch circuits, the voltage drop across each feeder circuit and branch circuit should be calculated. It is normally not necessary to the calculate voltage drop across the service conductors since they are normally only a short distance and it is the power company's responsibility to provide the nominal voltage at the service point. The voltage drop calculation will determine the amount of voltage lost along the conductors. Calculating the voltage drop across the system is important as it will ensure the voltage is sufficient to properly operate all ITS devices, to avoid inefficient operations as a result of excessive amounts of power being dissipated across the electrical system.

The electrical conductors carrying current to the service cabinet have resistance. The resistance of the conductors depends on the length of the conductors, size (gauge) of the conductors, and conductor material. When current flows through the conductors, the voltage drops along the length of the conductor, which results in a lower voltage at the end of the circuit. A similar voltage drop occurs in the return current of the neutral wire and is additive to the total voltage drop for a 2-wire circuit or unbalanced 3-wire circuit. If the resistance of the conductor is too high for the amount of current flowing through it, the voltage lost will be too high.

When providing power to an ITS device, the NEC recommends that the maximum voltage drop across the combined feeder and branch circuits not exceed 5% and the maximum individual voltage drop across the feeder circuit or the branch circuit not exceed 3%. In some instances, MnDOT may elect to utilize a maximum voltage drop of 5% or greater for the individual feeder circuit and branch circuit. In these instances, the designer should obtain approval from MnDOT as well as provide detailed design calculations for the continuous and peak power demand for the ITS application or device.

The voltage drop for a circuit is calculated as follows:

Total Voltage Drop = Voltage Drop on Highest Current Leg + Voltage Drop on Neutral

Voltage Drop = Current Load * Distance Factor *Resistance of Wire

Resistance of Wire – in ohms/1000 feet (from Table 3-1)

Current Load – in amps

Distance Factor = Distance/1000

Distance – is total length of wire (including slack)

For a 120 volt 2-wire circuit:

Current on Leg = Current on Neutral

Voltage Drop on Leg = Voltage Drop on Neutral

For a 120/240 volt 3-wire circuit with a balanced load:

Voltage Drop on Neutral = 0 volts (because there is no current on the neutral)

It is desirable to balance the loads on each leg of a 120/240 volt 3-wire circuit because it is more efficient since there is no additional voltage drop across the neutral. Having a system with balanced loads also extends the service life of transformers.

The preferred maximum voltage drop is calculated as follows:

Preferred maximum voltage drop = preferred % drop * volts

Preferred % drop = 3% for branch circuits, 3% for feeder circuits, and 5% total for branch with highest voltage drop and feeder circuits

Volts = voltage of circuit (typically 120 volts for 120/240 volt RTMC circuits)

When the voltage drop across an electrical circuit providing power to an ITS application exceeds the maximum recommended value, the designer may increase the size of the electrical conductors or increase the voltage of the circuit. When the size of electrical conductors are increased, the overall electrical resistance of the circuit will decrease, which results in a corresponding drop in the voltage lost across the circuit. Increasing the voltage at which electrical current is transmitted through the electric conductors will require use of a step-up transformer placed near the transformer or service drop and a step-down transformer placed near the ITS device location. MnDOT has a strong preference for increasing the size of the electrical conductors as opposed to using a step-up and step-down transformer, which is only used in extenuating circumstances and requires MnDOT approval.

Table 3-3 shows the maximum preferred amp load for a particular wire size and wire length carrying 120 volts and an unbalanced load. Table 3-4 shows the maximum preferred amp load for a particular wire size and wire length carrying 120/240 volts and a balanced load.

Table 3-2: Typical MnDOT ITS Device Power Requirements

Component(s)	Amp Load for Voltage Drop Calculations **	Notes
CABINET LOADS		
334 and 340 Cabinet	2.0	
Pole Cabinet with NID	0.5	
Pole Cabinet with video camera	1.5	
E-ZPass Reader with Beacon	1.0	
Shelter	2-P 35.0	includes 5 amp GFCI outlet
DMS *		
F8C1-20 / R8C1-20	5.0	32 x 112 pixel configuration
F8C2-20 / R8C2-20	10.0	64 x 112 pixel configuration
W18C3-20	2-P 18.0	96 x 240 pixel configuration
W18C4-20	2-P 21.0	128 x 240 pixel configuration
W24C3-20	2-P 22.0	96 x 336 pixel configuration
F14C1-20 / R14C1-20	10.0	32 x 208 pixel configuration
F14C2-20 / R14C2-20	16.5	64 x 208 pixel configuration
F14C3-20 / R14C3-20	2-P 13.5	96 x 208 pixel configuration
F18C1-20 / R18C1-20	11	32 x 256 pixel configuration
F18C2-20 / R18C2-20	2-P 11.0	64 x 256 pixel configuration
F18C3-20 / R18C3-20	2-P 15.5	96 x 256 pixel configuration
W30C3-20	2-P 29.0	96 x 432 pixel configuration
W30C4-20	2-P 35.0	128 x 432 pixel configuration
W40C3-20	2-P 40.0	96 x 592 pixel configuration
W40C4-20	2-P 50.0	128 x 592 pixel configuration

* - DMS feature description based on Ledstar model number

Model number - ABBCD-EE

A - W - walk-in access, F - front access, or R - rear access

BB - width in feet

C - color

D - # of rows of text

EE - pixel pitch (in millimeters)

** - 2-P ##.# is two-pole with ##.# amps per leg

Table 3-3: Maximum Preferred Amperage for 3% Voltage Drop with 120 Volts Unbalanced Load[1]

	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Wire Size (AWG)	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft
14	14.0	7.0	4.7	3.5	2.8	2.3	2.0	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9	0.9
12	20.0	11.1	7.4	5.6	4.4	3.7	3.2	2.8	2.5	2.2	2.0	1.9	1.7	1.6	1.5	1.4
10	30.0	17.6	11.8	8.8	7.1	5.9	5.0	4.4	3.9	3.5	3.2	2.9	2.7	2.5	2.4	2.2
8	45.0	28.1	18.8	14.1	11.3	9.4	8.0	7.0	6.3	5.6	5.1	4.7	4.3	4.0	3.8	3.5
6	65.0	43.9	29.3	22.0	17.6	14.6	12.5	11.0	9.8	8.8	8.0	7.3	6.8	6.3	5.9	5.5
4	85.0	69.2	46.2	34.6	27.7	23.1	19.8	17.3	15.4	13.8	12.6	11.5	10.7	9.9	9.2	8.7
3	100.0	85.7	57.1	42.9	34.3	28.6	24.5	21.4	19.0	17.1	15.6	14.3	13.2	12.2	11.4	10.7
2	115.0	112.5	75.0	56.3	45.0	37.5	32.1	28.1	25.0	22.5	20.5	18.8	17.3	16.1	15.0	14.1
1	130.0	130.0	92.3	69.2	55.4	46.2	39.6	34.6	30.8	27.7	25.2	23.1	21.3	19.8	18.5	17.3
0	150.0	150.0	120.0	90.0	72.0	60.0	51.4	45.0	40.0	36.0	32.7	30.0	27.7	25.7	24.0	22.5
00	175.0	175.0	150.0	112.5	90.0	75.0	64.3	56.3	50.0	45.0	40.9	37.5	34.6	32.1	30.0	28.1
000	200.0	200.0	200.0	150.0	120.0	100.0	85.7	75.0	66.7	60.0	54.5	50.0	46.2	42.9	40.0	37.5

	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600
Wire Size (AWG)	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft
14	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4
12	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7
10	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1
8	3.3	3.1	3.0	2.8	2.7	2.6	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.8
6	5.2	4.9	4.6	4.4	4.2	4.0	3.8	3.7	3.5	3.4	3.3	3.1	3.0	2.9	2.8	2.7
4	8.1	7.7	7.3	6.9	6.6	6.3	6.0	5.8	5.5	5.3	5.1	4.9	4.8	4.6	4.5	4.3
3	10.1	9.5	9.0	8.6	8.2	7.8	7.5	7.1	6.9	6.6	6.3	6.1	5.9	5.7	5.5	5.4
2	13.2	12.5	11.8	11.3	10.7	10.2	9.8	9.4	9.0	8.7	8.3	8.0	7.8	7.5	7.3	7.0
1	16.3	15.4	14.6	13.8	13.2	12.6	12.0	11.5	11.1	10.7	10.3	9.9	9.5	9.2	8.9	8.7
0	21.2	20.0	18.9	18.0	17.1	16.4	15.7	15.0	14.4	13.8	13.3	12.9	12.4	12.0	11.6	11.3
00	26.5	25.0	23.7	22.5	21.4	20.5	19.6	18.8	18.0	17.3	16.7	16.1	15.5	15.0	14.5	14.1
000	35.3	33.3	31.6	30.0	28.6	27.3	26.1	25.0	24.0	23.1	22.2	21.4	20.7	20.0	19.4	18.8

[1] Values in tables are based on copper conductors with wire characteristics listed in Table 3-1.

Table 3-4: Maximum Preferred Amperage for 3% Voltage Drop with 120/240 Volts Balanced Load[1]

	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Wire Size (AWG)	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft
14	15.0	14.0	9.3	7.0	5.6	4.7	4.0	3.5	3.1	2.8	2.5	2.3	2.2	2.0	1.9	1.8
12	20.0	20.0	14.8	11.1	8.9	7.4	6.3	5.6	4.9	4.4	4.0	3.7	3.4	3.2	3.0	2.8
10	30.0	30.0	23.5	17.6	14.1	11.8	10.1	8.8	7.8	7.1	6.4	5.9	5.4	5.0	4.7	4.4
8	45.0	45.0	37.5	28.1	22.5	18.8	16.1	14.1	12.5	11.3	10.2	9.4	8.7	8.0	7.5	7.0
6	65.0	65.0	58.5	43.9	35.1	29.3	25.1	22.0	19.5	17.6	16.0	14.6	13.5	12.5	11.7	11.0
4	85.0	85.0	85.0	69.2	55.4	46.2	39.6	34.6	30.8	27.7	25.2	23.1	21.3	19.8	18.5	17.3
3	100.0	100.0	100.0	85.7	68.6	57.1	49.0	42.9	38.1	34.3	31.2	28.6	26.4	24.5	22.9	21.4
2	115.0	115.0	115.0	112.5	90.0	75.0	64.3	56.3	50.0	45.0	40.9	37.5	34.6	32.1	30.0	28.1
1	130.0	130.0	130.0	130.0	110.8	92.3	79.1	69.2	61.5	55.4	50.3	46.2	42.6	39.6	36.9	34.6
0	150.0	150.0	150.0	150.0	144.0	120.0	102.9	90.0	80.0	72.0	65.5	60.0	55.4	51.4	48.0	45.0
00	175.0	175.0	175.0	175.0	175.0	150.0	128.6	112.5	100.0	90.0	81.8	75.0	69.2	64.3	60.0	56.3
000	200.0	200.0	200.0	200.0	200.0	200.0	171.4	150.0	133.3	120.0	109.1	100.0	92.3	85.7	80.0	75.0

	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600
Wire Size (AWG)	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft	Ft
14	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9
12	2.6	2.5	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4
10	4.2	3.9	3.7	3.5	3.4	3.2	3.1	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.2
8	6.6	6.3	5.9	5.6	5.4	5.1	4.9	4.7	4.5	4.3	4.2	4.0	3.9	3.8	3.6	3.5
6	10.3	9.8	9.2	8.8	8.4	8.0	7.6	7.3	7.0	6.8	6.5	6.3	6.1	5.9	5.7	5.5
4	16.3	15.4	14.6	13.8	13.2	12.6	12.0	11.5	11.1	10.7	10.3	9.9	9.5	9.2	8.9	8.7
3	20.2	19.0	18.0	17.1	16.3	15.6	14.9	14.3	13.7	13.2	12.7	12.2	11.8	11.4	11.1	10.7
2	26.5	25.0	23.7	22.5	21.4	20.5	19.6	18.8	18.0	17.3	16.7	16.1	15.5	15.0	14.5	14.1
1	32.6	30.8	29.1	27.7	26.4	25.2	24.1	23.1	22.2	21.3	20.5	19.8	19.1	18.5	17.9	17.3
0	42.4	40.0	37.9	36.0	34.3	32.7	31.3	30.0	28.8	27.7	26.7	25.7	24.8	24.0	23.2	22.5
00	52.9	50.0	47.4	45.0	42.9	40.9	39.1	37.5	36.0	34.6	33.3	32.1	31.0	30.0	29.0	28.1
000	70.6	66.7	63.2	60.0	57.1	54.5	52.2	50.0	48.0	46.2	44.4	42.9	41.4	40.0	38.7	37.5

BREAKER SIZING

Per the NEC, all electrical circuits require overcurrent protection. Circuit breakers help protect against excess current as the result of an overload or short-circuit. When the power reaches a certain level, the circuit breaker is designed to automatically interrupt the flow of power to prevent fires, damage to wiring or electronics, and personal electrocution. In order to function properly, the circuit breaker must be sized appropriately. To be sized appropriately, the circuit breaker should be designed to handle a minimum of 125% of the maximum continuous load and 100% of the non-continuous load. Continuous loads are loads that are expected to last three or more hours while non-continuous loads are those lasting less than three hours.

Circuit breakers typically used in service cabinets by MnDOT for ITS applications are noted below:

- 334 series cabinet: 30 amp single pole
- NID and/or camera with pole cabinet: 15 amp single pole
- Gate arm: 15 amp double pole
- 18' wide Ledstar DMS: 30 amp double pole
- 30' wide Ledstar DMS: 60 amp double pole
- 40' wide Ledstar DMS: 100 amp double pole

Main circuit breakers typically used in service cabinets:

- Standard service cabinet: 60 amp double pole main
- Service cabinet serving a shelter, a 40' DMS, or two 30' DMS: 100 amp double pole main

EXAMPLE CALCULATIONS

Several factors need to be considered when locating an ITS device including the source of power location and resulting conductor and conduit sizes required to serve the ITS devices at their required locations. If the cables become too large it is often desirable to obtain a source of power located closer to the site. Design of the power system required for an individual ITS location will generally follow the design steps and calculations outlined below.

1) Identify an available power source and determine its suitability to provide power to the proposed ITS site. Factors that impact suitability of the power source is whether it is located on MnDOT right-of-way and if the required voltage is able to be provided. The power source may be an existing electric service or require the installation of a new electric service.
2) The following needs to be determined for the feeder and branch circuits:
   - Current load required for each device
   - Combined current load of each circuit
   - Minimum conductor and circuit breaker size for the current load
   - Any increase in conductor size required to address excessive voltage drop

   Example (see Figure 3-7): If there is a service cabinet (metered) located just on MnDOT property that provides power to a service cabinet type special (non-metered) located 400 feet away where branch circuits serve a 334MP Control Cabinet (located 250' from service cabinet type special) and DMS (Ledstar model W30C4-20 located 200' from service cabinet type special), the following circuits need to be considered as a part of the design:

- Feeder circuit #1 is a 120/240 volt circuit that serves a main 2-pole circuit breaker in the service cabinet type special.
- Branch circuits from service cabinet type special are as follows:
    - Branch circuit #2 (DMS) is a 120/240 volt branch circuit that serves the DMS with a 2-pole circuit breaker located in the service cabinet type special
    - Branch circuit #3 (334MP Control Cabinet) is a 120 volt branch circuit that serves the 334MP Control Cabinet with a 1-pole circuit breaker located in the service cabinet type special

3) Determine the total current load required for the feeder circuit and each branch circuit including the cabinet, all internal equipment, and all ITS devices connected to the cabinet. Typical MnDOT ITS device current loads are included in Table 3-2.

   Using Table 3-2 the following are the current load required for the branch circuits:

   - Branch circuit #2 (DMS - Ledstar model W30C4-20): 35 amps on each leg
   - Branch circuit #3 (334 MP Control Cabinet): 2 amps (including all internal components)

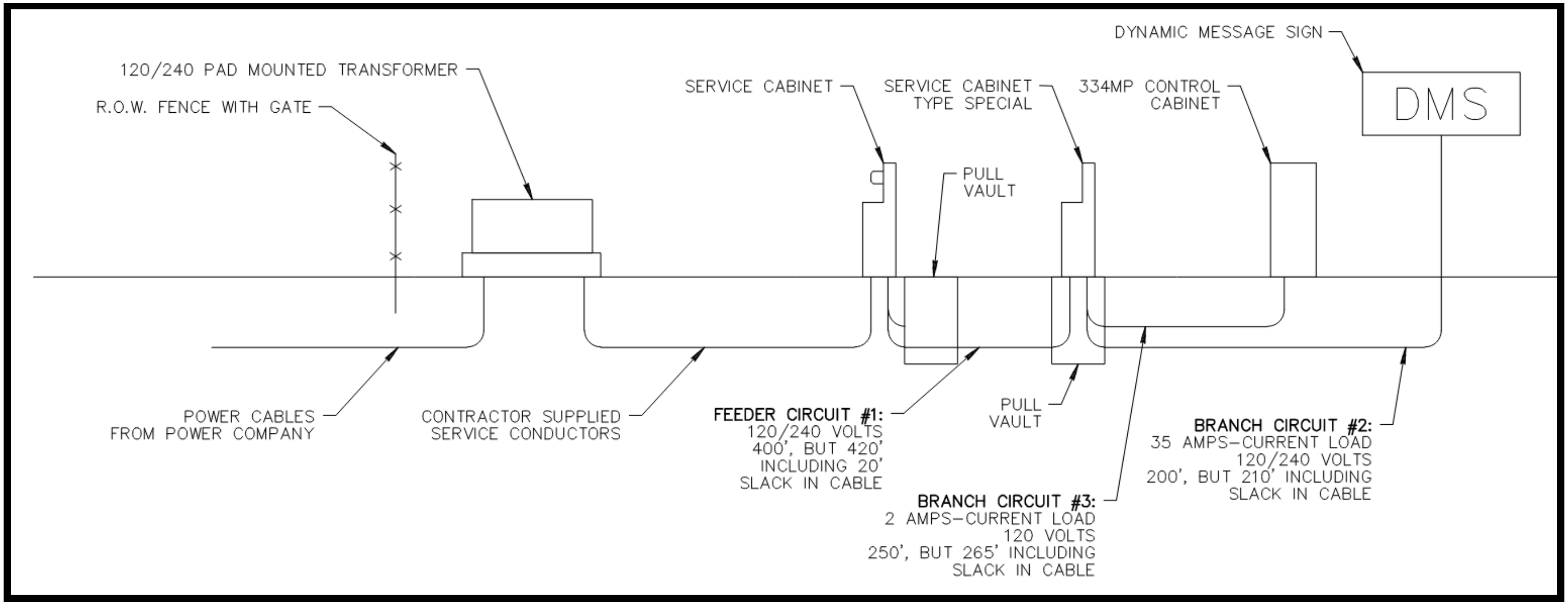
   Calculate the current required for an unbalanced 3-wire circuit (based on this example):

   - Feeder circuit #1 current load on highest current leg = current on branch circuit #2 + current on branch circuit #3
       - Feeder circuit #1 current load on highest current leg = 35 amps + 2 amps = 37 amps
   - Feeder circuit #1 current load on other leg = current on branch circuit #2
       - Feeder circuit #1 current load on other leg = 35 amps (the 2 amps from branch circuit #3 only is applied to 1 leg since branch circuit #3 is a 120 volt 2-wire circuit
   - Feeder circuit #1 current load on the neutral = current load on highest current leg – current load on other leg
       - Feeder circuit #1 current load on neutral = 37 amps - 35 amps = 2 amps

   For items not included in Table 3-2, the current load needs to be determined by contacting the manufacturer, reviewing product cut sheets, or taking actual measurements.

4) Calculate the voltage drop across the electrical conductors. If the voltage drop exceeds recommended values, the size of the electrical conductors should be increased.

Figure 3-7: Voltage Drop Example



Calculating the voltage drop and size the conductors to not exceed the maximum preferred voltage drop for the feeder and branch circuits as follows:

Branch circuit #2 (DMS):

Assume a #6 AWG wire initially (see Wire Gauge for minimum conductor size).

Voltage drop on highest current leg = 35 * [(210)/1000] * 0.41

Current load = 35 amps from step 3

Distance factor = Distance/1000

Distance = 200 feet so use 210 feet to account for slack

Resistance of wire = 0.41 from Table 3-1 using value for #6 AWG

Voltage drop on highest current leg = 3.01 volts

Voltage drop on neutral = 0 volts

Total voltage drop = 3.01 volts + 0 volts

Total Voltage drop = 3.01 volts

Does the voltage drop exceed the preferred maximum voltage drop?

Preferred maximum voltage drop = .03 * 120

Preferred % drop = 3% since this circuit is a branch circuit

Voltage of circuit = 120/240 volts for this DMS

Maximum preferred voltage drop = 3.60 volts

Since 3.0 is less than the maximum preferred voltage drop of 3.6, the #6 AWG wire size is adequate.

Branch circuit #3 (334 MP Control Cabinet):

Assume a #8 AWG wire initially (see Wire Gauge for minimum conductor size).

Voltage drop on highest current leg = 2 * [(265)/1000] * 0.64

Current load = 2 amps from step 3

Distance factor = Distance/1000

Distance = 250 feet so use 265 feet to account for slack

Resistance of wire = 0.64 from Table 3-1 using value for #8 AWG

Voltage drop on highest current leg = 0.34 volts

Voltage drop on neutral = 0.34 volts

Total voltage drop = 0.34 volts + 0.34 volts = 0.68 volts

Total Voltage drop = 0.68 volts

Does the voltage drop exceed the preferred maximum voltage drop?

Preferred maximum voltage drop = .03 * 120

Preferred % drop = 3% since this circuit is a branch circuit

Voltage of circuit = 120 volts for 334 MP Control Cabinet

Maximum preferred voltage drop = 3.60 volts

Since 0.68 is less than the maximum preferred voltage drop of 3.6, the #8 AWG wire is adequate.

Feeder Circuit #1 (feeder between service cabinet and service cabinet type special):

Assume a #6 AWG wire initially (see Wire Gauge for minimum conductor size).

Voltage drop on highest current leg = 37 * [(420)/1000] * 0.41

Current load = 37 amps from step 3

Distance factor = Distance/1000

Distance = 400 feet so use 420 feet to account for slack

Resistance of wire = 0.41 from Table 3-1 using value for #6 AWG

Voltage drop on highest current leg = 6.37 volts

Voltage drop on neutral = 2 * [(420)/1000] * 0.41

Current load = 2 amps from step 3

Distance factor = Distance/1000

Distance = 400 feet so use 420 feet to account for slack

Resistance of wire = 0.41 from Table 3-1 using value for #6 AWG

Voltage drop on neutral = 0.34 volts

Total voltage drop = 6.37 volts + 0.34 volts = 6.71 volts

Total Voltage drop = 6.71 volts

Does the voltage drop exceed the preferred maximum voltage drop?

Preferred maximum voltage drop = .03 * 120

Preferred % drop = 3% since this circuit is a feeder circuit

Voltage of circuit = 120 volts

Maximum preferred voltage drop = 3.60 volts

Increase the wire size to #2 AWG.

Voltage drop on highest current leg = 37 * [(420)/1000] * 0.16

All items remain the same except:

Resistance of wire = 0.16 from Table 3-1 using value for #4 AWG

Voltage drop on highest current leg = 2.49 volts

Voltage drop on neutral = 2 * [(420)/1000] * 0.16

Voltage drop on neutral = 0.13 volts

Total voltage drop = 2.49 volts + 0.13 volts = 2.62 volts

Total Voltage drop = 2.62 volts

Does the voltage drop exceed the preferred maximum voltage drop?

Since 2.62 volts is less than the maximum preferred voltage drops of 3.60, the #2 AWG wire is adequate.

Does the total voltage drop on Feeder Circuit #1 and Branch Circuit #2 exceed 5%?

2.62 volts + 3.01 volts = 5.63 volts

Since 5.63 volts < 0.05 * 120 volts = 6 volts the total voltage drop is okay.

Does the total voltage drop on Feeder Circuit #1 and Branch Circuit #3 exceed 5%?

2.62 volts + 0.68 volts = 3.30 volts

Since 3.30 volts < 0.05 * 120 volts = 6 volts the total voltage drop is okay.

The tables below present the current load and voltage drop calculated above for each of the circuits.

Circuit	Current Load (Amps)	Voltage Drop (Volts)
Feeder Circuit #1	**37.0**	**2.62**
Branch Circuit #2 (DMS)	**35.0**	**3.01**
	Total	**5.63**

Circuit	Current Load (Amps)	Voltage Drop (Volts)
Feeder Circuit #1	**37.0**	**2.62**
Branch Circuit #2 (DMS)	**2.0**	**0.68**
	Total	**3.30**

5) Determine the circuit breaker sizes for each circuit.

Select circuit breakers based on Breaker Sizing subsection:

Feeder Circuit #1 = 60 amp double pole since it is serving a standard service cabinet type special.

Branch circuit #2 (DMS) = 60 amp double pole since it is serving a 30’ wide DMS

Branch circuit #3 (334 MP Control Cabinet) = 30 amp single pole since it is serving a 334 series cabinet

Current loads on each circuit from step 3 above:

Feeder circuit #1 = 37 amps

Branch circuit #2 (DMS) = 35 amps

Branch circuit #3 (334 MP Control Cabinet) = 2 amps

Verify the current load on each circuit is less than the breaker rating:

Feeder circuit #1 - 37 amps * 125% = 46.3 amps < 60 amps

Branch circuit #2 (DMS) - 35 amps * 125% = 43.8 amps < 60 amps

Branch circuit #3 (334 MP Control Cabinet) - 2 amps * 125% = 2.5 amps < 30 amps

The current loads are multiplied by 125% because these particular loads are continuous loads.

Since all current loads are less than the circuit breaker sizes selected, the circuit breakers selected are acceptable.

6) Confirm the electrical conductors selected for each circuit in step 4 have a higher ampacity rating than the circuit breakers selected in Step 5.

Wire sizes from step 4:

Feeder circuit #1 = #2 AWG wire

Branch circuit #2 (DMS) = #6 AWG wire

Branch circuit #3 (334 MP Control Cabinet) = #8 AWG wire

Review Table 3-1 to obtain ampacity rating for the conductors used:

Feeder circuit #1 = 115 amps

Branch circuit #2 (DMS) = 65 amps

Branch circuit #3 (334 MP Control Cabinet) = 45 amps

Verify the ampacity is more than the breaker rating:

Feeder circuit #1 - 115 amps > 60 amps

Branch circuit #2 (DMS) - 65 amps > 60 amps

Branch circuit #3 (334 MP Control Cabinet) - 45 amps > 30 amps

Since the ampacity on all three circuits is greater than the breaker rating, the wire sizes selected are adequate.

If the ampacity is less than the circuit breaker rating, then the breaker rating needs to be reduced and/or the wire size needs to be increased.

The designer needs to verify the lugs of the circuit breaker used fit the size of the conductors being terminated at the lugs.

The calculations above show the manual voltage drop calculation process. Table 3-3 and Table 3-4 can also be used to determine the wire size for a particular conductor length and size for a circuit carrying 120 volts with an unbalanced load and 120/240 volts with a balanced load, respectively.

SURGE PROTECTION

Lightning strikes are the most common cause of power surges to the ITS field system. The resulting voltage surges can propagate long distances along the cable to the connected devices. In order to protect the related ITS deployment, appropriate surge protection measures must be provided for the ITS devices. These measures can be broken down into four components:

- Lightning rods at the top of or near the support structure
- Grounding system, usually consisting of one or more grounding rods
- Surge suppression hardware in the control cabinet
- Grounding conductor bonding the three above components

The provision of lightning rods is preferred for deployments involving great heights, such as video cameras and radio antenna at the top of tall poles that “stand out” among the surrounding landscape and vegetation. The use of lightning rods is usually omitted for deployments involving relatively low heights and where taller structures are present nearby.

In general, surge suppressors provide protection from energy (electric) surges by diverting and draining the excess (surge) energy to surrounding soil. It is therefore pertinent to combine the use of surge suppressors with a properly designed grounding conductor and grounding system. DMS, pole cabinets, and 334 series cabinets have digital surge suppressor units built in to protect against spikes.

The provision of one or more lightning rods over the ITS device, in conjunction with a grounding conductor(s), can often help to divert the lightning discharges away from the field device assembly. Lightning abatement measures such as this are only effective if the lightning rod, related terminations, and the grounding conductors are sufficiently robust to conduct and to survive lightning discharges.

Telecommunications cables and sensor cables from nearby locations, just like the utility power cable, are subject to the same possibility of lightning strikes. The requirement for appropriate surge protection measures must therefore be extended to all cables brought into the cabinet of all ITS deployments.

A proper grounding arrangement must be provided at the support structure and at the controller cabinet for the system. Where the controller cabinet is installed at or close to the base of the support structure, both the support structure and the cabinet may be bonded to the same grounding system.

It is important that the related grounding system is able to disperse the electric charge from the lightning strike quickly to the surrounding earth mass. This requirement is translated in the performance requirement on the grounding system to have “grounding resistance of 25 ohms or less.”

MnDOT uses two 5/8-inch, 15-foot, one-piece solid copper rods for grounding. When multiple rods are needed to achieve the required maximum ground resistance (25 ohms), space the ground rods at 6’ apart from each other or per NEC recommendations, whichever is greater.

Grounding rods, systems, and testing procedures are specified in the NEC. The designer should assess the site environmental conditions to determine if the grounding system identified in the 408 specifications is sufficient for the device location. Some devices require more robust grounding requirements, such as video cameras located at the tops of hills and mounted to high structures.

ITS systems usually include sensitive electronics located in an outdoor environment and mounted on metal poles. A lightning storm can cause the equipment to fail if it is not properly protected. Every control cabinet should have a quality, properly rated, solid state surge suppression device located where the power conductors terminate in the cabinet. In addition to the grounding required by the NEC at the service cabinet, the control cabinet should also have a grounding conductor going from its equipment ground bus to a ground rod. The ground rod may be the one used by the service cabinet or a different one if the cabinets are not co-located. If the system includes tall mounting poles and is not connected by metal conduit, the pole installation should also include a ground rod. Per the NEC, it is essential that all metal cabinets, poles, housings, conduits, etc. be connected into a properly bonded and grounded system. All communications and video field cables should have surge suppression at both ends where they enter a cabinet. Unfortunately, experience has shown that systems that are not properly grounded or protected from surges will not last long in the outdoor roadside environment.

High quality surge suppression is very important and typically costs $350-$400 per cabinet (good grounding is critical). Without surge suppression there can be a loss of equipment.

POWER OVER ETHERNET

Power over Ethernet (PoE) is an alternate method used to power a device or infrastructure using direct current over twisted-pair copper Ethernet cabling. PoE allows a single cable to transmit both data and power, eliminating the need for two separate cables. The Institute of Electrical and Electronics Engineers (IEEE) has developed a series of standards that define different types of PoE technology. Table 3-5 includes a list of different PoE standards and the maximum power than can be provided over the Ethernet cable.

Table 3-5: Power Over Ethernet Parameters

IEEE Standard	PoE Designation	Maximum Power (watts)	Maximum Transmission Distance (feet) [2]
802.3af 802.3af Type 1	PoE	15.4	250
802.3at Type 2	PoE+	30	250
802.3bt Type 3	PoE++	60	250
802.3bt Type 4	PoE++ (High Power)	100	250

Cat 5E twisted-pair copper cable used by MnDOT supports PoE. In order to utilize PoE, the switch port that the twisted-pair copper cable is connected to must also be capable of supporting PoE. Many wireless radios utilize PoE, as do a few different ITS devices including video cameras and vehicles detection. Pan-tilt-zoom (PTZ) cameras need PoE++ while static cameras use PoE+.

3.1.9. Alternative Energy Options

SOLAR

In remote rural areas, obtaining power from an electric service provider can be very expensive if there are no electrical facilities or infrastructure in the immediate area. For low-power ITS applications, and even a few higher-power applications, solar power may be an option. Solar power may be considered when obtaining power from a nearby electric service provider is not practical or is cost prohibitive. Solar

[2] Per the IEEE standard, the maximum transmission distance is 328 feet; however, MnDOT utilizes a maximum transmission distance of 250 feet for all PoE devices.

power can be versatile and is environmentally friendly, but several criteria should be evaluated when considering it as an option. When designing any ITS application that will utilize solar power, the design should be reviewed by an electrical engineer to ensure the system is sized appropriately. As an alternate to developing an individual design for the specific location, an off-the-shelf system may also be an option depending on the desired ITS application.

When designing an ITS device or system that will utilize solar power, several important factors should be considered. These factors include calculating the total power required by the system at any time of day, during any weather conditions, and during any month of the year; the frequency or percent of time that the system will be operational; the length of time the system must operate in the absence of any sunlight; and any terrain or vegetation that might impact operations today or in the future. Generally, when designing a solar power system for an ITS deployment, it is a good practice to overdesign the system to help counteract any unexpected weather conditions that might impact power generation. Another important consideration is the life-cycle replacement costs required to procure and install replacement batteries on average every three years.

During the winter months in Minnesota, the total hours of sunlight per day are limited, and there are often extended periods without sunlight that last multiple days. In these situations, the lack of available sunlight can severely impact the amount of power generated by solar cells and stored by the local batteries. These problems can be further exacerbated when snow and ice accumulate on the solar panels, further limiting their exposure to direct sunlight. Because of these limitations, solar is generally only used on a limited basis for low-power ITS applications (flashing beacons, blank-out signs, and some traffic detectors). Solar panels are more efficient at lower temperatures, but batteries typically lose capacity as the temperature drops. Off-the-shelf solar power systems are available for many low-powered ITS applications, which can save time and money in the design and installation process.

Certain ITS applications, including video cameras, may in limited situations be powered with solar but may have reduced up-time during the winter months and will require a lot more maintenance than a typical AC-powered system. The designer needs to design the solar array and battery system based on the design loads and anticipated weather conditions. ITS applications that utilize solar power should include remote monitoring capabilities to allow MnDOT to remotely check the status of the solar cells and batteries without having to wait until the system fails to perform a field visit.

WIND

Wind generated power is another option that can be used to provide power to an ITS device. Wind power should only be used when all other options for obtaining power have been exhausted, including obtaining power from an electric service provider or from solar. Due to the unpredictability and inconsistency of wind generated power, MnDOT does not consider it a reliable power source.

Similar to solar generated power, ITS applications that utilize wind power require batteries to store the power generated by the wind turbine for future use. Extended periods of no or little wind may result in a significant or complete draw down of available power stored in the batteries. During the winter months, colder temperatures can reduce overall battery capacity, which will further reduce the power available to operate the ITS device. Because of these limitations, wind power is generally only used as a last resort and should not be the primary power source for an ITS device. Wind power may, however, be used to complement another power source, such as solar, to provide a second, redundant source of power generation. Wind power generation typically requires infrastructure that has numerous moving parts. These moving parts require continuous maintenance, which increases the cost and staff time required to keep the system fully operational, especially when combined with battery maintenance and/or life-cycle replacement.

When designing a wind power system for an ITS deployment, it is good practice to overdesign the system to help counteract the impacts of a drawdown of power during extended periods of no or little wind. Wind turbines typically generate more power the higher they are mounted, which can create additional maintenance challenges. Off-the-shelf systems for wind power generation are available and, with MnDOT approval, may be considered when providing wind generated power to an ITS device.

BATTERIES

ITS applications that utilize solar and/or wind turbines to generate power will require an array of batteries connected to the power generation system in order to capture and store power for future use. The total number of batteries required for an individual ITS application will vary depending on the power required to operate the ITS application, the number and type of batteries utilized, the duration of time the ITS application will need to remain fully functional under 100% battery power, the ambient temperature and battery correction factor, the age of the battery, and the depth and duration of battery discharge cycles. MnDOT typically utilizes 100A-hour lead acid batteries for power storage. When selecting and designing an ITS application that will require battery power storage, the designer should consider long term battery maintenance costs and life cycle replacement. The estimated life of a typical 100A-hour battery will vary but, on average, MnDOT has observed an average lifespan of three years. Trailers use 6V batteries in a 12V array and static equipment uses 12V batteries in a 24V array.

BACKUP POWER

ITS applications and network communications equipment that support critical MnDOT functions or life safety services may require that a backup power system be included in the design. There are a few different technologies and systems used by MnDOT to provide backup power including diesel and propane generators and uninterruptable power supplies (UPS). Selecting the type of backup power system will vary depending on the type of ITS application and/or network communications being powered. Sizing the backup power system will utilize many of the same design parameters outlined in the prior section for sizing a battery system. The designer needs to be aware that certain proposed ITS applications or network equipment will require backup power, they should consult with the MnDOT project manager.

3.2. Communications

Communication protocols for ITS are being developed under the National Transportation Communications for ITS Protocol (NTCIP) standards development effort. These are open (non-proprietary), industry-based standards that make it possible for ITS devices from multiple vendors to exchange information — both with each other and with a central system — through a common communications interface. There are many NTCIP standards, each relating to one or more ITS applications.

3.2.1. Types

SERIAL

Many older ITS devices, and some new ITS devices, utilize serial communications. Serial communications can be either uni- or bi-directional and transmit one communication bit at a time. Some ITS devices utilize serial communications but can be connected via an Ethernet cable when a serial to Ethernet converter is used. Detector cards used by MnDOT in some traffic signal and ITS cabinets utilize serial communications. Additionally, the Wavetronix vehicle detector used by MnDOT utilizes a serial to Ethernet converter. ITS devices that utilize serial communications typically use communication cables that include a number of different types of connectors including RS-232, RS-422, and RS-485.

TRANSMISSION CONTROL PROTOCOL (TCP)/INTERNET PROTOCOL (IP)

All new ITS devices installed by MnDOT are connected to the statewide communications network using TCP/IP communications. TCP/IP or Transmission Control Protocol/Internet Protocol is a series of communications protocols used to connect devices on a network. TCP/IP governs how the data is exchanged. It also includes information on how that data is to be broken up into smaller packets and how that data should be addressed, transmitted, and routed through the network to its destination. Each ITS device on the network is then assigned a specific IP address.

3.2.2. Network Topology

Network topology is the general relationship between devices and how data flows throughout the network.

PHYSICAL

The physical network layer, often referred to as Layer 1, includes physical network hardware (hub, repeater, media converter, etc.) and communications cables that have no knowledge of the data bytes or frames being transmitted. Data in a Layer 1 network is transmitted to all hardware ports and across all communications cables.

LOGISTICAL

Beyond the physical network layer, more advanced networks utilize Layer 2 and Layer 3 technology. Layer 2, often referred to as the data link layer, provides direct data transfer between two devices within a network. Layer 2 communications utilize Media Access Control (MAC). Layer 3, often referred to as the network layer, includes the addition of network routing. MnDOT uses a private Layer 3 network within the 10.0.0.0 – 10.255.255.255 IP address range.

The following sections are isolated instances of common topologies; however, topologies are typically combined to develop the actual network. The pros, cons, and typical application by MnDOT of each topology reviewed is provided in Table 3-6.

Point to Point

Point to point is the simplest topology and is simply two points connected with a direct connection (see Figure 3-8). Point to point is of limited use in larger installations as it is non-redundant and only connects two points.

Figure 3-8: Point to Point Topology Schematic

Daisy Chain

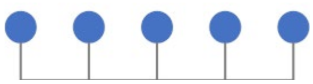
Daisy chain is a type of topology that involves chaining of point to point networks to connect additional devices. In a daisy chained network, all devices except the end devices pass communications along to the next device until the information gets to the intended recipient (see Figure 3-9). Daisy chains are non-redundant and fairly simple.

Figure 3-9: Daisy Chain Topology Schematic

Multi-Drop

Multi-drop is similar to a daisy chain that MnDOT used in twisted pair communications, except that all devices communicate on a common line (see Figure 3-10). Multi-drop systems require a method to address collisions as multiple devices are attempting to "talk" at the same time. Multi-drop has been used on MnDOT ITS systems but is not being used going forward in favor of topologies that support Ethernet – TCP/IP communications.

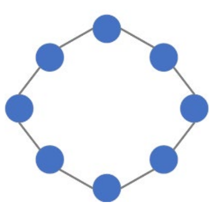
Figure 3-10: Multi-Drop Topology Schematic



Ring

Ring topology is similar to a daisy chain except the ends are connected back either through a loop back or both ends being connected to a router (see Figure 3-11). Rings are redundant; when a device or link is disabled working devices are kept online. When a ring is "broken," it becomes two daisy chains. A ring is only redundant for a single failure. A second failure isolates devices between the breaks.

Figure 3-11: Ring Topology Schematic

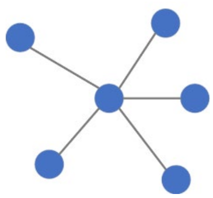


Star

A star topology consists of one central device being connected to multiple other devices by a direct connection (see Figure 3-12). A star is non-redundant; however, when an outage occurs, only devices on that leg of a star are affected. For MnDOT systems, only one or two devices are placed on a leg of the star so that the impact is limited if an outage occurs. A star requires less cable as only one line is required for outlying devices.

MnDOT most often applies a star topology for clusters of nearby devices. The center device may be placed in a ring and other individual devices are connected to that device. This limits risk since the entire ring is not impacted if an outage occurs. However, this physical layout of a star does not work well with the physical layout of a linear highway ITS system.

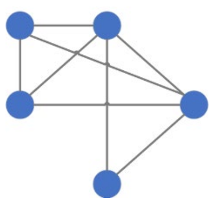
Figure 3-12: Star Topology Schematic



Multi-Point/Mesh

A multi-point topology consists of devices that have multiple connections to many other devices (see Figure 3-13). Multi-point topology is common in newer wireless devices to allow redundancy if a device becomes unavailable. This is also how the RTMCnet backbone is configured with routers being connected to multiple other routers. Multi-point is the most redundant topology as each connection has multiple redundant paths; however, it requires multiple connections to each device and is impractical for field devices on fiber optic communications in an ITS system.

Figure 3-13: Multi-Point Topology Schematic



Cloud

Using the "cloud" is not a topology in the same sense as the others discussed, but for the ITS designer it can be thought of in a similar manner. Using the cloud through either a wired or wireless internet service provider allows communication back to the ATMS or another device through the internet (see Figure 3-14). Cloud based connections allow for a connection where there is no existing owned infrastructure; however, it does place reliance on a third party to maintain the connection. In addition, there are recurring costs for the connection in the form of a monthly service fee. Many connections are also limited in available bandwidth. It works well for small clusters of isolated devices, or as a temporary connection.

Figure 3-14: Cloud Topology Schematic

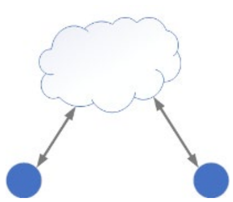
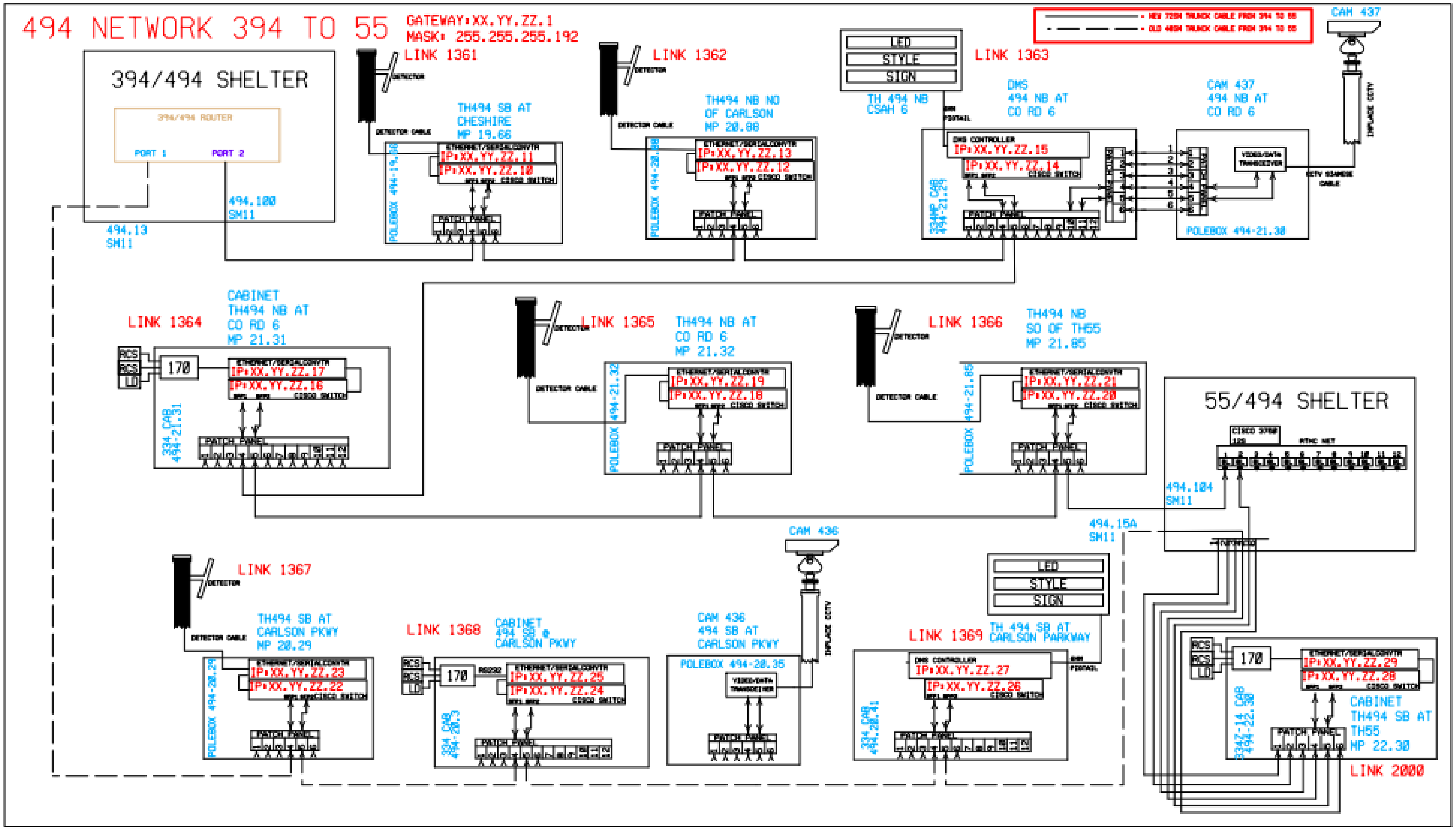


Table 3-6: Comparison of Common Communication Topologies

Topology	Pros	Cons	MnDOT Example Uses
Point to Point	Simple	No redundancy, only 2 devices connected	Point to point wireless
Daisy Chain	Simple	No redundancy can have bandwidth issues	Rarely used due to lack of redundancy
Multi-Drop	Allows for devices to be off line without disabling the network	Lower bandwidth, not compatible with Ethernet	Optelecom serial modems (no longer used for new installations)
Ring	Redundant as one device going off line allows communication in the other direction	Rings are limited in size due to spanning tree issues in the deployment MnDOT uses	Most MnDOT field network is deployed using rings
Star	Fairly simple	No redundancy, but impacts of an outage are limited	Deployed at interchanges and other clusters of devices
Multi-point	Highly redundant	Requires lots of ports and independent connections	RTMCnet Backbone
Cloud	Accommodates lack of owned communications infrastructure	Lower bandwidth than typical fiber connection, monthly fee, reliant on ISP	Used to bring small isolated networks or devices back to the ATMS. Also useful for temporary communications.

Figure 3-15 shows a network drawing of a common MnDOT network configuration. The network drawings can be obtained using Django. The network in the figure shows both ring and star typologies being utilized.

Figure 3-15: Network Diagram



3.2.3. Technologies

COPPER

Although MnDOT does not typically install new copper communications for long range, twisted pair copper is still used by MnDOT to communicate with some legacy devices in the field. MnDOT also uses CAT 6 copper Ethernet cables to communicate over very short distances, such as between cabinets on a common foundation to a video camera at the top of a fold-down pole. In the past, MnDOT has used six-pair 19 gauge and 12-pair 19 gauge twisted pair copper communications. New twisted pair copper communications are typically only installed at locations where existing copper communications are currently being used and upgrading to newer communications technologies or communications medium is impractical and/or cost prohibitive. There are a number of different copper communications protocols including RS-232, RS-422, and RS-485 or VDSL. Characteristics of these communications protocols are noted in Table 3-7.

Table 3-7: Serial Communications Protocol Characteristics

Protocol	Cabling	Comm. Mode	Susceptibility to Noise	Maximum Transmission Distance	Maximum Transmission Rate
RS-232	Single-ended	Full Duplex	High	50 feet @ 9.6K bps	19.2Kbps @ 50 feet
RS-422	Single-ended, Multi-drop	Full/Half Duplex	Low	4,000 feet @ 9.6K bps	10Mbps @ 50 feet
RS-485	Multi-Drop	Full/Half Duplex	Low	4,000 feet @ 9.6K bps	10Mbps @ 50 feet

FIBER

All new trunk fiber optic communications installed by MnDOT are single-mode fiber optic cables. In the past, MnDOT has used multi-mode fiber optic cable. There are several locations in the field where MnDOT is still using legacy multi-mode fiber optic communications. All MnDOT fiber optic cable assemblies for fiber optic cable shall comply with USDA RUS CFR 1755.900 (Specification for Filled Fiber Optic Cables) (https://www.govinfo.gov/content/pkg/FR-1994-07-05/pdf/FR-1994-07-05.pdf). The designer should refer to the MnDOT Approved Products List for approved fiber optic cable.

ETHERNET

IEEE 802 Ethernet is a standard communications protocol, or set of rules, used for connecting devices in a Local Area Network (LAN). Many ITS devices and infrastructure used in traffic signal and freeway management systems utilize Ethernet communications. These devices and equipment often include Ethernet ports and are connected using Ethernet cables. Ethernet ports allows a direct connection to a device or piece of equipment without the need for a protocol converter (i.e., serial to Ethernet). It is important to note that many legacy ITS devices and equipment used by MnDOT, as well as some new devices, still require the use of some sort of converter. Most new MnDOT ITS designs utilize Ethernet communications over a ring style network topology, while routers within MnDOT shelters utilize a mesh style network topology. The maximum allowable transmission distance for Ethernet cables is 300 feet. The designer should ensure all network equipment used is field-hardened when not installed in a climate-controlled environment. MnDOT shelters are climate-controlled environments (see Section 3.5 for more information on shelters).

WIRELESS – SERIAL AND IP

Unlicensed Spread-Spectrum Radio

Spread-spectrum radio wireless communications are commonly used for ITS applications because they are often cost effective when compared with wired communications. Radios using spread-spectrum wireless communications do not require Federal Communications Commission (FCC) paperwork and/or licensing to deploy, which allows them to be easily and quickly installed.

With spread-spectrum wireless communications, the designer must perform a site survey to examine the line of sight between each radio pair. If the site survey is done in the winter, conditions are liable to change in the spring when foliage returns to trees. The designer should be careful to consider things that are likely to change in the future, like annual growth of trees and/or places where new buildings or infrastructure could be built in the line of site between radios. One additional consideration for spread-spectrum wireless communications is Radio Frequency Interference (RFI). As the number of wireless devices exponentially increases over time, the area in which the wireless devices are installed may be competing with various other sources of 'noise' that will diminish the communication capabilities.

Licensed Wireless Radio

In some scenarios, the RFI in an area may be so severe that licensed wireless radio communications are required in lieu of standard spread-spectrum radios. Licensed wireless communications are generally reserved for use on backhaul links, over long-distance, or on communications links that require a large amount of bandwidth. The advantage of a licensed wireless radio is that for the particular frequency (or frequencies) used, the spectrum must be licensed for a limited use in the area in which the device will be operating. This prevents other wireless radios from operating on the same frequency and limits the amount of RFI. Licensed wireless communications are part of an evolving field with multiple competing technologies. ITS devices currently used by MnDOT that qualify as licensed wireless radios include Dedicated Short Range Communications (DSRC) and tolling antennas. If either of these devices are proposed on a project, the designer will need to follow the FCC Part 90 filing process (47 CFR Part 90 – Land Mobile Radio Service).

CELLULAR

In many places, especially in rural areas, point-to-point wireless communications infrastructure may not be feasible. In these situations, cellular communications may be utilized to provide connectivity to ITS devices without having to deploy an extensive communications network. Current cellular technology relies mostly on Evolution-Data Optimized (EVDO), High Speed Packet Access (HSPA), Evolved High Speed Packet Access (HSPA+), and Long-Term Evolution (LTE) technologies to deliver download speeds of up to 50 Megabits per second (Mbps) and upload speeds up to 20 Mbps. Cellular coverage may not be available in some areas of Minnesota and will vary by cellular carrier. Another possible limitation to cellular communications is data usage caps set in place by carriers, which can limit applications that can use cellular communications technology (e.g., video streaming, large data drops, etc.).

NTCIP 1218

NTCIP 1218 is a new communication protocol that specifies the logical interface between a roadside unit (RSU) and the controlling management stations. NTCIP 1218 defines information that may be exchanged across this interface. NTCIP 1218 first identifies the relevant RSU users and their needs, defines requirements that enable information exchanges that supports those needs, and finally defines the data objects and meta-data, including the relative structure of that data, necessary to meet these requirements. This communication protocol will be used for vehicles to connect to the RSU and includes cellular vehicle-to-everything (C-V2X).

3.2.4. Industrial Field Equipment

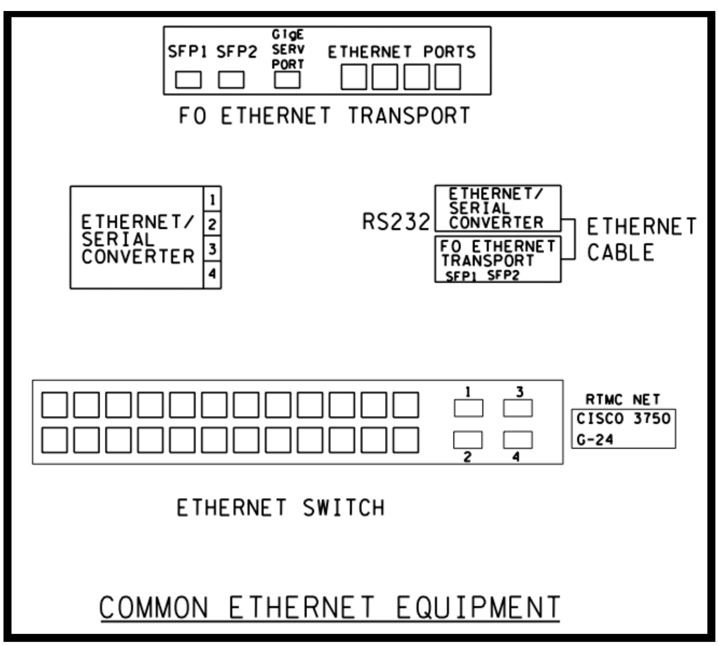
AMBIENT TEMPERATURE

The operating ambient temperature range shall be from -34°C (-30°F) to +74°C (+165°F). The storage temperature range shall be from -45°C (-50°F) to +85°C (+185°F). The rate of change in ambient temperature shall not exceed 17°C (30°F) per hour, during which the relative humidity shall not exceed 95 percent.

ETHERNET SWITCHES

Ethernet switches are used in wired networks to connect devices located on that network. MnDOT uses field hardened Ethernet switches in ITS and traffic signal cabinets to connect one or more IP addressable devices located inside or connected to the cabinet. A field hardened Ethernet switch is designed to withstand the extreme weather conditions often found in unconditioned environments, similar to that of an ITS or traffic signal cabinet. Ethernet switches are a State-provided item. Figure 3-16 shows common ethernet equipment that is used in MnDOT control cabinets. The number of SFP points in the FO ethernet transport depends on the number of pigtails being terminated in the cabinet (e.g. whether the daisy-chaining method is being used).

Figure 3-16: Common Ethernet Equipment



WEB RELAYS

Web relays are increasingly being utilized by MnDOT as part of newer ITS deployments. The purpose of a web relay is to provide a remotely accessible web interface that can be used to remotely reboot or power cycle the ITS device. In certain scenarios, rebooting an ITS device that is malfunctioning or that is locked-up may restore functionality to the device. By remotely resolving the issue, MnDOT is able to reduce maintenance costs and the staff time required for site visits and field maintenance. Web relays are standard in rural areas given the initial investment in the relay device is often minimal when compared with the potential costs associated with multiple field visits required to maintain the device.

3.2.5. Communications Design Considerations

Generally, the key design considerations for Center-to-Field (C2F) communications system for an ITS deployment are:

- Determine the required communications characteristics, mainly the required bandwidth (in Kbps or Mbps)
- Investigate what telecommunication options are available at/near the planned deployment site(s)
- Coordinate with the District to ensure that their requirements are being met
- If using public infrastructure, confirm with telecommunication service providers that the required communications service is available at the deployment location
- Compare the related costs, benefits, and security aspects of different communications methods and select the communication method for the site
- Incorporate the chosen communication method into the overall design
- Communications routed through the public World Wide Web must be approved by the RTMC

3.3. Conduit

3.3.1. Types

MnDOT utilizes a number of different conduit types and sizes for ITS related applications. The type and size of conduit is dependent on the specific location and case for which the conduit will be installed. The following list includes different types of conduit used by MnDOT:

- Rigid Steel Conduit (RSC) – MnDOT Specification 3801
- Intermediate Metal Conduit – MnDOT Specification 3802
- Non-metallic Conduit (NMC) – MnDOT Specification 3803
  - High-Density Polyethylene (HDPE) Conduit
  - Poly Vinyl Chloride (PVC) Conduit
- Liquid Tight Flexible Non-Metallic Conduit – MnDOT Specification 3804
- PVC Coated Hot Dipped Galvanized Rigid Steel Conduit – MnDOT Specification 3805

For most underground applications, Schedule 40 NMC satisfies the specifications. For above ground (i.e. exposed) or under roadway applications, MnDOT utilizes Schedule 80 NMC as the standard. MnDOT also uses RSC for above ground applications. MnDOT uses PVC Coated Hot Dipped Galvanized Rigid Steel Conduit when attaching the conduit to a bridge structure. The designer should review the individual specifications and dimensions for each conduit type to make sure it meets the requirements of the particular application and the cables that will be installed inside it. The designer should include a locate conductor in the conduit whenever an empty non-metallic conduit will be used for future purposes so that it can be easily located. For conduit under railroad, the designer should use Schedule 80 or as specified by the railroad authority.

3.3.2. Conduit Fill Ratio

Per the NEC, for conduits with three or more conductors, the total cross-sectional area of all enclosed wires must be less than 40% of the actual cross-sectional area of the conduit. Therefore, the maximum conduit fill ratio for all MnDOT power and communications conduit should not exceed 40% of the cross-sectional area of the conduit. An example conduit fill calculation spreadsheet is included in Table 3-8 that determines the minimum conduit diameter by type (RSC or NMC) based on the total number of wires/cables of each type to be included in a conduit. The maximum fill requirements are primarily driven by NEC standards and the need to provide a means of dissipating the heat produced by power cables inside a conduit. Refer to Table 3-9 for conduit dimensions. Calculations included in Table 3-8 are based on the conduit dimensions provided in Table 3-9.

Table 3-8: Example Conduit Fill Calculations

Total # of Wires/Cables	Type of Wire/Cable	Wire/Cable Diameter (inches)	Wire/Cable Cross-Sectional Area (sq. in.)	Total Cross-Sectional Area (sq. in.)
16	2/C No. 14	0.36	0.10174	1.6278
	3/C No. 8	0.67	0.35239	
	3/C No. 20	0.30	0.07065	
	3/C No. 12	0.46	0.16611	
1	3/C No. 14	0.40	0.12560	0.1256
	4/C No. 14	0.45	0.15896	
	4/C No. 18	0.33	0.08549	
	5/C No. 12	0.59	0.27339	
	5/C No. 14	0.48	0.18095	
2	6/C No. 14	0.53	0.22051	0.4410
	12/C No. 12	0.79	0.48992	
	12/C No. 14	0.71	0.39572	
	6PR No. 19	0.55	0.23746	
	FO cable	0.91	0.65037	
	Micro fiber	0.26	0.05309	
	Cat 6	0.27	0.05725	
	No. 3/0	0.67	0.35239	
	No. 2/0	0.59	0.27326	
	No. 1/0	0.55	0.23746	
	No. 1	0.51	0.20418	
	No. 2	0.43	0.14515	
	No. 4	0.35	0.09616	

Total # of Wires/Cables	Type of Wire/Cable	Wire/Cable Diameter (inches)	Wire/Cable Cross-Sectional Area (sq. in.)	Total Cross-Sectional Area (sq. in.)
	No. 6	0.30	0.07065	
	No. 6 Bare	0.16	0.02010	
	No. 8	0.28	0.06154	
	No. 10	0.20	0.03140	
			Total	2.1944

Minimum RSC conduit size = 3.0” diameter

Minimum NMC conduit size = 3.0” diameter

STANDARD CABLES

Table 3-8 above includes the dimensions for various cables used by MnDOT for ITS device installations. The standard types of the communications and power cables used for MnDOT ITS devices are noted below:

- DMS: Micro Fiber Optic Pigtail Cable (6MM) and power cables (size varies)
- Video camera: Armored Fiber Optic Pigtail Cable (6SM) and power cables (size varies)
- NID: Armored Fiber Optic Pigtail Cable (6SM) and power cables (size varies)
- Ramp Meter: 6/C No. 14
- Loop Detector: 2/C No. 14
- E-ZPass Toll Reader: Coax Cable LMR 600

Over the past several years, MnDOT has experienced numerous instances of water freezing and expanding inside a conduit that has resulted in damaged conduit and crushed fiber optic cables. The designer should consult MnDOT for input on the desired fiber installation method to reduce the likelihood of this occurring.

Power and fiber cables should be installed in separate conduits except in extreme or unique circumstances. In these circumstances and with MnDOT approval, power and fiber cables may be combined. No conductors besides power company conductors are allowed on the power company side of the service equipment.

3.3.3. Dimensions

Table 3-9 and Table 3-10 shows the dimensions of different types of conduit used by MnDOT for ITS related applications. For new underground construction, schedule 80 PVC or HDPE should be used. Although 4-inch conduit can be used, MnDOT typically uses a maximum conduit size of 3 inches. If 3-inch conduit is not large enough for the power or communications cables, additional 3-inch conduits may be utilized. The standard conduit size used for power cables is 2-inch NMC. When fiber optic cable will be used and installed by blowing the fiber through the conduit, MnDOT uses 1.5-inch NMC as the standard, although 1.25-inch NMC may sometimes be used. For aboveground conduit connecting underground conduit to a pole cabinet, schedule 80 PVC or RSC should be used.

Table 3-9: Typical Conduit Dimension for Rigid Steel Conduit (RSC)

Trade Size (In.)	Inside Diameter (in.)	Total Area (sq. in.)	40% Area (sq. in.)
1/2	0.632	0.314	0.125
3/4	0.836	0.549	0.219
1	1.063	0.887	0.355
1-1/2	1.624	2.070	0.828
2	2.083	3.406	1.362
2-1/2	2.489	4.863	1.945
3	3.090	7.495	2.998
4	4.050	12.876	5.150
5	5.073	20.202	8.081

Table 3-10: Typical Conduit Dimension for Schedule 80 PVC and Schedule 80 HDPE (NMC)

Trade Size (In.)	Inside Diameter (in.)	Total Area (sq. in.)	40% Area (sq. in.)
1/2	0.526	0.217	0.087
3/4	0.722	0.409	0.164
1	0.936	0.688	0.275
1-1/2	1.476	1.710	0.684
2	1.913	2.873	1.149
2-1/2	2.290	4.117	1.647
3	2.864	6.439	2.576
4	3.786	11.252	4.501
5	4.768	17.846	7.138

3.3.4. Bridge Conduit

Whenever possible, MnDOT's preference is to avoid installing power or communications conduit on bridge structures. This preference is due to the additional coordination and design challenges incurred when attaching conduit to a bridge structure. There are situations where attaching a conduit to a bridge structure cannot be avoided. In these situations, the following detail should be referenced:

Hanger Bracket Detail:
http://www.dot.state.mn.us/rtmc/pdfdgn_design/cab/CONDUIT%20HANGER%20BRACKET_dt1.pdf

The designer needs to consider the appropriate number of expansion and deflection fittings required to accommodate the expansion and contraction rates of both the conduit and bridge. An adequate number of hanger brackets must be included to ensure maximum allowable conduit deflection rates are not exceeded.

3.3.5. Boring

The designer should identify on the plans all locations where boring will be required to place the conduit, including below roadways, ponds, slope paving, and storm sewer. All bores under roadways must be at a 60" minimum depth, and this depth may need to be increased to not interfere with existing infrastructure such as storm sewer pipes or gas mains. The bore depth should be called out on the plan sheets if this will be required at a particular location.

3.3.6. Innerduct

Innerduct is not typically used by MnDOT for ITS applications, although MnDOT does use innerduct when installing fiber optic cables within inplace rigid steel conduits such as under railroads or on/within bridges.

3.3.7. Pull Tape

Pull tape should be specified in the plans whenever it is to be included with the conduit installation. Pull tape should also be included with the conduit installation when MnDOT is to install the communications cable after contractor installation of the conduit or when the electric service provider will install the power conductors after contractor installation of the conduit. Pull tape should be called out in the plan as flat nylon, as rope tends to cut into non-metallic conduit.

3.3.8. Warning Tape

Warning tape shall be included with all conduit installations containing fiber optic cables, with the exception of bored conduits, as described in Division SZ. Warning tape should be 3.15 inches (80mm) wide, stretchable, orange in color, and bear a permanent legend that states "CAUTION: MnDOT CABLE BELOW".

3.3.9. Warning Markers

Installation of buried fiber optic trunk lines require that buried cable signs with an orange plastic sheath are included in the design along the conduit route to adequately delineate the conduit path. The designer should include the buried cable sign placement detail linked below in the plans.

Buried Cable Sign Placement Detail: http://www.dot.state.mn.us/rtmc/pdfdgn_design/fiber/New-2020-05-19/BURIED%20CABLE%20SIGNING_dt1.pdf

Vault Protector Marker Posts (State-provided) also need to be installed at all fiber optic splice vaults and fiber optic pull vaults at splicing locations. The Vault Protector Marker Post is shown in the "Fiber Optic Splice Vault Installation Detail" and the "Fiber Optic Pull Vault at Splicing Locations Installation Detail."

3.3.10. Future Needs

When designing conduit for ITS applications, the designer should consider the need to install additional power or communications cables in the future. If future power or communications cables will likely be needed, additional space should be provided in the conduit to accommodate these additional cables without exceeding the maximum conduit fill ratio. If the future cables to be installed exceed the maximum fill capacity of the conduit, a larger size conduit should be used.

3.4. Conduit Access

3.4.1. Pull Vaults

Pull vaults are the current standard used by MnDOT and perform several important functions:

- Provide drainage for the conduit system to prevent freezing water from damaging the conduit and/or cables
- Provide a location for bending the conduit run without damaging the cables
- Provide a junction for conduits coming from different directions
- Facilitate pulling cables over long distances
- Provide access to the system for maintenance

MnDOT has utilized a number of different types of handhole standards over the years for ITS applications, so much of MnDOT's existing ITS infrastructure still includes handholes. As previously noted, pull vaults are the current MnDOT standard for all new ITS applications. The standard pull vault installation detail is shown at the link below (each pull vault installation shall include a pull vault extension).

Pull Vault Installation Detail: http://www.dot.state.mn.us/rtmc/pdfdgn_design/cab/NEW-2020-05-19/PULL%20VAULT%20INSTALL_dt1.pdf

MnDOT's standard is to splice fiber optic cables within a splice vault, but on a case-by-case basis splicing may be approved within a pull vault. If fiber splicing is requested and approved by the RTMC to take place in a pull vault, the standard pull vault installation detail is shown in the link below. If there is only one fiber pigtail that needs to connect to the trunk fiber, the designer may use a pull vault with a splice enclosure as permitted by the RTMC. If more than one fiber pigtail is needed, the designer must use a splice vault.

Fiber Optic Pull Vault at Splicing Locations Installation Detail:
http://www.dot.state.mn.us/rtmc/pdfdgn_design/fiber/New-2020-05-19/PULL%20VAULT%20WITH%20SPLICING_dt1.pdf

For non-fiber optic cable runs, the maximum pull vault spacing used by MnDOT is 350 feet. The designer may use their judgment for final spacing determination. For instance, if there is a 400-foot conduit run from the controller cabinet and a ramp meter, an intermediate pull vault could be omitted. For fiber optic cable runs, the maximum pull vault spacing used by MnDOT is 600 feet. For lengths of fiber optic cable over 600 feet, the cable must be blown instead of pulled. The maximum pull vault spacing used by MnDOT for blown fiber is approximately 6,000 feet. When locating conduit runs and pull vaults, the designer should consider the total number of conduits entering and exiting the pull vault. Whenever possible, the designer should make sure that no more than six conduits enter/exit an individual pull vault as it becomes increasingly challenging to maintain and reduces the likelihood the pull vault could be used to connect a new conduit as part of a future project. Additionally, pull vaults that include fiber splicing require a drain from the pull vault to prevent damage to the fiber and permit maintenance that is included in the Standard Splicing Pull Vault Installation Detail discussed above. Pull vaults should not be located in wet areas (i.e., ditch bottoms).

3.4.2. Splice Vaults

Splice vaults are typically installed at junction points along a fiber trunk line or where ITS infrastructure must be connected to the trunk line to route communications back to a central location. In rural areas where there are fewer junction points and ITS devices, there is reduced need for splice vaults. In these areas, splice vaults should be placed a maximum of approximately 6,000 feet apart. Splice vaults should not be located in wet areas (i.e., ditch bottoms).

If there is only one fiber pigtail that needs to connect to the trunk fiber, the designer may use a pull vault with a splice enclosure as permitted by the RTMC. If more than one fiber pigtail is needed, the designer must use a splice vault. The standard splice vault installation detail is shown at the link below.

Standard Splice Vault Installation Detail: http://www.dot.state.mn.us/rtmc/pdfdgn_design/fiber/New-2020-05-19/FO%20SPLICE%20VAULT%20INSTALLATION_dt1.pdf

3.5. Equipment and Service Cabinets and Shelters

3.5.1. Selection and Construction

CABINETS

MnDOT uses several different cabinet types for various applications, including the 334MP cabinet, 334Z cabinet, 340 cabinet, pole cabinet, service cabinet, service cabinet type special, and service cabinet 240/480 with stepdown transformer. The typical applications each cabinet type is used for and the components for each cabinet type are listed below:

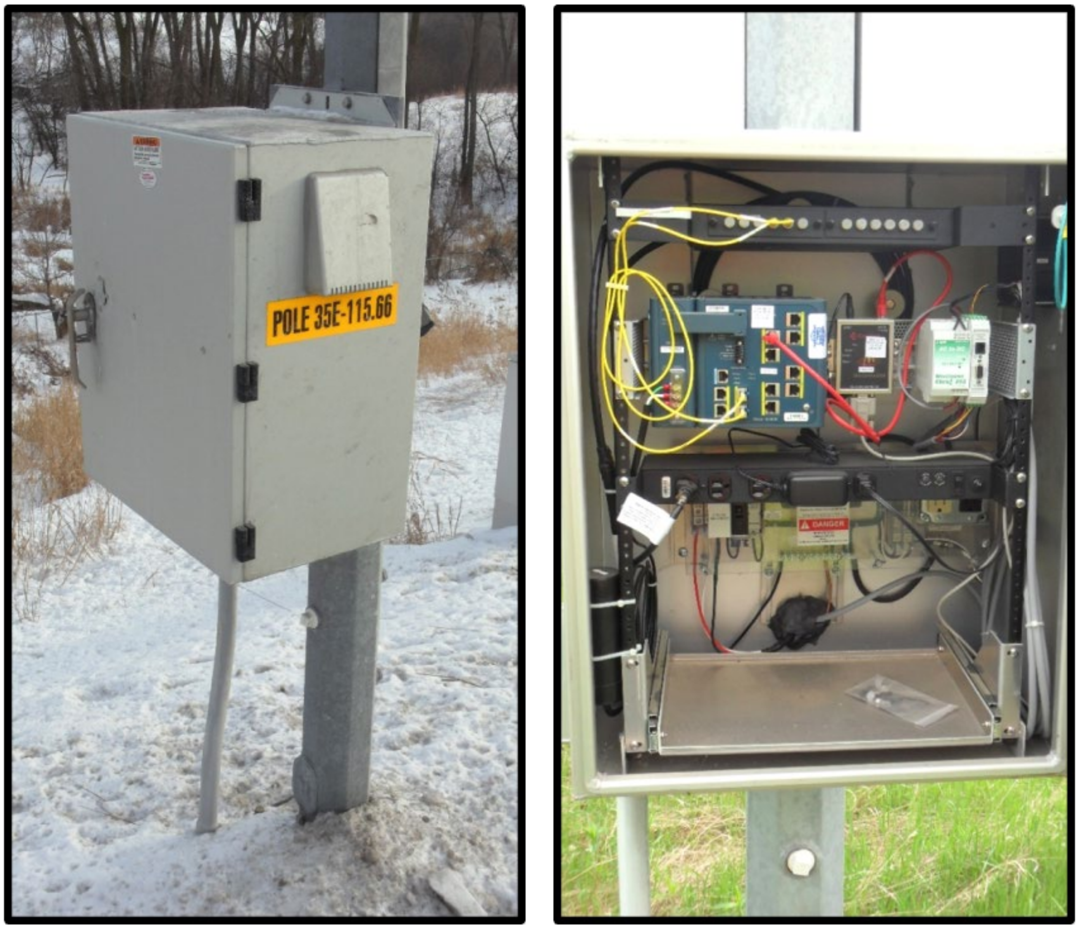
- 334Z is the typical cabinet used for ramp metering and loop detectors and includes:
    - 19” rack
    - Type 170 controller
    - Fiber optic patch panel
    - Main breaker inside of cabinet (no circuit breaker enclosure, just the breaker)
    - Outlet strip
    - Flasher modules
    - AC power surge protection
    - Thermostatically controlled ventilation
    - Sheath grounding units (for locating system)
    - Detector card rack
    - Loop detection terminal blocks wired to detector card rack
    - Neoprene cabinet gasket

Figure 3-17: 334Z Cabinet

- 334MP is the cabinet typically used for DMS control, fiber patching, and any other use where metering or detection is not needed. These cabinets typically include:
  - 19" rack
  - Fiber optic patch panel
  - Main breaker inside of cabinet (no circuit breaker enclosure, just the breaker)
  - Outlet strip
  - AC power surge protection
  - Thermostatically controlled ventilation
  - Sheath grounding units (for locating system)
  - Neoprene cabinet gasket
- 334MP-DET is an MP cabinet upgraded with equipment necessary for vehicle detection. It is the same as an MP with the addition of the detector card rack and terminal blocks wired to the detector card rack.

- 340 cabinet is a double wide cabinet with a fully functional 334Z on one side and 334MP on the other.
- Pole cabinet is a cabinet with a short 19" rack designed for mounting on poles. A pole cabinet is typically used on video camera or NID poles for fiber termination, transmission equipment, and power for video camera equipment. These cabinets can be found on MNDOT's APL.

Figure 3-18: Pole Cabinet



- Service cabinet (metered) is standard service cabinet used at ITS deployments. The service cabinet is designed for 200A, 120/240 volt, three wire, single phase power. It also includes a meter socket. It is constructed with 30 panel knock outs for breakers and comes with the following breakers (unless otherwise specified):
  - 1 – 60A 2-pole main breaker
  - 1 – 30A 1-pole breaker
  - 4 – 15A 1-pole breakers

  There are times when different breakers are required for a particular ITS deployment. It is the designer's responsibility to identify any changes on the plans from the standard breaker configuration that is normally provided per MnDOT's APL specification.

Figure 3-19: Service Cabinet

- Service cabinet type special (non-metered) – is identical to a service cabinet (metered) with the exception of not including a meter socket. It is the designer's responsibility to identify any changes on the plans from the standard breaker configuration that is normally provided per MnDOT's APL specification.

Figure 3-20: Service Cabinet Type Special

- The service cabinet 240/480 with stepdown transformer may be used outside of Metro District if that District prefers to share one meter and source of power for lighting and TMS.

Figure 3-21: Service Cabinet 240/480 with Stepdown Transformer

CLIMATE-CONTROLLED SHELTERS

MnDOT uses climate-controlled shelters at critical backbone communications locations and junction points. These shelters often include critical communications hardware that is not field hardened and thus must be installed in a climate-controlled environment. These shelters may include a backup power source or generator as a result of the critical communications infrastructure they support. The two sizes of shelter that MnDOT currently uses are 10’x12’ and 12’x18’, with the size of shelter chosen for a given location depending on how many system connections need to be made. Generally, more space is needed in an urban area such as at a system interchange.

ENVIRONMENTAL HARDENING

Most MnDOT equipment and service cabinets are not climate-controlled and are often susceptible to extreme temperature and weather conditions. As a result, all equipment installed in the cabinets must be field hardened to withstand these temperature and weather extremes. Examples of field equipment that must be hardened to perform during these extremes include Ethernet switches, surge suppressors, and communications converters.

3.6. Additional Supporting Infrastructure

Proposed ITS devices often require that additional infrastructure be installed to support the ITS device. This infrastructure may include the design for various structural components required to mount or support the device, poles, foundations, attenuators, barriers, and/or guardrail installations. The following subsections provide additional details for the design of supporting infrastructure associated with ITS applications.

3.6.1. Posts and Poles

When a proposed DMS will be installed on a sign bridge, the design may include either a new sign bridge or the modification of an existing sign bridge. If modifying an existing sign bridge, a structural analysis and design will be required, and the designer will need to coordinate with the MnDOT signing and bridge groups to incorporate all necessary structural components. If installing a new sign bridge, the designer will need to coordinate with MnDOT Signing and consult the MnDOT Standard Plan Sheets 700 Series for design of the sign bridge.

For all structural steel components, the designer must take fabrication lead times into consideration. Typical structural steel lead times vary but may exceed 26 weeks. If a project is on an accelerated schedule, the designer should consider whether MnDOT should furnish the structural steel components independently and provide them to the contractor for installation.

The designer will also need to consider whether a Federal Aviation Administration (FAA) airspace review (FAA Form 7460-1 Notice of Proposed Construction or Alteration) filing will need to be completed for proposed ITS structures. The requirements for filing with the FAA for proposed structures vary based on a number of factors including height, proximity to an airport, location, and frequencies emitted from the structure. The FAA provides a Notice Criteria Tool that may be utilized by the designer to receive a preliminary determination from the FAA as to whether an FAA airspace review is required for the proposed structure. See the following link:

https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm

The airspace review submittal to the FAA should be filed with adequate lead time prior to the final submittal date. It is desirable to obtain preliminary determinations from the FAA as soon as device locations are determined. The designer is required to have an account set up with the FAA airspace review website in order to file with the FAA and is also required to input relevant client/sponsor contact information into the airspace review database. One can register as a new user and manage air space review cases through the FAA website at the following link:

https://oeaaa.faa.gov/oeaaa/external/userMgmt/permissionAction.jsp?action=showLoginForm

Depending on the specific situation, it may also be warranted for a separate FAA airspace review to be filed for construction equipment that will be utilized to install the proposed permanent structure.

3.6.2. Foundations

Most new ITS device installations will require a foundation to be installed for the pole or sign structure that the ITS device will be mounted on. The designer will need to consider whether a standard MnDOT foundation design will be adequate for the particular ITS application or if a special design is required.

For a new DMS sign bridge, there are two standard footing design types, a spread footing and a shaft footing. When the DMS and sign bridge installation is part of a roadway reconstruction project, a spread footing is typically used. If the DMS and sign bridge installation is over an existing roadway, a shaft footing is typically used. All new sign bridges will require that a soil boring be performed at each foundation location to determine whether the standard design is adequate. Poles required for NID and video cameras typically utilize a standard foundation and do not require a soil boring. In areas with unique or poor-quality soil conditions, a special foundation design may be required.

During construction it is important that the required compaction levels be achieved as required by MnDOT Standards Specifications for Construction and any Special Provisions.

Figure 3-22: NID Pole

3.6.3. Guardrails

When a new sign bridge is required for a DMS installation, guardrail will be required to protect the structure from one or both directions. In rural areas, a plate beam guardrail installation may be used and is typically covered by Standard MnDOT Plan Sheets. In urban areas, a special installation with concrete barrier and impact attenuator are required along with a paved maintenance pull-off on the outside shoulder. If there is a vegetated median, the plate beam guardrail installation is used. In locations where a median barrier is present, the sign bridge is typically mounted on the structural barrier foundation. When a special installation is required, ITS cabinets and pull vaults are placed directly behind the concrete barrier. In rural areas, ITS cabinets should be placed outside of the clear zone or protected by a guardrail installation.

3.6.4. Pull Off Areas and Grading

There are a variety of situations where roadway design and related quantities need to be provided in the plans. A few examples include:

- Filling in an area to provide an elevated location for a cabinet pad so it does not end up in a wet area
- Creating a level work area so a ladder can be safely used by workers to service the ITS devices
- Pull-off area that is level and located farther away from the active traffic lanes to provide a safer area to park work vehicles including bucket trucks
- A four-foot wide perimeter of Type 9 Mulch around splice vaults, poles, cabinets, and shelters should be considered in areas that do not have established lawn (mowed approximately weekly).
- Erosion control measures need to be considered when work is adjacent to rivers, wetlands, and other environmentally sensitive areas. Depending on the level of impacts, the plans may require a SWPPP and erosion control details.

The designer needs to include the appropriate pay items and quantities in the plans to allow for these features to be constructed when required.

3.7. ITS Device Design

3.7.1. Vehicle Detection

INTRODUCTION AND USAGE

Vehicle detection is a critical component of an effective traffic management program. MnDOT uses real-time and historic data from vehicle detection devices for a number of different traffic applications. The two primary uses of real-time vehicle detection data by MnDOT are traffic responsive ramp meter operations and the calculation of travel times. Ramp meters running traffic responsive operations utilize density data from the mainline and ramp to control the rate of vehicles released by the ramp meter. Higher downstream mainline volumes will result in a decreased vehicle release rate and, conversely, lower downstream ramp volumes will result in higher vehicle release rates. When ramp meter volumes become high enough to create a queue that extends to the adjacent arterial, the ramp meter is programmed to increase its release rate.

A number of ITS systems used by MnDOT, including MnDOT's IRIS ATMS software, rely on real-time traffic data from vehicle detection devices. These systems process vehicle data and use it to display vehicle speeds and congestion areas along instrumented roadway segments. Speed data from multiple detection sites can be aggregated to calculate travel times along a particular corridor. These travel times can then be displayed on DMS or on the Minnesota 511 Travel Information website and mobile application. Third-party probe-based vehicle speed data can also be used to calculate travel times, but this data is typically delayed by one to two minutes on average and thus not as reliable as real-time speed data from vehicle detection devices.

Vehicle speed data can be used by MnDOT personnel to help locate incidents or potential problem areas. Over time, vehicle detection data can be used to develop and track performance metrics and overall transportation system performance. MnDOT also uses vehicle detection to assist with tolling enforcement. MnDOT's Truck Rollover Warning System (TROWS) uses individual vehicle speed and classification information, in conjunction with other data inputs, to alert drivers that they are traveling too fast for an upcoming curve. MnDOT's truck parking information management system utilizes vehicle detection to provide truck parking space availability at various parking facilities.

MnDOT also archives volume and speed data from vehicle detection devices. This historic data can be used to complete traffic studies and reports and is used in the planning processes for future roadway improvements. This data is also used for transportation research, transportation data and analytics (TDA), and traffic modeling.

DETECTION TYPES

MnDOT utilizes several different types of vehicle detection technologies as part of currently deployed traffic detection systems and/or new detection deployments, including:

- Intrusive detection (in-roadway)
    - Inductive loops
    - Magnetometers
- Non-intrusive detection (above or on side of roadway)
    - Microwave radar
    - Ultrasonic

Table 3-12 includes a description of the strengths, weaknesses, and capability of several detection types.

Inductive Loop Detection

One of the more common types of vehicle detection currently used by MnDOT is inductive loop detection. An inductive loop is an insulated wire, comprised of four wire turns per loop, imbedded in the roadway surface. The inductive loop is installed via sawcut or an NMC installed in/under the pavement that is connected to a loop amplifier card located in a nearby ITS cabinet. The wire loop carries a small oscillating DC electrical current operating at a specific frequency. When a vehicle passes over or stops above the loop, the conductive metal from the vehicle creates a reduction in the overall inductance of the loop. The decrease in inductance results in a corresponding decrease in electrical impedance and increase in electric current in the wire loop. The change in electric current, or percent change when using older inductive loop technology, actuates the loop amplifier card output relay. The traffic controller monitors the output relay 60 times per second to sense passage or presence of a vehicle. The total number of milliseconds it is occupied is then used to derive vehicle speed.

Magnetometer Detection

Another type of vehicle detection used by MnDOT is magnetometer-based vehicle detection. Magnetometer-based vehicle detection detects the presence and/or movement of ferrous metal included in a vehicle by measuring changes in the earth's magnetic field in one or more directions (x-, y-, and z-axis) produced by that vehicle. Magnetometers can be connected to an electronics unit in an ITS cabinet via wired or wireless communications. MnDOT uses magnetometer-based vehicle detection for the truck parking system. Vehicles that utilize aluminum or other non-ferrous materials may not be detected by a magnetometer.

Microwave Radar Detection

The other predominant type of vehicle detection used by MnDOT is microwave vehicle detection. A microwave vehicle detector transmits microwave energy across an area of roadway and when a vehicle travels through that detection beam, a portion of the transmitted microwaves are reflected off the vehicle and back to the detector. The detector receives the reflected microwaves and detects the presence of a vehicle. Two commonly used types of microwave radar detection are continuous wave

(CW) radar and frequency modulated continuous wave (FMCW) radar. CW radar detectors transmit a continuous beam of microwaves at a constant frequency and FMCW radar detectors transmit microwaves at a constantly changing frequency.

MnDOT currently utilizes side-fire FMCW microwave vehicle detection to detect vehicles traveling along freeway mainlines. These detectors utilize dual radar beams that are transmitted from the same detector. The dual radars act as a virtual detection zone and can detect when the vehicle enters the detection zone (penetrates the first beam) and when the vehicle leaves the zone (penetrates the second beam). By comparing the time between entry and exit, along with the length of the detection zone, the detector is able to determine an accurate measure of vehicle speed and classification. The detector is also able to determine the vehicle's direction depending on which of the two beams is penetrated first.

Figure 3-23: NID

MnDOT currently has a contract to use Wavetronix detection. The minimum, recommended, and maximum detector mounting heights are listed in Table 3-11 below. MnDOT typically mounts the detector between the recommended and maximum height. The mounting height for the detector is based on height above the pavement surface at the nearest edge of the first detection lane. If the ground is not level with the pavement surface, the height of the pole will be different than the detector mounting height. The designer must obtain a cross section to determine the proposed detection pole location. Figure 3-23 below illustrates an example cross section for determining pole placement and height.

Table 3-11: Wavetronix Mounting Height

Offset from first Detection Lane (ft)	Recommended Mounting Height (ft)	Minimum Mounting Height (ft)	Maximum Mounting Height (ft)
6	12	9	19
7	12	9	19
8	12	9	20
9	12	9	21
10	12	9	22
11	12	9	23
12	13	10	24
13	13	11	25
14	14	11	26
15	15	12	26
16	15	12	27
17	16	13	28
18	17	14	29
19	17	14	30
20	18	15	30
21	19	15	31
22	20	16	31
23	22	16	32
24	24	16	33
25	26	17	33
26	26	17	34
27	27	18	35
28	27	18	35
29	27	18	36
30	29	19	37
31	29	19	37
32	29	19	38
33	30	19	39
34	30	19	39
35	30	20	40
36	30	20	41
37	31	20	41
38	31	21	42
39	33	21	43
40	33	22	43
41	34	22	44
42	34	22	44
43	35	22	45
44	35	23	46
45	36	23	46
46	36	23	47
47	36	24	48
48	38	24	48

Offset from first Detection Lane (ft)	Recommended Mounting Height (ft)	Minimum Mounting Height (ft)	Maximum Mounting Height (ft)
49	38	24	49
50-200	39	25	Must be < offset

Figure 3-24: Detector Folding Pole Placement and Height

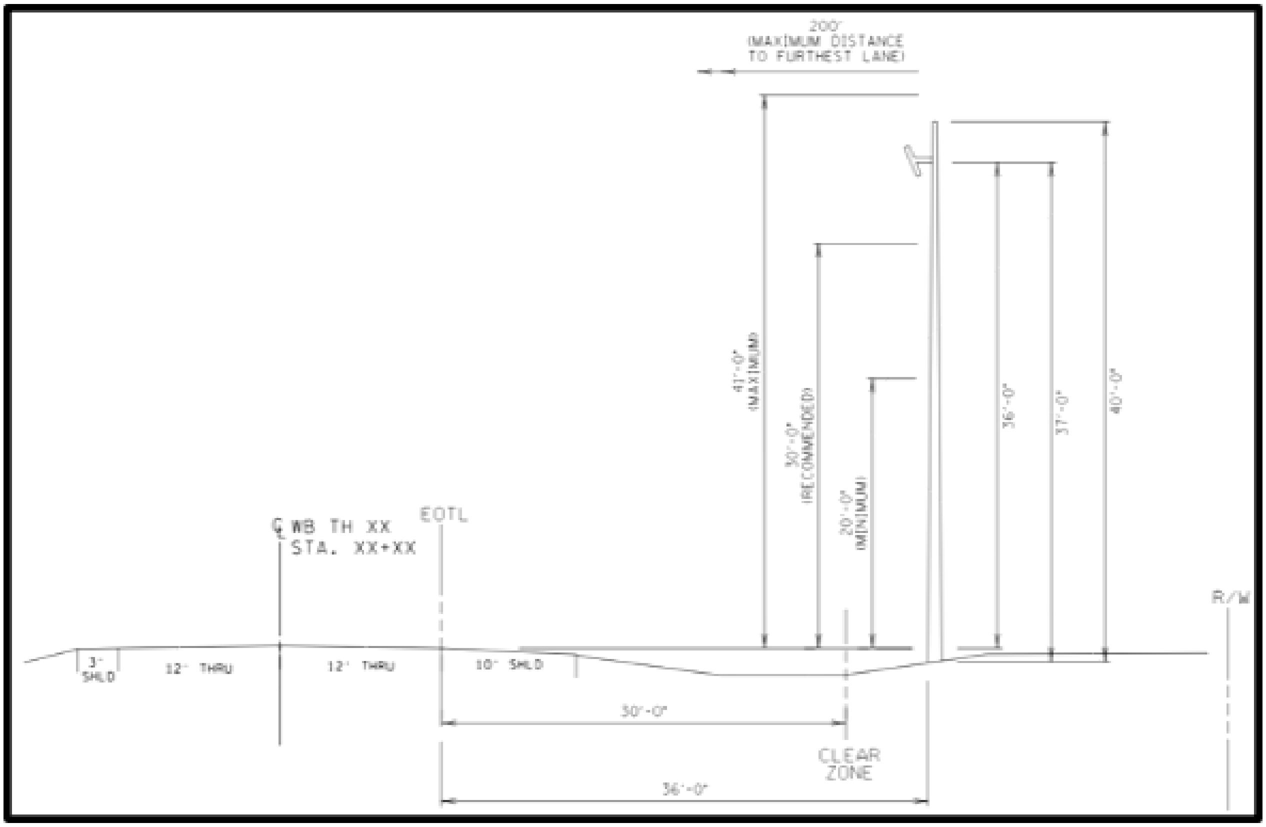


Table 3-12: Detector Technology Strengths and Weaknesses

Technology	Strengths	Weaknesses	Capability
Inductive loop	• Flexible design that satisfies a variety of applications • Mature, well understood technology • Large experience base • Provides basic traffic parameters • Insensitive to inclement weather such as snow, rain, and fog	• Installation requires pavement cut if doing a retrofit project • Installation may decrease pavement life • Installation and maintenance require a lane closure • Wire loops are subject to traffic	• Inductive loops are capable of detecting volume, presence, occupancy, speed, headway, and gap • Some high frequency inductive loops are capable of detecting vehicle classification

Technology	Strengths	Weaknesses	Capability
	• Provides best accuracy for count data • Common standard for obtaining accurate occupancy measurements • Low cost for single detection area	and temperature stresses • One loop is needed per lane, which will require multiple loops at locations with more than one lane in each direction • Detection accuracy may decrease when design requires detecting many vehicle classes	
Wireless (in-pavement) magnetometer (used for truck parking applications)	• Less susceptible than loops to stresses caused by traffic • Insensitive to inclement weather such as snow, rain, and fog	• Battery powered and thus will eventually run out of power and require replacement • Wireless communications are susceptible to signal blockage • Installation requires drilling hole in pavement and sealing with epoxy	• Magnetometer-based detection is capable of detecting volume, presence, speed, headway, and gap • Multiple magnetometer detectors can be used to obtain vehicle classification
Wired (in-conduit) magnetometer	• Less susceptible than loops to stresses caused by traffic • Insensitive to inclement weather such as snow, rain, and fog	• When conduit is installed in pavement, it can decrease overall pavement life expectancy • Installation requires boring conduit and sliding through the detector and cable	• Magnetometer-based detection is capable of detecting volume, presence, speed, headway, and gap • Multiple magnetometer detectors can be used to obtain vehicle classification
Microwave radar	• Typically, insensitive to inclement weather at the relatively short ranges encountered in	• Susceptible to vehicle occlusion • Higher cost	• Microwave radar is capable of detecting volume, speed, headway, gap, and vehicle classification (based

Technology	Strengths	Weaknesses	Capability
	traffic management applications • Direct measurement of speed • Multiple lane operation available		on an average length)
Passive infrared (only used by MnDOT in detectors that combine multiple detection technologies)	• Multizone passive sensors measure speed	• Passive sensor may have reduced vehicle sensitivity in heavy rain, snow and dense fog • Some models are not recommended for presence detection	• Infrared sensors are capable of detecting volume, speed, headway, gap, and vehicle classification (based on length)
Ultrasonic (only used by MnDOT in detectors that combine multiple detection technologies)	• Multiple lane operation available • Capable of over-height vehicle detection	• Environmental conditions such as temperature change and extreme air turbulence can affect performance • Large pulse repetition periods may degrade occupancy measurement	• Ultrasonic sensors are capable of detecting volume, presence, and occupancy

Source: FHWA Traffic Detector Handbook

DETECTORS USING MULTIPLE DETECTION TECHNOLOGIES

A number of vehicle detectors utilize multiple different types of detection technology. By combining multiple different types of detection technology, an individual vehicle detector can take the place of multiple detectors and can be used to overcome weaknesses of an individual detection technology. The TDC3 detector from ADEC Technologies is an example of a vehicle detector that uses multiple types of detection technology. The TDC3 detector utilizes Doppler radar, ultrasonic, and passive infrared detection technologies to provide a comprehensive set of vehicle data.

VEHICLE CLASSIFICATION

Many of the different types of vehicle detection technologies are capable of measuring vehicle classification including inductive loops, magnetometers, microwave radar, and passive infrared. The most common type of vehicle classification is based on vehicle axles. Axle-based classification often includes both the number of axles per vehicle as well as axle spacing for each vehicle. The FHWA has defined 13 vehicle classes based on axle configurations, which are identified in Table 3-13. MnDOT typically utilizes vehicle detection to determine speed, volume, and occupancy, but does not typically determine vehicle classification. Although the RTMC seldom uses vehicle classification data, this data can be provided to other groups that need this data.

Table 3-13: FHWA Vehicle Classification

Class	# Axles	Vehicle Description	Notes
1	2	Motorcycles	
2	2	Passenger vehicles	Sedans, coupes, and station wagons
3	2	Other 2-axle, 4-tire single unit vehicles	Includes pickups, vans, campers
4	2 or more	Buses	Includes only traditional buses
5	2	2-axle, 6-tire, single unit trucks	
6	3	3-axle single unit trucks	
7	4 or more	4-axle single unit trucks	
8	3,4	4 or fewer axle single-trailer trucks	Semi with trailer
9	5	5-axle single-trailer trucks	
10	6 or more	6 or more axle single-trailer trucks	
11	4,5	5 or fewer axle multi-trailer trucks	
12	6	6-axle multi-trailer trucks	
13	7 or more	7 or more axle twin trailer semi-trucks	

COMPONENTS

Typical components required for a vehicle detector are identified in Table 3-14 along with the corresponding section of this design manual that should be referenced for additional design information related to that component.

Table 3-14: Detection Components

Component	Manual Locations
Loop Detector	This section
NID	This section
NID Pole	This section
Control Cabinet	Section 3.5
Power	Section 3.1
Communications	Section 3.2

GENERAL DESIGN CONSIDERATIONS

When selecting the type of detection and detection location that will be utilized for a project, several factors should be considered. A list of general design considerations is included below.

1) Does the detector meet the “needs” outlined in the project Concept of Operations, Regional Operations Plan, and/or MnDOT statewide ITS architecture?
2) Can the detector accurately detect all desired vehicle data required for the project (i.e., vehicle volume, speed, occupancy, and/or classification)?
3) Does the detector satisfy the precision, spacing, and accessibility requirements for the project?
4) Is the detector able to function during all times of the year, all times of the day, and all weather conditions?

5) Does the detector minimize the amount of new infrastructure needed and allow for devices to be collocated where possible?
6) When in-pavement detection will be used, is the pavement condition of sufficient quality to support operation of the detection for its maximum life expectancy?
7) Has the proposed detector infrastructure been evaluated for conflicts with other existing or proposed infrastructure such as bridges, signs, or drainage elements?
8) Has the detector site been chosen so that it will minimize maintenance costs and safety concerns (e.g., is there sufficient space to park a bucket truck without the need for a full lane closure and significant traffic control)?
9) The index numbers of existing detectors can be found on the All Detector Report (http://data.dot.state.mn.us/datatools/)
10) The numbering system comes from a database from the RTMC operations group. Number from right to left. N1, N2, etc. and the letter represents the direction of traffic flow (e.g. N means northbound).
11) Loop detector sizes for mainline lane detection are typically 6 feet by 6 feet for a 12-foot lane and are centered in the lane. Loop detectors located on ramps are 6-feet long, but the width varies. The width of these loops is the ramp roadway width, not including any shoulder, minus 6 feet (i.e. 2 * 3 feet from the edge of pavement to each side of the ramp). Figure 3-24 shows how the widths of the loops are determined.

Figure 3-25: Loop Detector Configuration on Entry Ramps

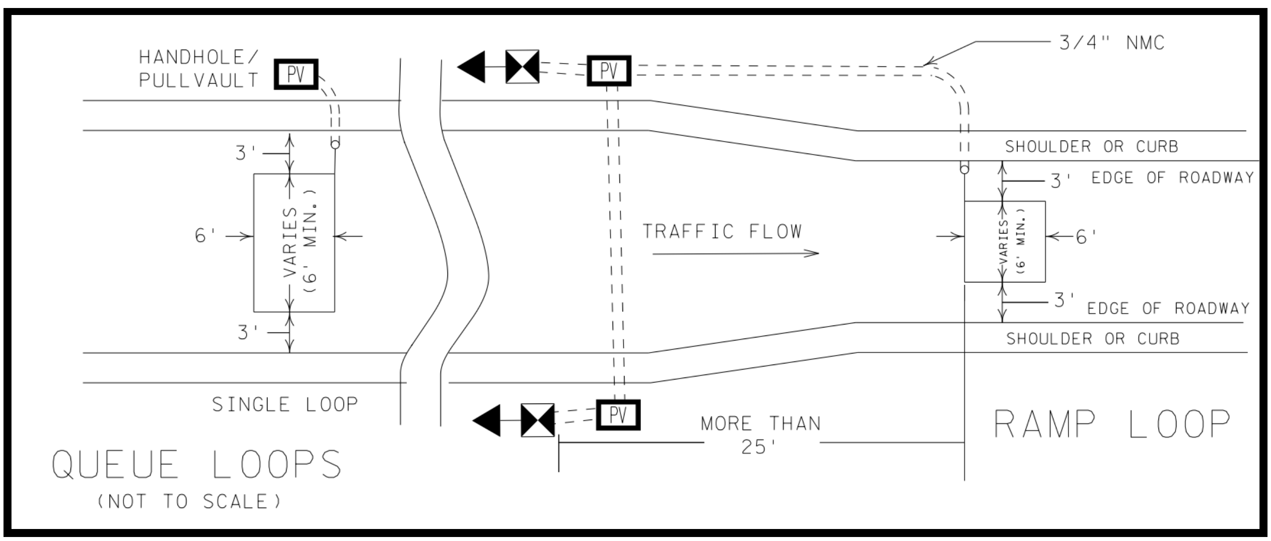


Figure 3-26: Loop Detector Index Number

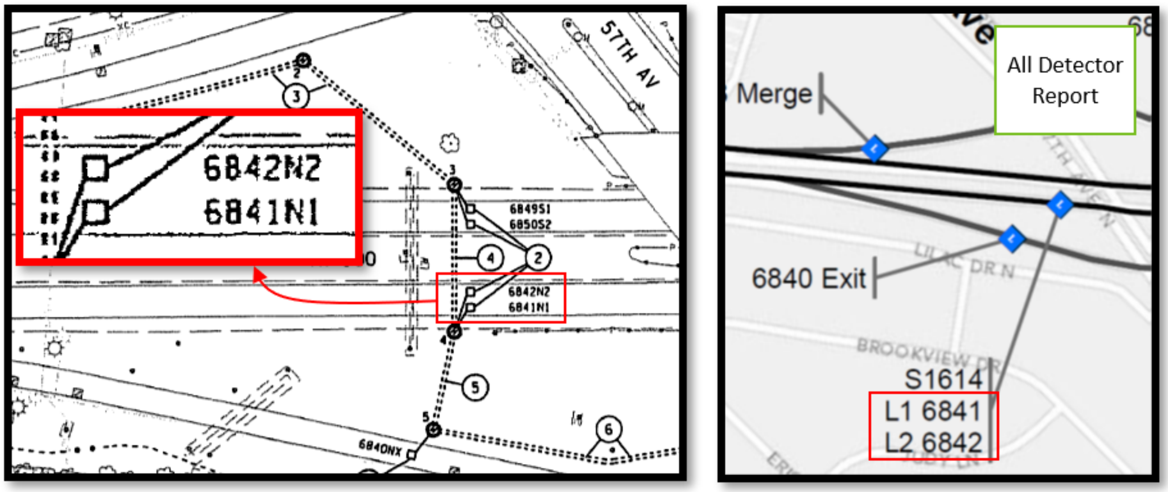
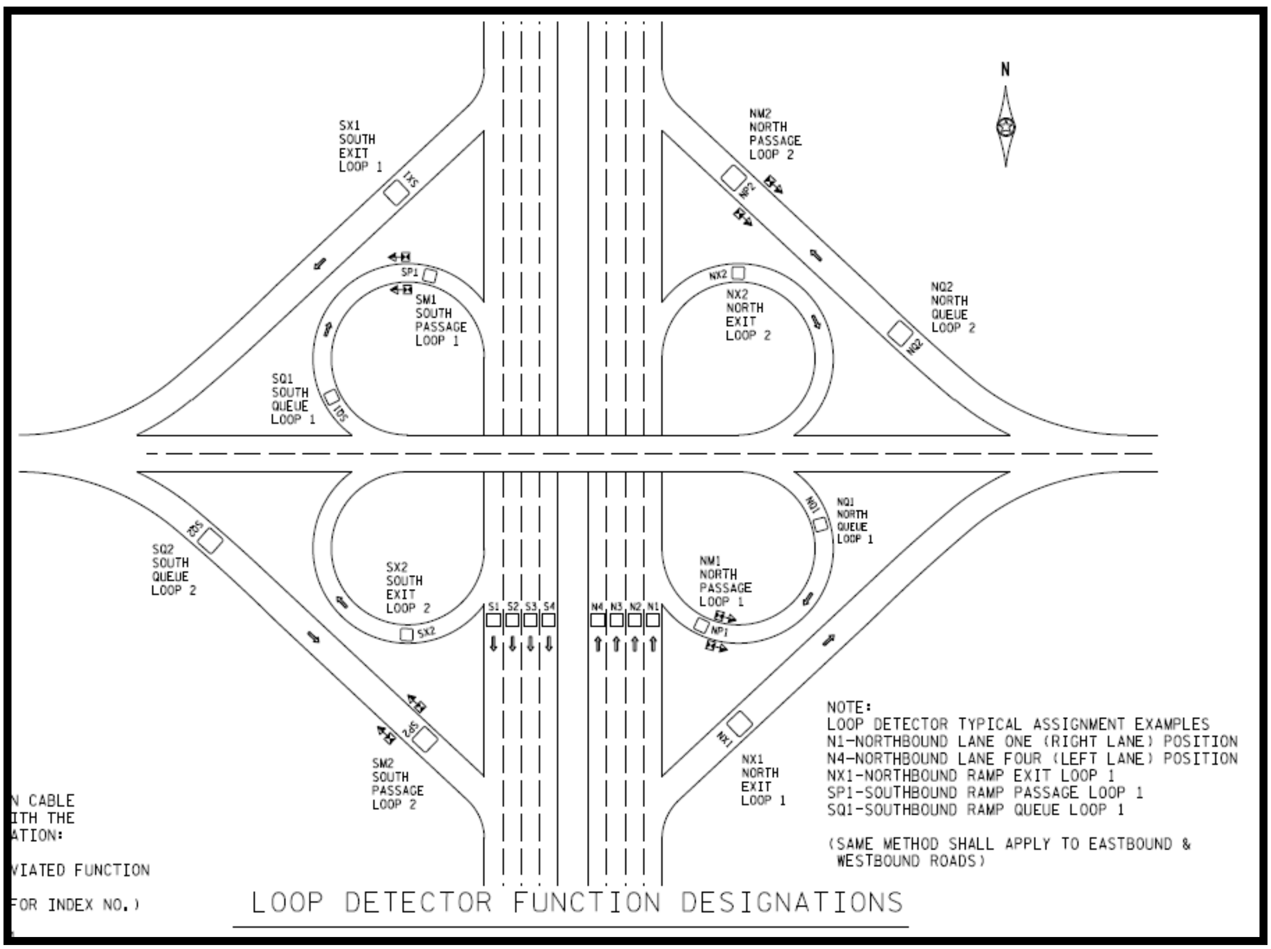


Figure 3-27: Loop Detector Function Designations



Mainline Detection (Microwave Radar)

1) When placing a detector, avoid placing detection in areas with a significant amount of weaving and where traffic is slowing for merging vehicles as this can lead to erroneous counts.

2) Mainline detectors in the Metro District are typically located every half-mile.
3) When placing a detector, consider the location of future infrastructure (e.g., future lanes, shoulders, etc.).
4) Is the detector mounted at a height that falls within the manufacturer's recommended range?
    a. MnDOT typically mounts the detector between the recommended and maximum height.
5) Is the detector capable of detecting all traffic lanes and is the detector far enough away (12 foot minimum distance is required) from the closest lane but no more than 200 feet from the farthest lane so that it can accurately detect all traffic lanes? The designer should identify the distance from the NID to each traffic lane on the plans.
6) Is the detector mounted high enough to prevent occlusion of vehicles when adjacent to larger vehicles?
7) Is there a high median barrier that might cause occlusion or adversely impact the detector's ability to function properly?
8) Is there guardrail present that might cause reflection or adversely impact the detector's ability to function properly?
9) Is the detector far enough away from a bridge or sign structure to prevent any negative impacts of the bridge or sign structure? The minimum clearance is 40 feet.
10) Do the existing and/or proposed grades slope up or down such that they would prevent the detector from accurately measuring vehicles in the farthest travel lanes?
11) If a new pole is required for the detector, is the pole located beyond the clear zone or protected by a suitable safety barrier?
12) Is another detector located on the opposite side of the roadway and, if so, is there sufficient offset in placement to avoid interference with one another? The minimum offset is 70 feet.
13) If buses will be utilizing the shoulder, the detector should be located such that it is capable of detecting traffic on the shoulder.

Ramp Detection (Inductive Loops)

1) When installing a loop detector in existing pavement, check the pavement condition and avoid areas where the pavement is damaged.
2) When installing a loop detector in new concrete pavement, the loop detector should be placed a minimum of 3 feet from dowel baskets at pavement joints. Do not place the loop detector above a culvert, where there would likely be supplemental pavement reinforcement.
3) When a porkchop is present at the upstream end of the ramp, the location of the queue detection loop(s) may need to be adjusted to capture both traffic movements or two loops may be needed.
4) When locating a passage loop detector, place the loop at least 25' beyond the ramp meter.
5) When a HOV bypass lane is provided, a passage loop detector should also be provided for the HOV bypass lane in addition to the passage loop detector beyond the ramp meter.
6) Naming of loops is very important, consult with the MnDOT RTMC operations group for loop naming.

VEHICLE DETECTION DESIGN PROCESS

General design steps for all ITS devices are listed in Section 4.7 and detailed design steps for vehicle detection are listed in Section 4.8.1.

3.7.2. Video Cameras

INTRODUCTION AND USAGE

Video cameras are one of the primary tools used by MnDOT to remotely monitor real-time traffic conditions across the State's transportation system and make informed traffic management decisions. MnDOT traffic operations and maintenance personnel located at the RTMC or other State facilities can use this video to identify congestion, incidents, and/or other potential issues and implement traffic management strategies designed to reduce their impacts and improve safety and mobility. Most MnDOT video cameras have pan-tilt-zoom (PTZ) capabilities that allow an operator to remotely position the camera to obtain the best possible visual of the area of concern. The State Patrol are also located in the RTMC and use video to enhance incident response. This video provides the situational awareness needed to deploy the appropriate emergency response and clearance vehicles to the scene. Video allows MnDOT to cooperatively work with incident response personnel to quickly resolve the issue and restore normal traffic operations along the corridor. MnDOT and the State Patrol utilize video cameras to:

- Monitor real-time traffic conditions
- Manage traffic and congestion
- Locate and/or verify traffic incidents and disabled vehicles
- Improve incident management and response
- Verify messages posted on Dynamic Message Signs (DMS)
- Observe and/or verify local weather conditions and hazards
- Dispatch safety, operations, or maintenance personnel
- Monitor work zone operations and temporary traffic control

Figure 3-28: Video Camera

MnDOT also shares snapshots and video from these camera video feeds with the public through the Minnesota 511 Traveler Information System. Travelers can utilize these video snapshots and video to obtain current traffic conditions and identify potential congestion or incidents along their planned travel route.

COMPONENTS

Typical video camera components are identified in Table 3-15 along with the section of this design manual to reference for additional information on that component. Video camera warrants are discussed in Section 2.4.3.

Table 3-15: Video Camera Components

Component	Manual Location
Video Camera	This Section
Mounting Hardware	This Section
Pole Cabinet	Section 3.5
Power	Section 3.1
Communications	Section 3.2

VIDEO CAMERA

MnDOT has deployed several different types and styles of video cameras over the years and not all cameras rely on the same technology, features, and functionality. The type of video camera is largely dependent on when it was deployed, its intended use, and the constraints of the location in which it was installed. The following includes a brief overview of the types and styles of video cameras currently used by MnDOT. MnDOT utilizes digital cameras where the digital video encoder hardware and/or software CODECS are integrated directly into the video camera unit and no additional hardware is required in the field cabinet. MnDOT's standard for all new video cameras in use is high-definition (HD); however, there are still many standard-definition (SD) cameras deployed across the State. MnDOT is in the process of upgrading all SD cameras to HD, but the process will take time. As SD cameras fail, they will be replaced with HD cameras. The camera housing is made up of the environmental enclosure and PTZ unit, heaters, wipers, etc. MnDOT typically uses barrel style cameras. Barrel cameras were traditionally used in fixed locations but have seen many advancements in recent years and now provide PTZ capabilities and are used extensively by MnDOT. Dome cameras previously were used but due to icing challenges and a blind spot with the domes due to the mounting, they are typically not used by MnDOT. There are some other cameras used by MnDOT for specific applications such as truck parking and gate arm monitoring.

Video cameras can be fixed or controlled. Fixed video cameras are stationary and cannot be remotely repositioned. Repositioning a fixed video camera requires physically repositioning the camera in the field. These cameras are often deployed for security purposes, focus on a particular area of interest, and typically provide zoom-in/zoom-out and focus functionality.

Controlled video cameras, often referred to as PTZ cameras, allow users to remotely reposition the camera to view a particular area of interest. Freeway video cameras deployed by MnDOT are PTZ cameras.

FIELD OF VIEW

Current video camera technology allows for camera spacing of up to 2 miles and a field of view of 1-2 miles in each direction if the camera mounting, topography, road configuration, and weather are ideal. The location for video cameras is dependent on the terrain, number of horizontal and vertical curves, desire to monitor weaving areas, identification of high-incident locations, and the need to view ramps and arterial streets. Each prospective site must be investigated to establish the camera range and field-of-view that will be obtained as a function of mounting height and lens selection.

PERFORMANCE BANDWIDTH

It is an issue if there is not a high bandwidth connection to the camera. For example, in some remote rural areas the camera may be using a wireless link with much less bandwidth than a fiber optic connection. In cases of limited bandwidth, there are trade-offs related to camera resolution, refresh rate, and compression losses. The communication system needs to be designed to effectively allow access to the video and minimize bottleneck links. Performance also affects camera control. In a low bandwidth situation, there is a delay between issuing the camera movement command and when the camera moves, which makes it difficult to point the camera where desired in real-time. In these situations, it is helpful if the camera control includes the ability to use presets so that the operator can easily point the camera in the desired direction.

VIDEO CAMERA MOUNTING OPTIONS

For fixed location video camera systems, video cameras are permanently mounted either on existing structures along the freeway or on specially installed camera poles.

FOLDING POLE

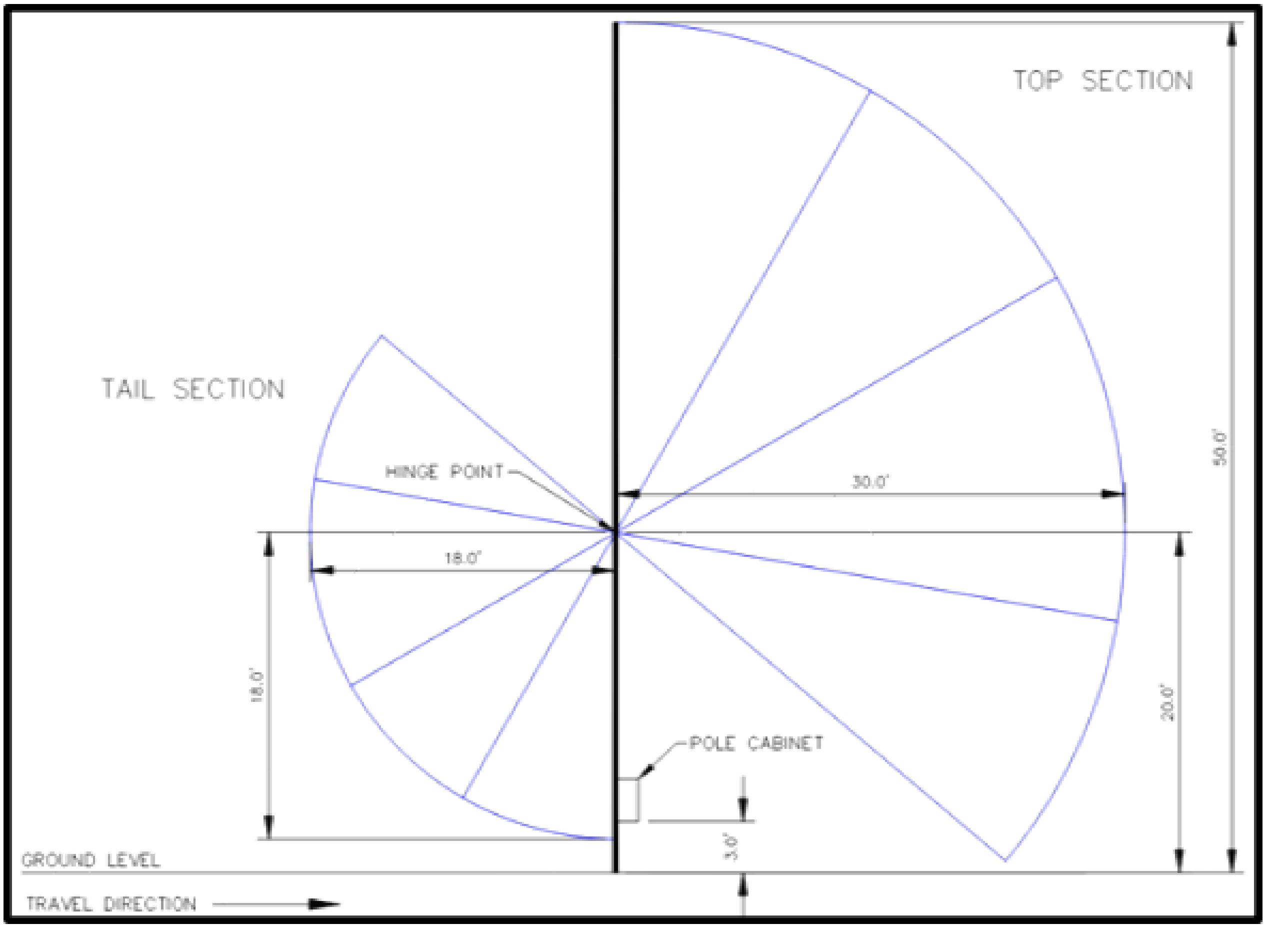
MnDOT video cameras are typically mounted on a 50-foot high video camera folding pole. See below for the typical video camera folding pole detail. NID folding poles, which have varying heights, are also used to mount video cameras. Additional and current details can be found on the approved/qualified product list (APL/QPL) at http://www.dot.state.mn.us/products/. Folding poles allow for installation and maintenance without the need for bucket trucks, ladders, etc.

Video Camera Pole Installation Detail:

http://www.dot.state.mn.us/rtmc/pdfdgn_design/cam/CCTV%20POLE%20INSTALLATION_dt1.pdf

Figure 3-28 below illustrates the swing path of the 50' video camera folding pole. The designer must consider this when determining the locations of poles, cabinets, etc. and their proximity to trees and other obstacles to ensure that the swing path of the pole is not obstructed.

Figure 3-29: 50' Video Camera Folding Pole Swing Path



EXISTING STRUCTURES

If the video camera is to be mounted on an existing structure, coordination with the appropriate MnDOT functional group is required. For instance, cameras mounted on a bridge require coordination with the bridge group.

TRAFFIC SIGNAL INSTALLATION

A video camera system may be included at a traffic signal or arterial management system. For these systems, coordinate with the traffic signal owner to determine the correct quadrant(s) to locate the camera. These are often installed on a specially designed mounting pole that takes the place of one of the signal luminaire davit arms.

VIDEO CAMERA DESIGN CONSIDERATIONS

This section includes high-level design considerations and guidance to assist ITS practitioners engaged in video camera design for MnDOT. The sections below include several questions designers should seek to answer as they begin the video camera system design process.

Location/Placement Guidelines

- Has the camera location been chosen/designed with consideration to maximizing visibility?

- Has the pole location been designed with consideration to the swing path of the folding pole?
- Has a site for the camera been chosen that considers the available utilities and the cost/constraints associated with connection to those utilities?
- Has the site been chosen with consideration to protecting the camera structure and ensuring that it will last without undue maintenance necessary to the structure and the surrounding site?
- Has a site been chosen that makes the best use of the operational needs of a video camera system (e.g., incident management)?
- Has a site been chosen that satisfies safety requirements for personnel performing maintenance on the system?
- Has the site been selected so that it will minimize maintenance costs (e.g., there is sufficient shoulder to park a bucket truck without the need for a full lane closure to perform maintenance activities)?
- Is the structure the video camera is mounted on located beyond the clear zone or protected by a suitable safety barrier?
- Has the site been chosen considering safety and conditions so that access will be available year-round, in all weather conditions, and at all times of the day?
- Has the availability of communications infrastructure been evaluated? If a wireless link must be used, tradeoffs will need to be made regarding camera resolution, refresh rate, and compression losses.

Video Camera Type

- What application is the video camera being used for? Different cameras are used for more specific applications such as truck parking and gate monitoring.

Camera Mount

- Will the camera be mounted on a standard folding pole, existing structure, or traffic signal pole? If mounted on an existing structure or traffic signal pole, coordination with other functional groups will be required.

Control Cabinet

- The new standard is to include a pole cabinet on all video camera and NID poles for future proofing purposes, as CAV-X applications may eventually utilize them.

Procurement

- Which components are State-provided, and which are to be provided by the contractor? MnDOT has a multi-year contract for the procurement of video cameras. Video cameras, 334 style control cabinets, and communication cables (between the Ethernet switch and video camera), as well as Ethernet switches, are typically furnished and installed by the State. Service cabinets, pole cabinets, video camera and NID poles, conduit, pull vaults, and power cables are furnished and installed by the contractor.

VIDEO CAMERA DESIGN PROCESS

General design steps for all ITS devices are listed in Section 4.7 and detailed design steps for video cameras are listed in Section 4.8.2.

3.7.3. Dynamic Message Signs

INTRODUCTION AND USAGE

A Dynamic Message Sign (DMS) is an electronic sign mounted adjacent to or above the roadway that is capable of displaying multiple messages to passing motorists. Depending on its location and use, a DMS may also be referred to as a Variable Message Sign (VMS), Changeable Message Sign (CMS), or Blank-Out Sign (BOS). DMS messages can be changed locally but are typically managed remotely from a central location or traffic management center (TMC). DMS have many different applications including:

- Incident management and route diversion
- Warning of adverse weather conditions
- Special event applications associated with traffic control or conditions
- Control at crossing situations
- Lane, ramp, and roadway control
- Priced or other types of managed lanes
- Travel times
- Warning situations
- Traffic regulations
- Speed control
- Destination guidance
- AMBER alerts

Figure 3-30: Dynamic Message Sign

DMS messages are typically focused on safety or transportation conditions and are comprised of three primary components: a problem statement, a location, and a recommended action. The problem statement informs the motorist of a particular event or incident, the location provides general information on the location of that event or incident, and the recommended action informs the motorist of the action they should take. The MN MUTCD includes several additional requirements for developing and displaying messages on a DMS.

COMPONENTS

Typical DMS components are identified in Table 3-16 along with the section of this design manual to reference for additional information on that component.

Table 3-16: DMS Components

Component	Manual Location
Dynamic Message Sign	This Section
Sign Structure	This Section
Control Cabinet	Section 3.5
Power	Section 3.1
Communications	Section 3.2

DMS DESIGN CONSIDERATIONS

This section includes high-level design considerations and guidance to assist ITS practitioners engaged in DMS design for MnDOT. The sections below include several questions designers should seek to answer as they begin the DMS design process.

Longitudinal Placement

- Is the DMS located in the Metro District, an urban area outside of the Metro District, or a rural area?
- Is the DMS visible and unobscured?
- Is the DMS located sufficiently upstream of any potential diversion routes?
- Is the DMS located a sufficient distance upstream or downstream of any existing guide signs?

Lateral Placement

- Is the DMS structure located outside of the clear zone or protected by a suitable safety barrier?
- Has the lateral offset of the DMS been accounted for when calculating the length of the Reading and Decision Zone?

CAV Considerations

- Will nearby CAV roadside units (RSUs) require direct data feeds from the DMS?
- Will nearby CAV RSUs benefit from shared infrastructure required as part of the DMS installation?

Sign Characteristics

- All new DMS are to be full matrix, full-color, and have a 20 mm pixel pitch. Prior DMS characteristics varied based on the DMS application. It is important to note that DMS standards may change, and designers should verify current DMS characteristics and design requirements used by MnDOT before beginning design.
- Which DMS size is required for the application? Typical DMS sizes include 8 feet by 18 feet, 8 feet by 32 feet, and 8 feet by 42 feet. The most commonly used sizes are 8 feet by 18 feet and 8

feet by 32 feet, but other sizes may be used in special circumstances or when dictated by existing or proposed conditions.

Viewing Angle

- Has a sign viewing angle been chosen that complements the roadway alignment and the DMS structure?

Sign Access

- Are there any traffic, environmental, or safety factors that warrant a specific type of sign access? Different access types include walk-in, rear access, and front access. Walk-in DMS are preferred for all overhead DMS as these style signs are easier to maintain and reduce the impact on traffic operations. Front access was previously used for E-ZPass price display insets on static E-ZPass sign panels, but these have now been replaced with full 8 foot by 18 foot DMSs.
- If walk-in DMS is used, is a left door or right door needed? This is dependent on site-specific considerations and must be determined before DMS can be procured.
- If the DMS is ground-mounted, is there an Occupational Safety and Health Administration (OSHA)-compliant area for the placement of a ladder for maintenance operations?

Structure

- Is the DMS overhead (roadway bridge or standard truss (full sign bridge or cantilever design) or ground mounted?
- Have visibility, road speed/volume, right-of-way, maintenance, and cost been considered when selecting the type of sign structure?
- Is there sufficient vertical clearance for the sign and the sign structure? The minimum low steel clearance value is currently 16 feet 4 inches although MnDOT uses 17 feet 4 inches to the lowest hanging device.

Procurement

- Which components are State-provided, and which are to be provided by the contractor? MnDOT has a multi-year contract for the procurement of DMS and 334 Style Control Cabinets. DMS and control cabinets are typically furnished by the State and installed by the contractor. Service cabinets, conduit, pull vaults, communication cables, and power cables are typically furnished, installed, and terminated by the contractor.

Control Cabinet

- Is the control cabinet located within a reasonable distance of the sign?
- Is the sign face visible from the control cabinet location?

LOCATION AND DESIGN

The ideal location for a permanent DMS on a controlled access roadway is in advance of an interchange or access point in order to inform drivers in advance and provide them with sufficient time to take some action in response to the message being displayed on the sign. A DMS should not compete with existing roadway guide signs. At times, relocation of static signs may be required to install a DMS at a critical location. In general, DMS should be located:

- Upstream of major decision points (e.g., exit ramps, freeway-to-freeway interchanges, or intersection of major routes that will allow drivers to take an alternate route)

- Upstream of bottlenecks, high-accident areas, and/or major special event facilities (e.g., stadiums, convention centers)
- Where regional information related to weather conditions such as snow, ice, fog, wind, or dust is critical

The ease with which a sign can be detected in the environment (conspicuity) and the ease with which the message can be read (legibility) will enhance the effectiveness of motorists' visibility of the DMS and its message. In addition, the way the message is displayed must be considered (e.g., if the message is too luminous, it can be easily detected but difficult to read because of glare). Factors that affect the legibility of light-emitting DMS include the character height; font style; character width (spacing and size of pixels); spacing of characters, words, and lines; size of sign borders; and contrast ratio.

The designer needs to consider the site characteristics of the area in which the DMS will be located. Factors that should be considered include:

- The operating speed of traffic on the roadway
- The presence and design characteristics of any vertical curves that may impact sight distance
- The presence of horizontal curves and/or obstructions such as trees, bridge abutments, or construction vehicles that constrain sight distance to the DMS around the curve
- The location of the DMS relative to the position of the sun (for daytime conditions)
- The location of any static guide signs in the vicinity
- Presence of wetlands
- Whether unusual site-specific weather conditions apply that could degrade sign visibility

Other design considerations include sign size (which affects message length and support structure requirements), maintenance access (e.g., walk-in housings, front access), technology, viewing angle and distance, and character size.

The maximum length of a message that will be displayed on the sign is primarily dictated by the amount of information a driver can reliably read and comprehend during the period they are within the legibility distance of the DMS. The maximum length of a DMS message is also controlled by the characteristics of the sign. These include the type of sign (typically LED), the number of lines available, and the number of characters on each line. Each of these characteristics will affect the distance at which a sign can be read and, consequently, how much information can be presented on it. Guidance on MnDOT DMS messages is documented in "2012 CMS Manual of Practice," although it should be the responsibility of the TMC manager/supervisor to assess the DMS characteristics and determine the maximum length of message to display.

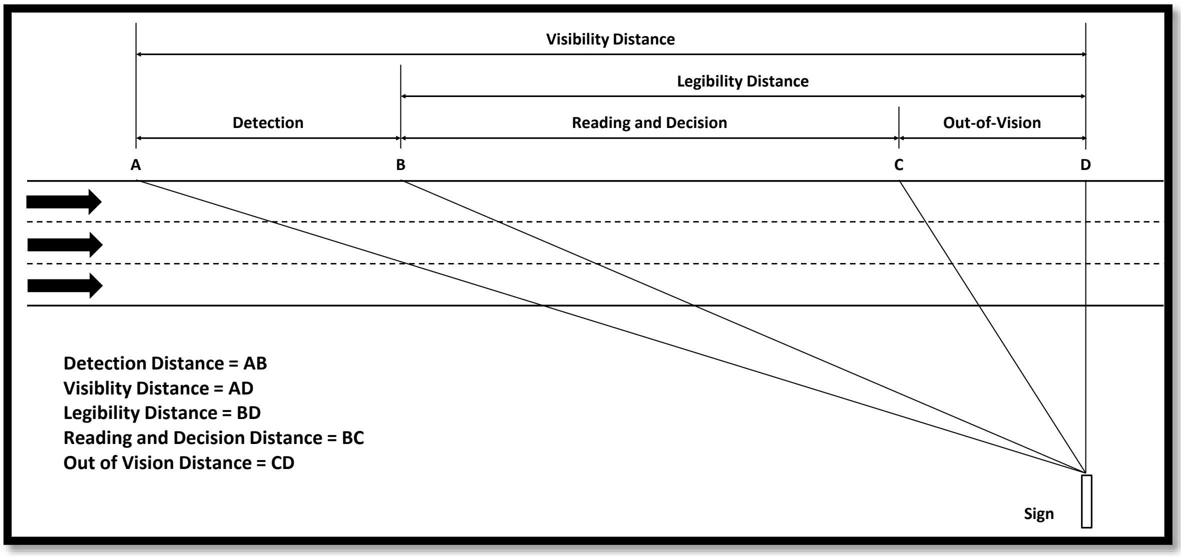
LONGITUDINAL PLACEMENT

As noted earlier, the primary considerations related to longitudinal placement of a DMS are to minimize obstructions of and by the DMS, provide maximum visibility of the DMS message, and allow the driver ample time in which to read, process, and react to the message. When the DMS is located near at-grade intersections, the designer needs to ensure that the DMS does not negatively affect intersection sight distances. Once the DMS visibility distance has been determined, the designer will need to check for existing guide signs in the area to ensure that they will not obstruct the visibility of the DMS. DMS and guide signs should be spaced far enough apart to allow the driver time to read and process the information on each sign. Typically, DMS should be located a minimum of 800 feet from an upstream or downstream guide sign.

The approach area to a DMS can be divided into three zones as shown in Figure 3-30.

- Detection Zone
- Reading and Decision Zone
- Out-of-Vision Zone

Figure 3-31: DMS Visibility (Not to Scale)



Detection Zone

At typical (70 mph) highway speeds, the DMS should be visible to the approaching driver from between 1,000 to 2,000 feet away. The visibility distance should also be increased if the DMS is placed at an offset from the travel lanes.

Reading and Decision Zone

As a general rule, the message panels on a highway-deployed DMS usually contain room for three lines of text, each with 12 to 21 characters.

Drivers need approximately one second per word to read and comprehend a message. Traveling at 70 mph, this equates to roughly enough time to read and comprehend a 10-word message. The character height, cone of vision, and lateral placement must all be considered when determining the placement of the sign in order to meet sight distance requirements. Typically, the design needs to have drivers recognize the sign at least 800 feet away, and drivers need to be able to comprehend the message a minimum of 600 feet away.

Out-of-Vision Zone

Once the driver gets close to the sign, they will not be able to read the message. The out-of-vision zone distance is determined by the viewing angle of the sign, the structure the sign is attached to, and the lateral placement of the sign.

LATERAL PLACEMENT

National standards regarding lateral placement of signs must be followed when locating and designing a DMS. For overhead mounted DMS, which lane(s) the DMS is placed above depends on the application. For express lane pricing signs, the DMS should be centered over the express lane, while a general purpose DMS should be centered over the general-purpose lanes. Roadside DMS must be placed outside of the clear zone or shielded with a Manual for Assessing Safety Hardware (MASH) compliant crashworthy barrier if placed within the clear zone. The designer should use the MnDOT Road Design Manual and the AASHTO Roadside Design Guide to determine the appropriate clear zone at the DMS location. The DMS structure must be placed far enough behind the guardrail to comply with the minimum guardrail clearance values. Consideration should also be made for snow being thrown by plows, so placing the sign structure right behind the guardrail is not ideal.

The offset of the DMS (i.e., horizontal distance to the sign from the travel lanes) will require additional sight distance to clearly view and react to the sign.

Sign Type Selection

The selection of the sign type, the configuration of the display, and the technology employed all have direct and indirect impacts on the visibility of the message that will be displayed on the DMS. RTMC operations staff need to be consulted to confirm the planned use of the sign and associated DMS model and mounting location.

Matrix Characteristics

DMS display characters and symbols in a matrix format are generally designed in one of the following three patterns:

- Character matrix (oldest)
- Line matrix (older)
- Full matrix (current)

Full matrix DMS displays are the standard format used for permanent MnDOT applications. In this format, the entire display consists of a continuous matrix of pixels.

The industry-standard DMS matrix technology is Light-Emitting Diode (LED) signs. LEDs are semiconductors that emit light when current is applied. Typically, several individual LEDs are "clustered" together to create each pixel. Color displays use a red-green-blue (RGB) cluster for each pixel. LEDs have the added benefit of being able to display signs in full color with the appropriate LED type. The reliability of LEDs is very high.

MnDOT has a multiyear contract for the procurement of full-matrix LED-style DMS.

VIEWING ANGLE

Viewing angles are defined as the area in which the intensity of the LEDs is at 50% of their maximum brightness when a traveler is viewing the DMS from a straight position. For example, at 15 degrees off-center, the LED brightness in a standard 30 degree viewing cone would be 50% of the maximum intensity. The DMS display brightness is adjusted to accommodate different ambient light conditions (day, night, solar glare).

Viewing angle is an important design consideration and will depend on the mounting location of the DMS and the curvature of the roadway. MnDOT does not typically utilize DMS where the viewing angle is less than 15 degrees (30-degree cone).

The roadside signs are skewed so they are not perpendicular to the road to maximize the legibility of the sign. The designer needs to align the DMS so it is perpendicular to the driver's position 500 feet from the sign. The skew angle will vary depending on the offset from the side of the road. The skew angle typically varies from 3-12 degrees. All DMSs mounted on standard truss sign bridges are mounted perpendicular to the road. For DMSs mounted to roadway bridges, the acceptable skew varies from 3-10 degrees. The DMS must be mounted flat to the face of the bridge due to structural design and access considerations, so if the bridge is skewed more than 10 degrees the DMS cannot be placed on that bridge.

SIGN ACCESS

DMS generally utilize one of three different types of access: rear, walk-in, and front access. For overhead or cantilever DMS, MnDOT prefers walk-in style signs in order to avoid the need for traffic control or lane closures for maintenance and to reduce impacts on traffic operations. When installing a DMS near a ditch or drainageway, the designer should consider the walk-in style with the door on the side to provide the closest access to the ground. The designer will also need to consider any clearing and/or grading required around the sign in order to provide an OSHA-compliant work area for the sign. The designer should also consider whether there is room for a maintenance vehicle to access the site and maintain the sign, and in some cases a vehicle pull-off is desired.

OVERHEAD VERSUS ROADSIDE MOUNTING

If there are more than two lanes per direction of traffic or heavy traffic with two lanes per direction, the overhead mount is preferred since other traffic has less opportunity to obstruct the visibility of the DMS. For two lane roads (one lane per direction) or for four lane roads with light traffic, a roadside mounted DMS may be acceptable and is typically less expensive. Table 3-17 provides some pros and cons of the various support types.

Table 3-17: DMS Support Type Comparison

Support Type	Pros	Cons	Other Considerations
Overhead (mounted on roadway bridge)	• Preferred option • Better for visibility • Lower cost than standard sign truss	• Less visibility than mounted on standard truss if bridge has a larger skew	• Can be used on any roadway type • Utilize on high volume roadways
Overhead (mounted on standard truss)	• Best for visibility • No skew compared to roadway bridge mount	• Higher cost than mounted on roadway bridge	• Alternative if limited right-of-way • Can be used on any roadway type
Overhead (mounted on cantilever – 18' DMS only)	• Best for limited right-of-way situations where roadside DMS won't fit	• Higher cost than roadside	• Alternative to roadside if limited right-of-way • Maximum span length is 34 feet

Support Type	Pros	Cons	Other Considerations
Roadside	• Lowest cost	• Smaller display • Worst for visibility • More susceptible to damage during snow removal activities	• Need adequate right-of-way to place outside of the clear zone to minimize the chance of it being hit

The minimum low steel clearance value is 16 feet 4 inches for roadway bridges per federal guidelines, and the MnDOT standard for standard sign trusses is 17 feet 4 inches.

DMS DESIGN PROCESS

General design steps for all ITS devices are listed in Section 4.7 and detailed design steps for DMS are listed in Section 4.8.3.

3.7.4. HOT Lanes

INTRODUCTION AND USAGE

MnDOT operates several toll lane facilities in the Minneapolis-Saint Paul Metropolitan Area, and they all operate as High Occupancy Toll (HOT) lanes. During set times of day, transit buses, motorcycles, and vehicles with two or more occupants (includes children of all ages) (HOV 2+) may drive in the designated E-ZPass Express Lanes for free. Single occupant vehicles that have a E-ZPass account and toll tag must pay a fee to drive in the E-ZPass Express Lanes during set times of day. During all other times of day, all motorists may drive in the E-ZPass Express Lanes (with the exception of the reversible lane sections on I-394). Overhead E-ZPass signs will read “OPEN TO ALL TRAFFIC” when the lanes are open to all motorists.

The fees to drive in the E-ZPass lanes during peak-travel times range between $0.25 and $8. Having variable pricing helps keep traffic in the E-ZPass lanes flowing between 45 mph and the posted speed limit during peak-travel times. Pricing is dependent on the speeds in the E-ZPass lane only and does not consider the general-purpose lanes. The DMS Pricing Sign is updated every three minutes and changes depending on the current demand and speeds in the E-ZPass lane.

The purpose of these projects is to improve travel times and reduce congestion for users along the highway, and to provide an uncongested express lane for transit buses, motorcycles, high-occupancy vehicles (HOV 2+), and single-occupancy vehicles paying an electronic toll. Drivers that use the HOT lanes will experience improved traffic flow, reduced congestion, and better commute times along the route.

COMPONENTS

Typical components required for a HOT lane project are shown in Table 3-18 along with a reference to the section of this manual discussing the component.

Table 3-18: HOT Lane Components

Component	Discussion
Toll Reader (RSU)	This Section
Tolling Antenna	This Section
Enforcement Beacon System	This Section
DMS Pricing Sign	This Section

Component	Discussion
Overhead Structures	This Section
Control Cabinet	Section 3.5
Power	Section 3.1
Communications	Section 3.2

TOLL READER

The toll reader is located in the controller cabinet and requires Ethernet communications. The toll reader is also referred to as a roadside unit (RSU). This RSU is not the same as the RSU used in connected vehicle applications. Every location with a toll reader is technically a toll plaza. The E-ZPass tag information is sent via a signal that is obtained by the tolling antenna and sent to the toll reader that records the tag ID. The E-ZPass toll collection system detects and processes E-ZPass tags, which are then provided to IRIS for further processing. IRIS utilizes tag IDs from the toll collection system to track traveling vehicles to determine the length of the trip and ultimately the price that is charged to the customer's prepaid account.

TOLLING ANTENNA PLACEMENT

Tolling antenna placement is largely driven by the placement of the DMS pricing signs and regulatory E-ZPass signs shown in Figure 3-34 and Figure 3-35. The preferred placement of the tolling antenna is below the regulatory sign directly after the second DMS pricing sign at the beginning of the lane, but this may not always be possible due to site-specific constraints. If it cannot be placed below the regulatory sign, it should be placed below the second DMS pricing sign. After the first tolling antenna location, additional tolling antenna placement is largely determined by interchange entrance ramp locations where vehicles may enter the E-ZPass lane. This gives the driver time to decide whether they want to enter/stay in the HOT lane before reaching the tolling antenna and being charged a fee. The mounting height and angle (15 degrees) of the tolling antenna are also important for optimal operations. Tolling antenna overhead sign truss and bridge mounting details are provided in Figure 3-31 and Figure 3-32, respectively. If the tolling antenna is not placed correctly, the antenna could read toll tags in the adjacent general-purpose lane. It is also important to note that the tolling antenna is directional, so for a reversible lane facility, such as the I-394 E-ZPass reversible lane section, there must be separate tolling antennas mounted for each direction of operation.

Figure 3-32: Tolling Antenna Overhead Sign Truss Mounting Detail

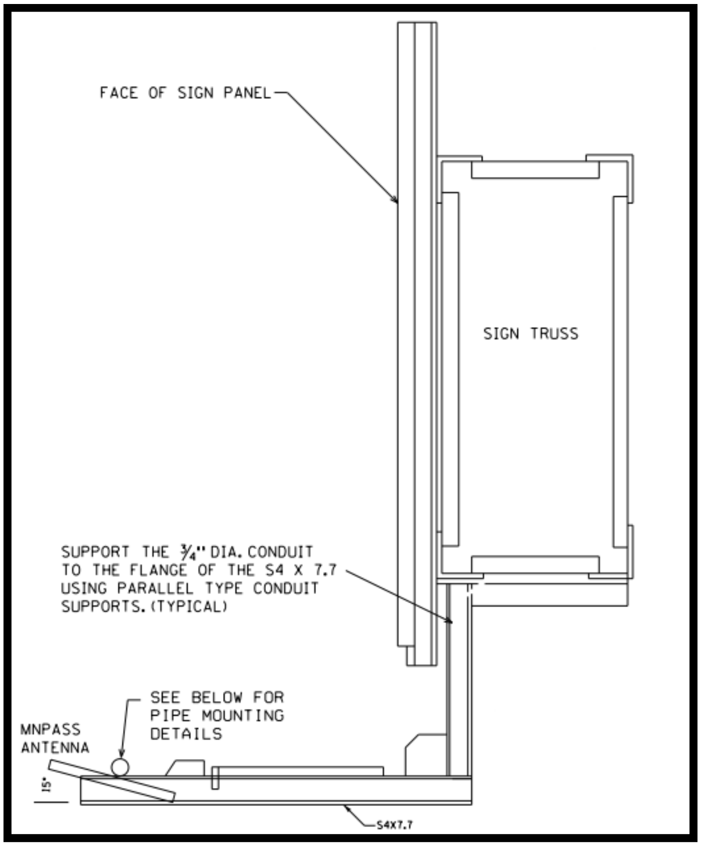


Figure 3-33: Tolling Antenna Bridge Mounting Detail

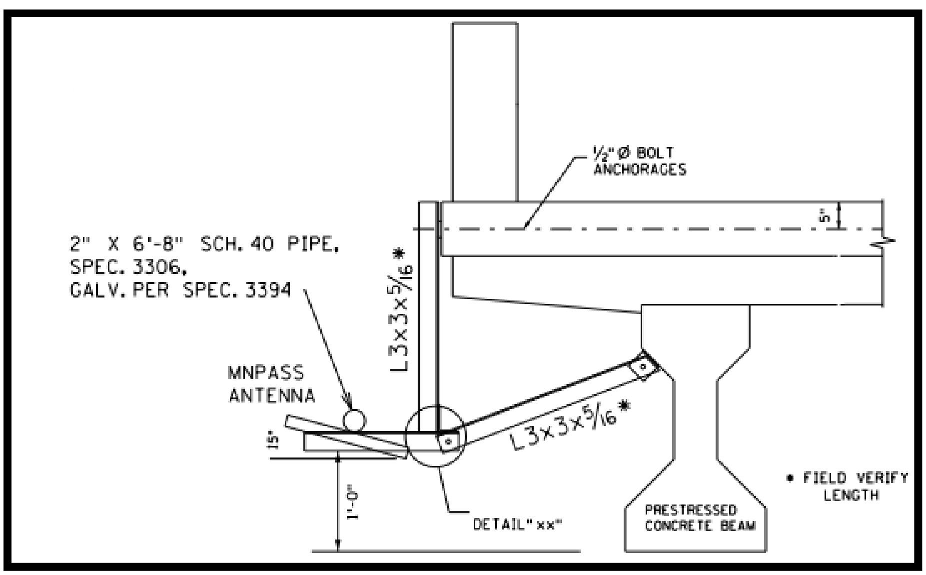
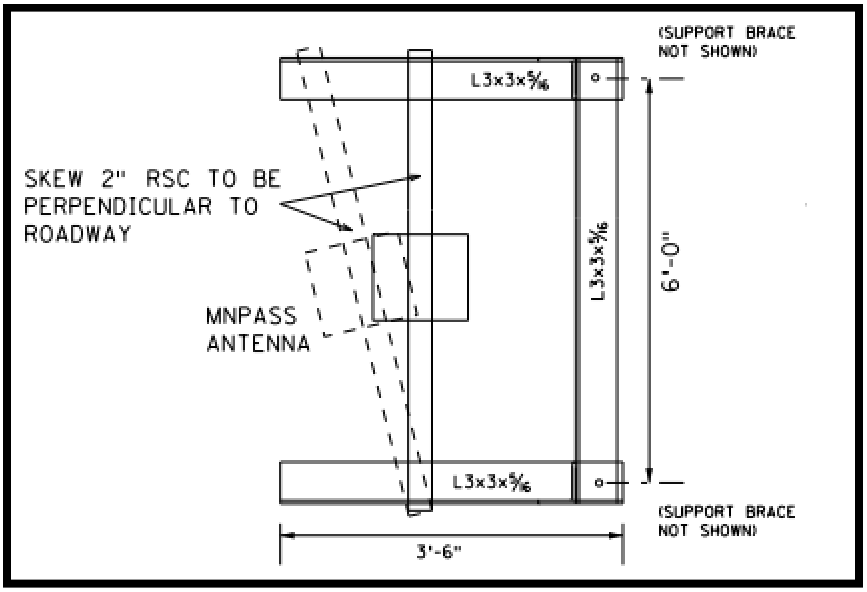


Figure 3-34: Tolling Antenna Pipe Mounting Detail



ENFORCEMENT BEACON SYSTEM PLACEMENT

The enforcement zone should be placed where there is adequate roadway width to be able to have a wide shoulder adjacent to the HOT lane for a State Patrol officer to park where the officer is able to view the enforcement beacon and the vehicle committing the violation. The preferred left shoulder width to provide an enforcement shoulder is 10 feet. It is striped the same as a regular left shoulder, so the only difference is the additional pavement width. A 10-foot continuous inside shoulder is preferred in both directions, but if this is not possible the inside shoulder width can be alternated to provide intermittent enforcement shoulders in each direction. The officer uses the enforcement beacon while parked and while driving. The enforcement beacon must be placed at the same location as the tolling antenna. The enforcement device consists of an ADEC TDC3 detector and a beacon that displays different colors based on whether it successfully read a toll tag via the toll reader. When the ADEC TDC3 detector detects a vehicle in the HOT lane, it sends a signal to obtain a read from the tolling antenna, which then attempts to read a toll tag via the toll reader. Depending on whether the toll reader registers a valid read, the toll reader then sends via a contact closure a signal to the two enforcement light colors. The enforcement beacon displays a blue light for a valid read and an amber light for an invalid read. Locations for enforcement need to be considered during the design, and areas of adequate width need to be provided to:

1. Allow the State Patrol to pull over violators in an area that will not result in the HOT lane being blocked
2. Provide a pull-off at strategic locations where State Patrol can park and observe vehicles and the enforcement beacon simultaneously

DMS PRICING SIGN PLACEMENT

DMS pricing sign placement is based on Figure 3-34 and Figure 3-35. There are typically two DMS pricing signs toward the beginning of the HOT lane. The first DMS pricing sign should be placed between ¼ and ½ mile prior to the start of and at intermediate openings in the HOT lane. For intermediate openings, it should be placed approximately 2,000 feet after the major entrance ramp. Formal collaboration between the RTMC and the signing group is required for HOT lane design since signing is a major component of the design.

OVERHEAD STRUCTURES (SIGN BRIDGE OR ROADWAY BRIDGE)

DMS pricing signs, tolling antennas, enforcement beacons, and regulatory E-ZPass signs are all mounted above the HOT lane on sign bridges or roadway bridges. For each device, requirements for the sign bridge design vary as listed below:

- All sign bridges require sign post nipples to accommodate cables for ITS devices
- Walkways must be included for DMS pricing signs, but they are not included if there is only a tolling antenna mounted to the structure

For devices to be placed on roadway bridges, the roadway bridge location should be close enough to adhere to all the placement guidelines in this section.

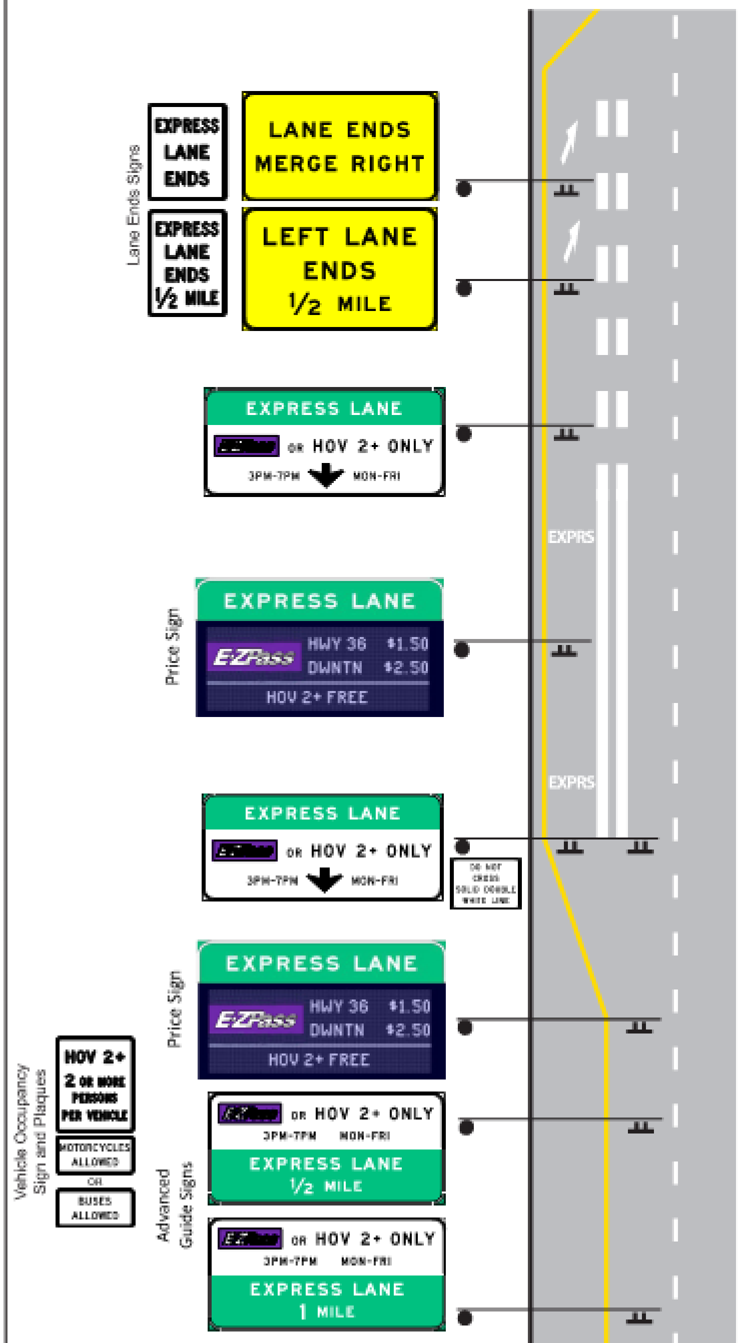
CONTROL CABINET PLACEMENT

Once the toll reader and DMS pricing sign placement has been determined, the placement of the controller cabinets can be established. This placement involves many factors, including:

- Distance between the controller cabinet and the tolling antenna
- Safety of the cabinet location
- Grades
- Drainage
- Maintenance accessibility (parking availability for maintenance vehicles)

A 334MP style cabinet is used at tolling antenna and DMS pricing sign locations. The distance between the controller cabinet and equipment is of concern since the toll reader communication cable has distance and bending radius constraints. All cabinets for a HOT lane facility utilize an urban concrete median barrier and maintenance vehicle pull-off design, shown below in Figure 3-36 and Figure 3-37.

Figure 3-35: Sample E-ZPass Signing Plan (Added Lane)



Lane Ends Warning Signs
Install ½ mile in advance of and at the end of the managed lane.

Express Lane Ends Signs
Install the EXPRESS LANE ENDS ½ MILE (R3-42a) at least ½ mile in advance of the termination of the managed lane on the left (median) post of the overhead sign structure for the LEFT LANE ENDS ½ MILE warning sign. The EXPRESS LANE ENDS (R3-42) shall be installed at the termination of the lane on the left (median) post of the overhead sign structure for the LANE ENDS MERGE RIGHT warning sign.

Periods of Operation Signs
Install the Period of Operation sign at the initial entry point to the managed lane and ¼ mile to ½ mile prior to the beginning of any solid double white lines. Following entrance ramps install the Period of Operation sign following a Price Sign (if installed) approximately 3000ft after each entrance ramps as space allows. If a Price Sign is not installed following an entrance ramp, then install the Period of Operation sign approximately 2000ft after the entrance ramp as space allows.

Price Signs
Install the Price Sign between ¼ mile and ½ mile prior to the initial entry point of the managed lane. If there is 1 mile and ½ mile advance guide signs, the Price sign should go after the ½ mile advanced guide sign. If sign space is limited, and the advance guide signs are required to be installed at ½ mile and ¼ mile, then install the Price Sign between the ½ mile and ¼ mile advance guide signs.

Do Not Cross Solid Double White Line Signs
Install the DO NOT CROSS SOLID DOUBLE WHITE LINE sign at the beginning of the solid double white line and after each entrance ramp where new drivers to the corridor may see a solid double white line.

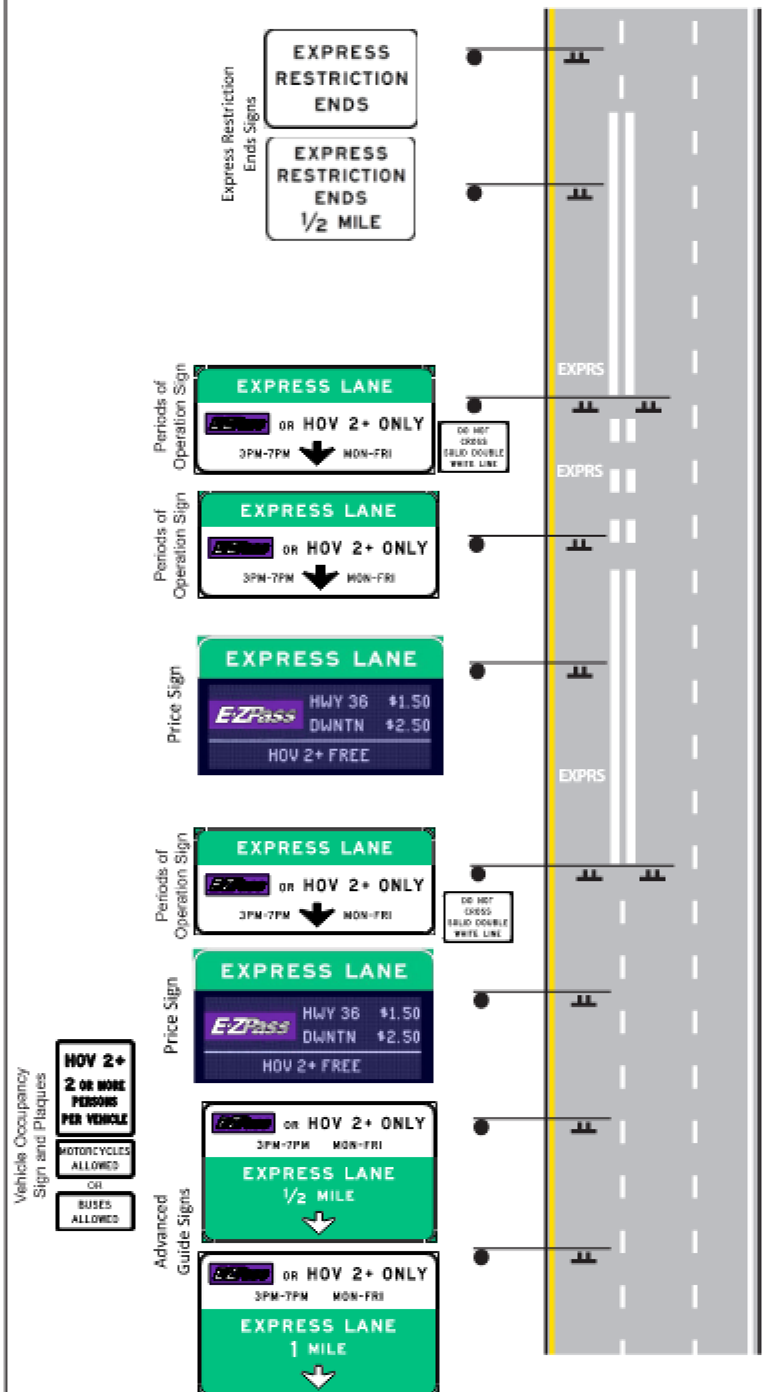
Vehicle Occupancy Signs and Plaques
Install two Vehicle Occupancy signs at the beginning of each Express Lane. Add the buses only plaque under one sign and Motorcycles Allowed plaque under the other sign.

Advance Guide Signs
Install at least ½ mile and at approximately 1 mile prior to the initial entry point.

NOTE: See Pavement Markings Section for guidance on use of pavement markings.

September 2019	E-ZPass SIGNING ADDED MANAGED LANE	FIGURE 6.XX

Figure 3-36: Sample E-ZPass Signing Plan (Dropped General-Purpose Lane)



Express Restriction Ends Signs
Install the EXPRESS RESTRICTION ENDS ½ MILE sign overhead at least ½ mile in advance of the termination of the managed lane. The EXPRESS RESTRICTION ENDS sign shall be installed overhead at the termination of the managed lane.

Periods of Operation Signs
Install the Period of Operation sign at the initial entry point to the managed lane and ¼ mile to ½ mile prior to the beginning of any solid double white lines. Following entrance ramps install the Period of Operation sign following a Price Sign (if installed) approximately 3000ft after each entrance ramps as space allows. If a Price Sign is not installed following an entrance ramp, then install the Period of Operation sign approximately 2000ft after the entrance ramp as space allows.

Price Signs
Install the Price Sign between ¼ mile and ½ mile prior to the initial entry point of the managed lane. If there is 1 mile and ½ mile advance guide signs, the Price sign should go after the ½ mile advanced guide sign. If sign space is limited, and the advance guide signs are required to be installed at ½ mile and ¼ mile, then install the Price Sign between the ½ mile and ¼ mile advance guide signs.

Do Not Cross Solid Double White Line Signs
Install the DO NOT CROSS SOLID DOUBLE WHITE LINE sign at the beginning of the solid double white line and after each entrance ramp where new drivers to the corridor may see a solid double white line.

Vehicle Occupancy Signs and Plaques
Install two Vehicle Occupancy signs at the beginning of each Express Lane. Add the buses only plaque under one sign and Motorcycles Allowed plaque under the other sign.

Advance Guide Signs
Install at least ½ mile and at approximately 1 mile prior to the initial entry point.

NOTE: See Pavement Markings Section for guidance on use of pavement markings.

September 2019	E-ZPass SIGNING GENERAL PURPOSE LANE BECOMES MANAGED LANE	FIGURE 6.YY

Figure 3-37: Concrete Median Barrier Design Special 1 Detail

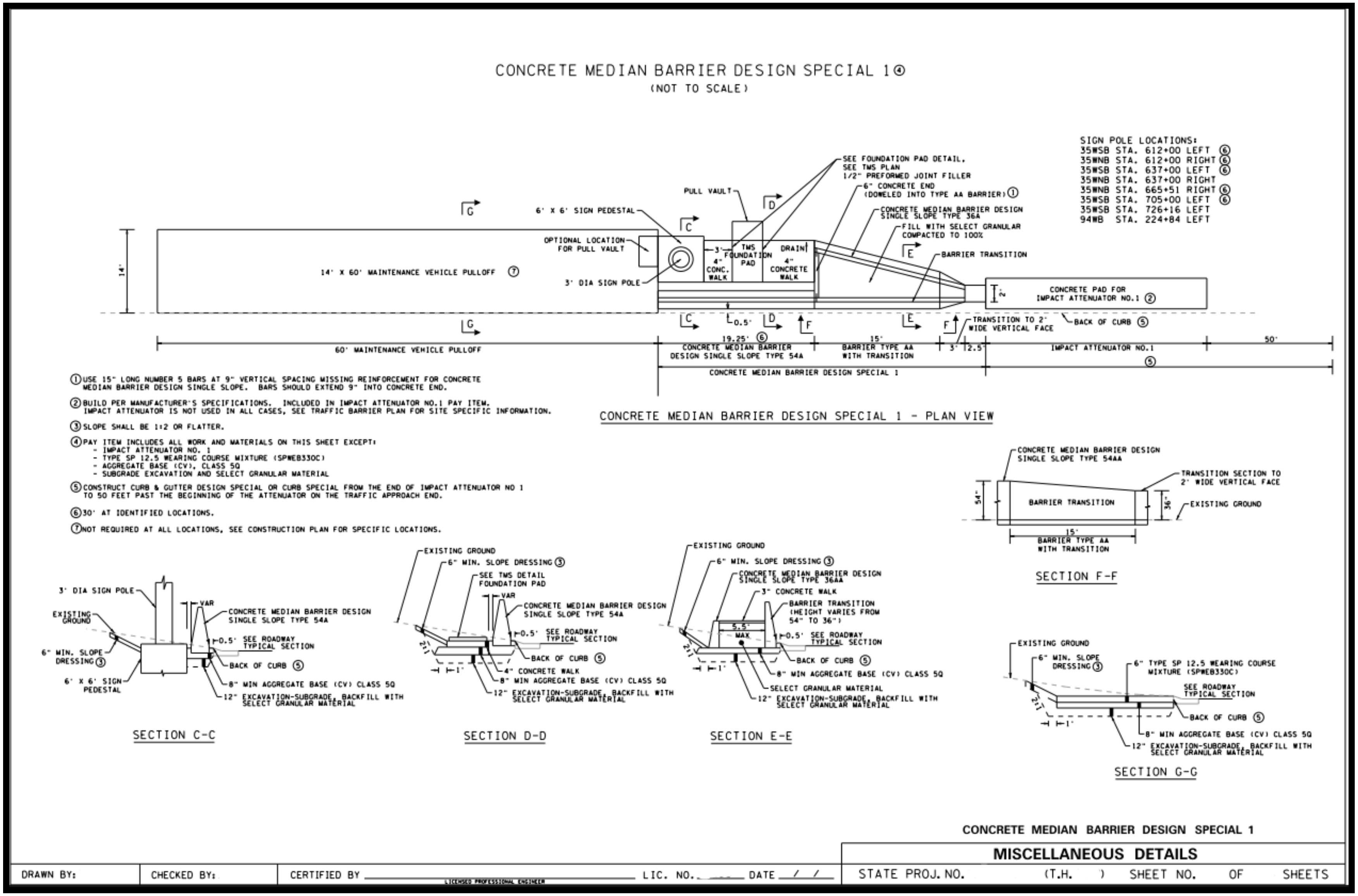
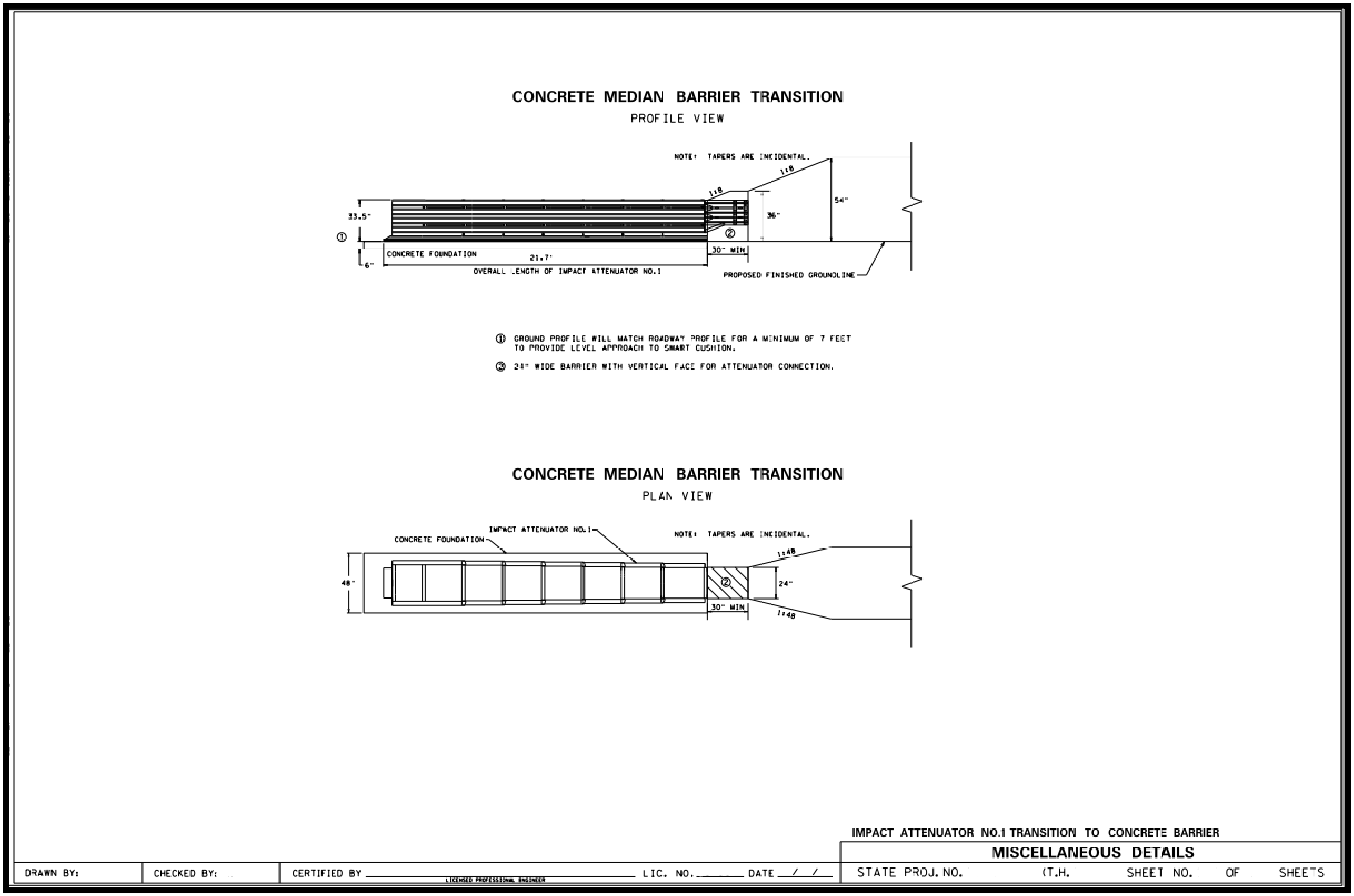


Figure 3-38: Concrete Median Barrier Transition Detail



HOT LANE DESIGN CONSIDERATIONS

This section includes high-level design considerations and guidance to assist ITS practitioners engaged in HOT lane design for MnDOT. Below is a list of several questions that designers should seek to answer as they begin the HOT lane design process. The design of HOT lane facilities requires significant coordination with the signing and pavement marking groups throughout the design process.

- How many segments will the HOT lane corridor be divided into? This is largely dependent on the number of and spacing between interchanges. The 8 foot by 18 foot DMS pricing sign that is typically used can list one or two segments, although if three segments need to be listed a 10 foot by 18 foot DMS will need to be used.
- Will enforcement zones be provided? Downstream enforcement will require intermittently wide inside shoulders for State Patrol to park and enforcement beacons for State Patrol to determine whether a violation has occurred. The enforcement device must be placed in close proximity to the tolling antenna (within 10 feet along the structure).
- What is the interchange spacing? This drives what the toll reader and DMS pricing sign spacing needs to be.
- At the start of a HOT lane, it is preferred to place the toll reader downstream of the second DMS pricing sign below the regulatory E-ZPass sign, but they may need to be placed below the second DMS pricing sign if sign spacing is not adequate.
- Will the HOT lane begin as an added lane or will the general-purpose lane drop and become the HOT lane? It is preferred to begin the HOT lane as an added lane to reduce confusion and last-minute lane changes.
- The controller cabinet should be placed as close as possible to the tolling antenna. The current communications cable for the toll reader (LMR600 ¾-inch coaxial cable) has distance and bending radius limitations, so the total length of the LMR600 cable should not be longer than 100 feet. Longer lengths must be analyzed and approved by MnDOT.
- The DMS pricing signs should be right-justified with the right edge of the DMS over the lane line with the general-purpose lane and should not encroach on the general-purpose lane.
- Placement of DMS pricing signs should provide adequate time for drivers to decide if they want to enter/stay in the HOT lane. See Figure 3-34 and Figure 3-35 for typical HOT lane design.

HOT LANE DESIGN PROCESS

General design steps for all ITS devices are listed in Section 4.7 and detailed design steps for HOT lanes are listed in Section 4.8.4.

3.7.5. Ramp Meters

INTRODUCTION AND USAGE

Ramp metering is an effective strategy for reducing crashes and congestion on the freeway as well as providing more reliable travel times. Ramp meters control the rate at which vehicles enter the mainline such that the downstream capacity is controlled, thereby allowing the freeway to carry the maximum volume at a uniform speed.

Another benefit of ramp metering is its ability to break up platoons of vehicles that have been released from a nearby signalized intersection. The mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time. However, when platoons (i.e., groups) of vehicles attempt to force their way into freeway traffic, turbulence and shockwaves are created, causing the mainline flow to breakdown. Reducing the turbulence in merge zones can also lead to a reduction in sideswipe and rear-end type accidents that are associated with stop-and-go, erratic traffic flow.

MnDOT has researched the use of ramp meters extensively. This research found that the use of ramp metering results in increased vehicle throughput, decreased travel times, increased speeds, improved trip reliability, and fewer crashes on freeways. The capacity of a metered freeway is higher than an unmetered freeway. The Transportation Policy Plan documents that metered freeways have a higher capacity than unmetered freeways with 1,950 versus 1,750 vehicles per hour per lane, respectively.

Ramps may be metered as one lane, as two metered lanes, as two metered lanes with an HOV bypass, and as two metered lanes with a metered HOV bypass. The single lane metering applies only to retrofit situations where widening of a ramp or loop is not practical, and in some cases to new construction where the RTMC decided to implement one lane metering. In all other cases, a two-lane metering of the on-ramps and loops shall be designed.

Figure 3-39: Ramp Meter

When first implemented, MnDOT operated ramp meters by time of day. For the past 30 years, MnDOT has used adaptive ramp metering. The adaptive ramp metering algorithm is incorporated into their ATMS (IRIS) along with field devices (ramp meters, ramp detection, and mainline detection) to operate the ramp metering system. IRIS looks at freeway operations three miles downstream of the ramp meter or to the closest bottleneck.

COMPONENTS

Typical components required for a ramp meter project are shown in Table 3-19 along with a reference to the section of this manual discussing the component.

Table 3-19: Ramp Meter Components

Component	Discussion
Ramp Meter Signals and Mounting	This Section
Control Cabinet	Section 3.5
Power	Section 3.1
Communications	Section 3.2

RAMP METER SIGNALS AND MOUNTING

Ramp meter pedestal poles are no longer painted and are spun anodized aluminum.

One-Way Ramp Control Signal Detail:

http://www.dot.state.mn.us/rtmc/pdfdgn_design/ramp/ONE%20WAY%20RAMP%20CONTROL%20SIGNAL_dt1.pdf

RAMP METER DESIGN CONSIDERATIONS

Ramp Meter Signal Placement

Depending on the geometric layout of the ramp, the ramp meter type and ramp meter signal placement need to be determined. This placement involves many factors, including:

- Are one-way or two-way ramp meter signals needed based on the ramp geometry?
- The placement of the ramp meter signals must consider providing adequate acceleration distance and queue storage. The designer should work with the RTMC operations group to determine the optimal design.

Ramp Meter Cabinet Placement

Once the ramp meter type, ramp meter signal placement, and geometric layout of the ramp have been determined, the placement of the controller cabinet can be established. This placement involves many factors, including:

- Visibility of the signals from the controller cabinet
- Distance between the controller cabinet and the loop detectors
- Distance between the controller cabinet and the signals on the ramp
- Safety of the cabinet location (do not place the cabinet on the outside of a curve)
- Grades
- Drainage
- Maintenance accessibility (parking availability for maintenance vehicles)

For maintenance considerations, it is preferred that the signals be visible from the controller cabinet, but this is not always possible. The distance between the cabinet and equipment is also of concern, since longer distances may require heavier gauge cables typically not used in standard ramp meter design. Section 3.1.8 discusses cable sizing and voltage drop calculations. Heavier gauge cables can be used where required, but they increase the number of different cables on a contract and increase construction costs.

It should also be noted that only four ramps can be run out of one cabinet for ramp metering. For cases with more than four ramps, such as a cloverleaf interchange with ramps for all eight movements, at least two cabinets would be needed if all ramps were to be metered.

The slope of the terrain for cabinet placement must be no steeper than 4:1. Placement of the cabinet on 3:1 slopes or steeper require grading provisions to provide a level area around the cabinet.

Loop Detector Placement

Demand, passage, and queue loop detection required for ramp meter installations are typically illustrated at precise locations in the ramp meter plans. The plans should provide all loop detection information including location (station), description (type), and size (in feet). When placing queue loop detection for ramp meter applications, the designer should work with RTMC operations to determine the optimal location. MnDOT uses four turns per loop detector; additional details can be found in the MnDOT Standard Plans.

Detection is a critical component of effective ramp meter operations. Accurate detection on the mainline and ramps is crucial for effective adaptive ramp metering. Further information on detection can be found in the detection Section 3.7.1.

Advance Warning Sign Placement

Placement of a traditional advanced warning sign (e.g., “Ramp Metered When Flashing”) depends upon the functional intent of the warning signs.

- Pre-Entrance Notification: Under pre-entrance notification, the functional intent of the sign is to warn motorists approaching the ramp that it is currently being metered. The placement of advance warning signs under this scenario should provide adequate sight distance along the cross street, allowing the motorist ample time to decide whether to enter the freeway system at that location, or bypass the ramp meter and travel along alternate routes.
- Post-Entrance Notification: Under post-entrance notification, the functional intent of the sign is to warn motorists upon entering the ramp that metering is currently being implemented. The placement of advance warning signs under this scenario should provide adequate sight distance upon entering the ramp while allowing sufficient distance between the sign and estimated back of queue.

RAMP METER DESIGN PROCESS

General design steps for all ITS devices are listed in Section 4.7 and detailed design steps for ramp meters are listed in Section 4.8.5.

4. Plans, Specifications, and Estimate (PS&E) Design Steps

4.1. General

The objective of this chapter is to present the fundamental procedures and standard practices related to the design of ITS. The final product of the pre-construction activities in ITS design is the plans and Special Provisions. Supporting the plans and Special Provisions are the standard design practices, Standard Plates Manual, the Minnesota Standard Specifications for Highway Construction, other applicable national and local standards, and any necessary agreements.

4.1.1. Required Sheets

Standard ITS design plans shall contain at least the following sheets:

- Title Sheet
- General Layout Sheets (showing location of plan sheets)
- TMS Components & Standard Plates
- Utility Listings & Construction Notes
- Estimated Quantities
- Construction Plans
- Detail Sheet Tabulation
- Details Sheets (may include one or more of the following)
    - Pull Vault Detail
    - Fiber Optic Pull Vault, Splice Vault, and Splice Vault Installation
    - Typical Foundation Details
    - Install Fiber Optic (FO) Patching Shelter
    - Cabinet Details
    - Signing Layout Details
    - Sign Structural Details
    - Loop Detector Details
    - DMS Grounding Typical
    - Video Camera Pole Detail and Pole Installation Detail
    - Pole Mounted Fiber Termination Cabinet
    - Buried Cable Sign Placement Detail
    - Guardrail Installations
    - End Treatment Details
    - Fiber Distribution Equipment Details and Cable Labeling Details
    - Other(s)
- Communications Schematics/Testing
- Standard Plan Sheets
- Signing Plans
- Other(s)

Section 4.7 in this chapter illustrates the steps followed to complete the design process for ITS design. The ITS sample plan is available from the OTE website at http://www.dot.state.mn.us/its/design.html.

4.1.2. Sheet Size and Scale

Final ITS plans should be prepared on 11 by 17 inch plan sheets. The original title sheet shall be of vellum composition. The scale for the construction plans shall be 100 scale. Each sheet of the plan must be properly identified in the lower right corner (State Project or State Aid Project Number and Sheet XX of XX).

The licensed professional engineer responsible for or under whose supervision the work is performed shall sign the title sheet.

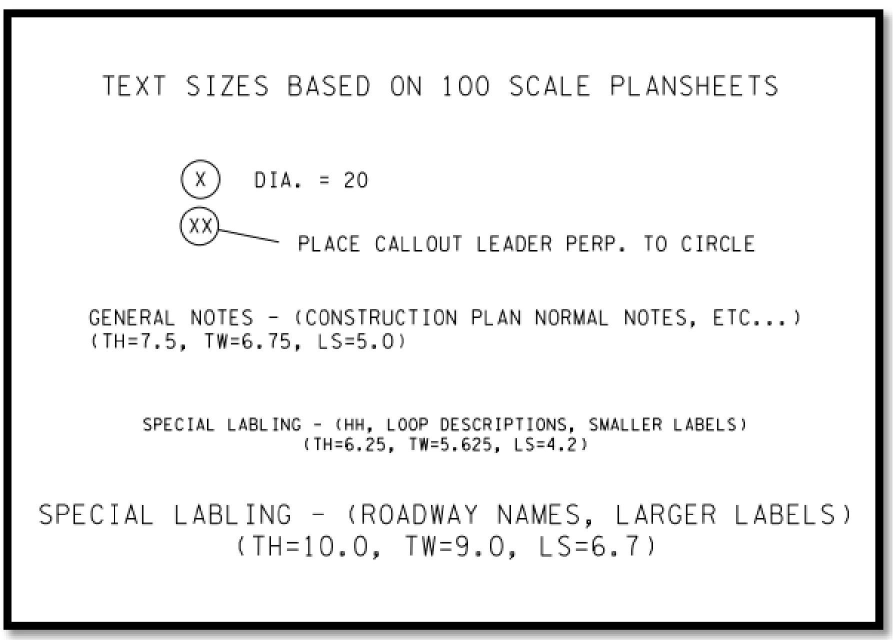
4.1.3. CADD Standards

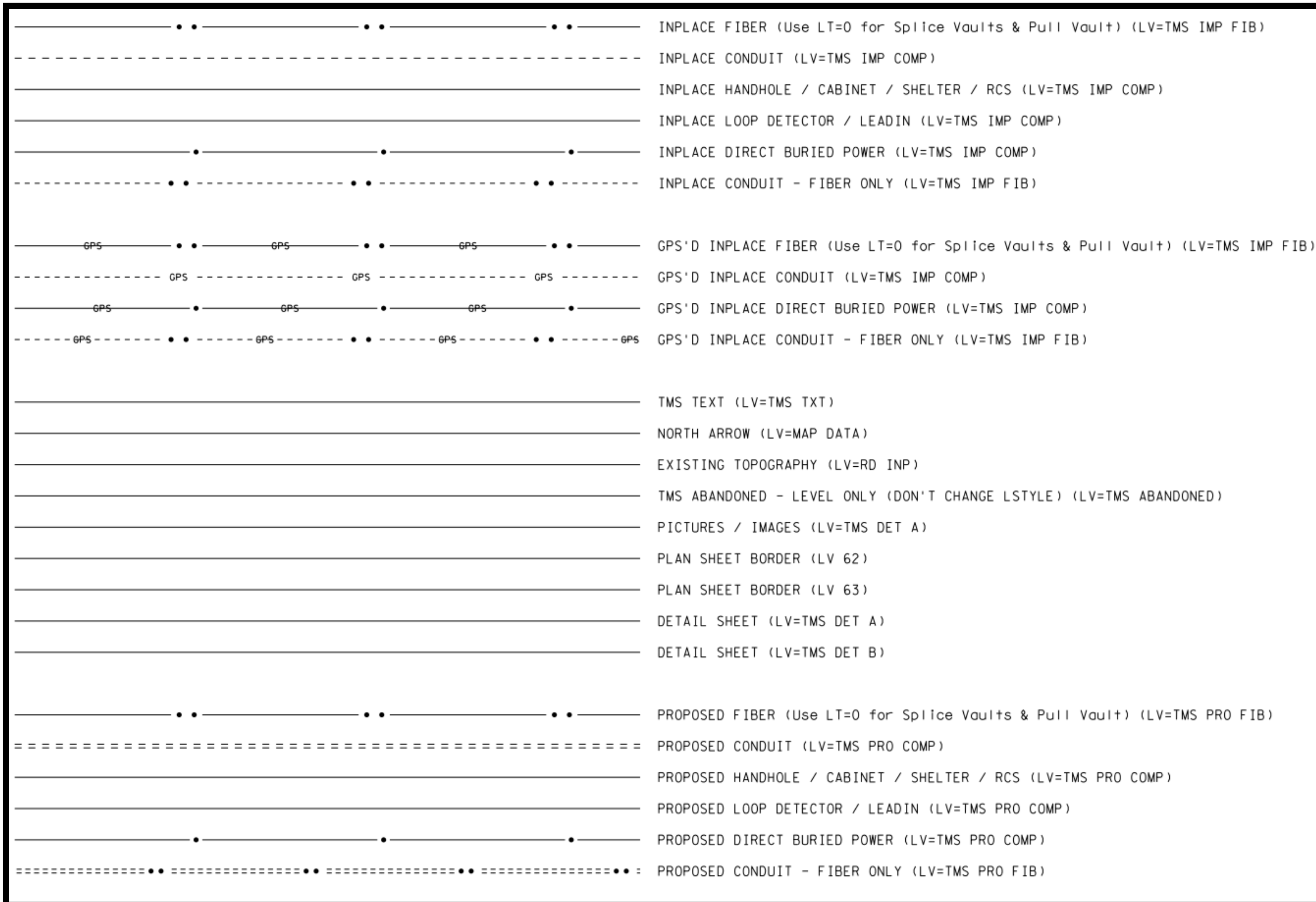
MnDOT and the RTMC have specific CADD standards that should be followed. MnDOT's Computer Aided Engineering Services (CAES) Unit develops CADD standards. MnDOT's website for CADD Resources and Data Standards is: http://www.dot.state.mn.us/caes/index.html.

MnDOT CADD Standards are documented here: http://www.dot.state.mn.us/caes/files/pdf/mndot-caddstandardsdocumentation.pdf.

There are a variety of tables, tabulations, and notes that are created and inserted into the plans. These items are created in Word and Excel and are imported into MicroStation using MS Office Importer rather than creating them in MicroStation. This process is required by CAES standards and it is important so that there is consistency with items such as font, text size, line weights, row heights, and column widths. It is also considerably more efficient to create and edit these documents in Word and Excel.

RTMC specific standards for font number, text size, line types, and levels are shown below:

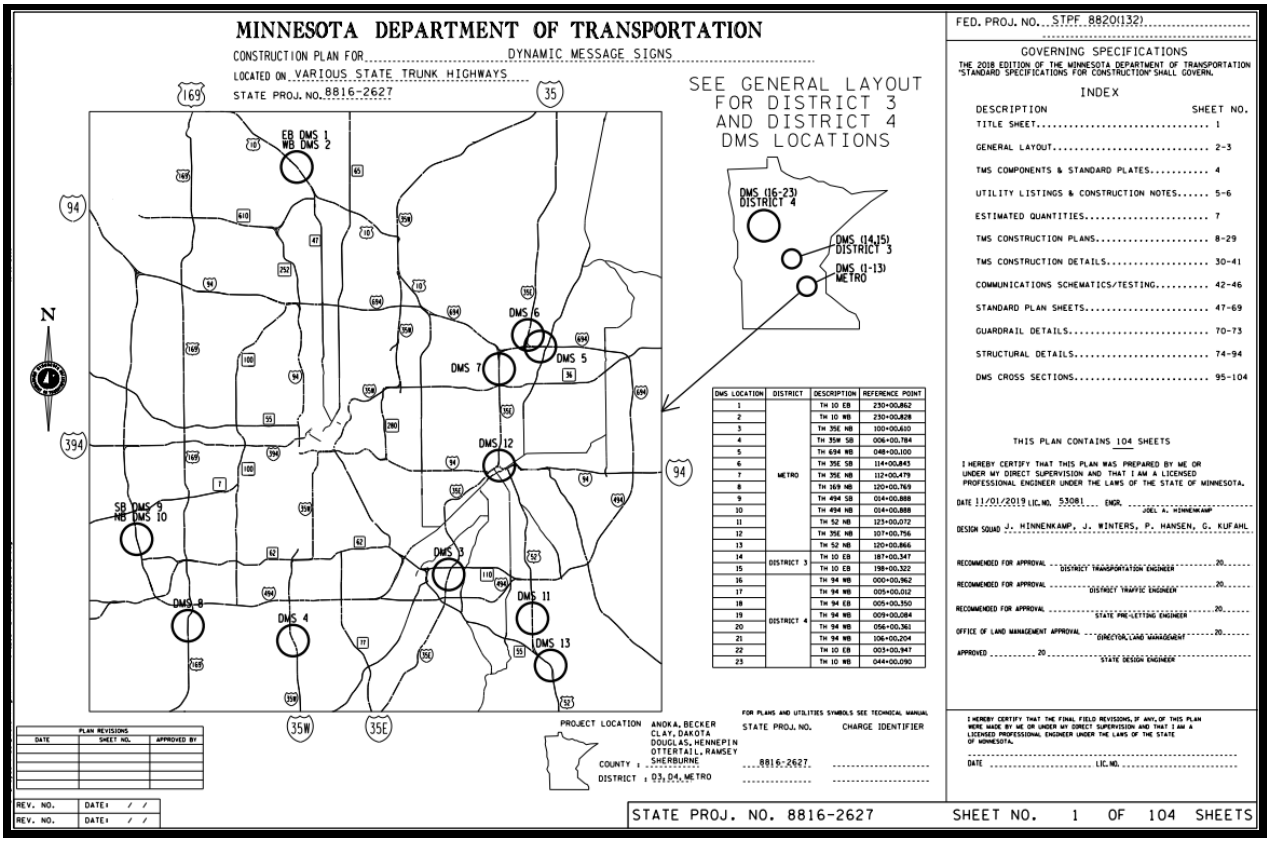



INPLACE FIBER (Use LT=0 for Splice Vaults & Pull Vault) (LV=TMS IMP FIB)
INPLACE CONDUIT (LV=TMS IMP COMP)
INPLACE HANDHOLE / CABINET / SHELTER / RCS (LV=TMS IMP COMP)
INPLACE LOOP DETECTOR / LEADIN (LV=TMS IMP COMP)
INPLACE DIRECT BURIED POWER (LV=TMS IMP COMP)
INPLACE CONDUIT - FIBER ONLY (LV=TMS IMP FIB)
GPS
GPS'D INPLACE FIBER (Use LT=0 for Splice Vaults & Pull Vault) (LV=TMS IMP FIB)
GPS'D INPLACE CONDUIT (LV=TMS IMP COMP)
GPS'D INPLACE DIRECT BURIED POWER (LV=TMS IMP COMP)
GPS'D INPLACE CONDUIT - FIBER ONLY (LV=TMS IMP FIB)
TMS TEXT (LV=TMS TXT)
NORTH ARROW (LV=MAP DATA)
EXISTING TOPOGRAPHY (LV=RD INP)
TMS ABANDONED - LEVEL ONLY (DON'T CHANGE LSTYLE) (LV=TMS ABANDONED)
PICTURES / IMAGES (LV=TMS DET A)
PLAN SHEET BORDER (LV 62)
PLAN SHEET BORDER (LV 63)
DETAIL SHEET (LV=TMS DET A)
DETAIL SHEET (LV=TMS DET B)
PROPOSED FIBER (Use LT=0 for Splice Vaults & Pull Vault) (LV=TMS PRO FIB)
PROPOSED CONDUIT (LV=TMS PRO COMP)
PROPOSED HANDHOLE / CABINET / SHELTER / RCS (LV=TMS PRO COMP)
PROPOSED LOOP DETECTOR / LEADIN (LV=TMS PRO COMP)
PROPOSED DIRECT BURIED POWER (LV=TMS PRO COMP)
PROPOSED CONDUIT - FIBER ONLY (LV=TMS PRO FIB)

4.2. Typical Plan Sets and Components

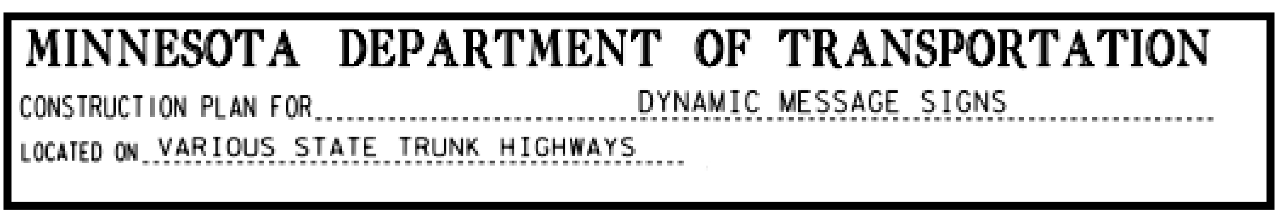
4.2.1. Title Sheet

The title sheet is required for all ITS plans. It includes information such as the title block, project location, governing specifications, etc. A sample title sheet is shown below. Primary components of this sheet are further described later in this subsection. Contact the project manager to obtain project boundaries.



PLAN DESCRIPTION AND LOCATION

This defines the type of work being performed and the location of the work. The location identified should list intersections from west to east or south to north.



MINNESOTA DEPARTMENT OF TRANSPORTATION

CONSTRUCTION PLAN FOR DYNAMIC MESSAGE SIGNS

LOCATED ON VARIOUS STATE TRUNK HIGHWAYS

GOVERNING SPECIFICATIONS AND INDEX OF SHEETS

This defines the governing specifications for the project, the project funding, and the index of sheets contained within the plan set. Generally, it is located in the upper right-hand corner of the title sheet, under the Federal Project number or statement “STATE FUNDS”.

GOVERNING SPECIFICATIONS

THE 2018 EDITION OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION "STANDARD SPECIFICATIONS FOR CONSTRUCTION" SHALL GOVERN.

INDEX

DESCRIPTION	SHEET NO.
TITLE SHEET	1
GENERAL LAYOUT	2-3
TMS COMPONENTS & STANDARD PLATES	4
UTILITY LISTINGS & CONSTRUCTION NOTES	5-6
ESTIMATED QUANTITIES	7
TMS CONSTRUCTION PLANS	8-29
TMS CONSTRUCTION DETAILS	30-41
COMMUNICATIONS SCHEMATICS/TESTING	42-46
STANDARD PLAN SHEETS	47-69
GUARDRAIL DETAILS	70-73
STRUCTURAL DETAILS	74-94
DMS CROSS SECTIONS	95-104

THIS PLAN CONTAINS 104 SHEETS

FIELD REVISIONS CERTIFICATION NOTE

This identifies:

- Who the plan set was developed by (or under the direct supervision of)
- That individual's state of Minnesota registration information.

I HEREBY CERTIFY THAT THE FINAL FIELD REVISIONS, IF ANY, OF THIS PLAN WERE MADE BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

______________________________ LIC. NO. __________ DATE: __________

PRINTED NAME:

This block is located under the index of sheets.

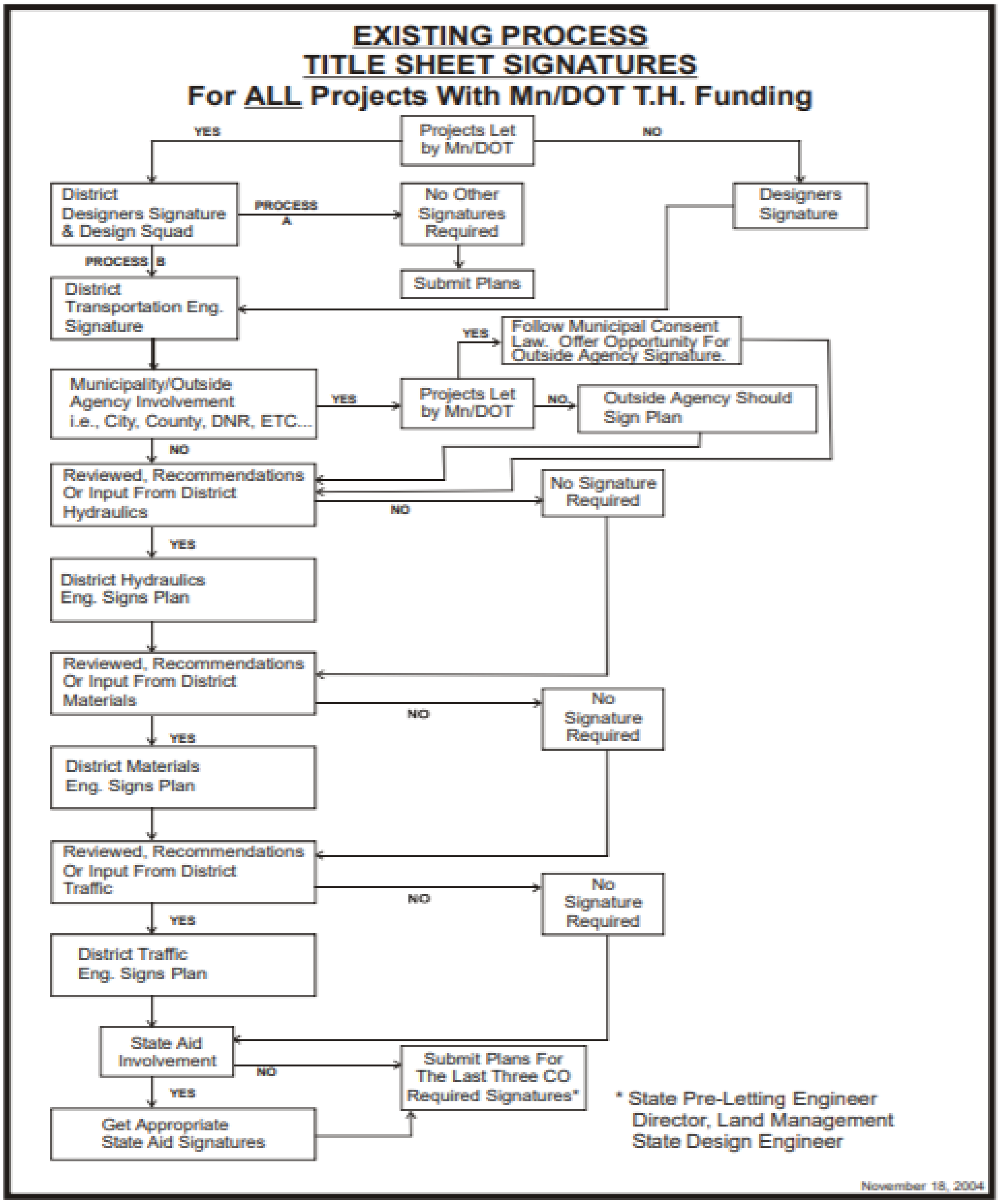
STATE PROJ.NO. XXXX-XX (T.H.156=112) SHEET NO. 1 OF 20 SHEETS

Note: On the title sheet, after the state project number, the trunk highway and legislative route number must be shown in parenthesis (T.H. 156 = ###) where ### is the legislative route number.

SIGNATURE BLOCK

The designer should consult with the project manager to ensure that the appropriate signature block is used. Chapter 1 of the MnDOT Design Scene includes a flowchart for determining which signatures are required. The Design Scene is located at the link below, and a screenshot of the flowchart is included below.

http://www.dot.state.mn.us/pre-letting/scene/index.html



The image below shows the signatures that are required for a typical State Transportation Improvement Plan (STIP) project. This block is located below the Plan Preparation Certification note.

RECOMMENDED FOR APPROVAL __________________________ 20______
DISTRICT TRANSPORTATION ENGINEER

RECOMMENDED FOR APPROVAL __________________________ 20______
DISTRICT TRAFFIC ENGINEER

RECOMMENDED FOR APPROVAL __________________________ 20______
STATE PRE-LETTING ENGINEER

OFFICE OF LAND MANAGEMENT APPROVAL __________________________ 20______
DIRECTOR, LAND MANAGEMENT

APPROVED __________ 20 __________________________
STATE DESIGN ENGINEER

PROJECT NUMBERS AND SHEET NUMBERS

The project numbers and sheet numbers are shown in the lower right-hand corner of the title sheet and on all other sheets. For revisions to the plan made after project advertisement, an "R" shall be used after the sheet number. For stand-alone ITS projects all sheets are numbered numerically, but for projects where the TMS plans are part of a larger plan set the TMS sheets are numbered with the prefix SZ (e.g. SZ01) and are included at the end of the plan set after all the numerical sections. This is typically done for all functional group plans outside the construction group, including Traffic Control Plans (TC), Permanent Pavement Marking Plans (PM), Lighting Plans (SL), Signing Plans (ST), Traffic Management System Plans (SZ), and Traffic Control Signal System Plans (SS).

STATE PROJ.NO. XXXX-XX (T.H.156=112) SHEET NO. 1 OF 20 SHEETS

A SP in the project number stands for State Project. A SP is necessary for any project on a trunk highway. A SAP is a State Aid Project number indicating that the local agency is using State Aid funds to finance their share of the project. If the project has federal funding, the SAP becomes a SP. All state aid numbers should be listed on all sheets to which they apply.

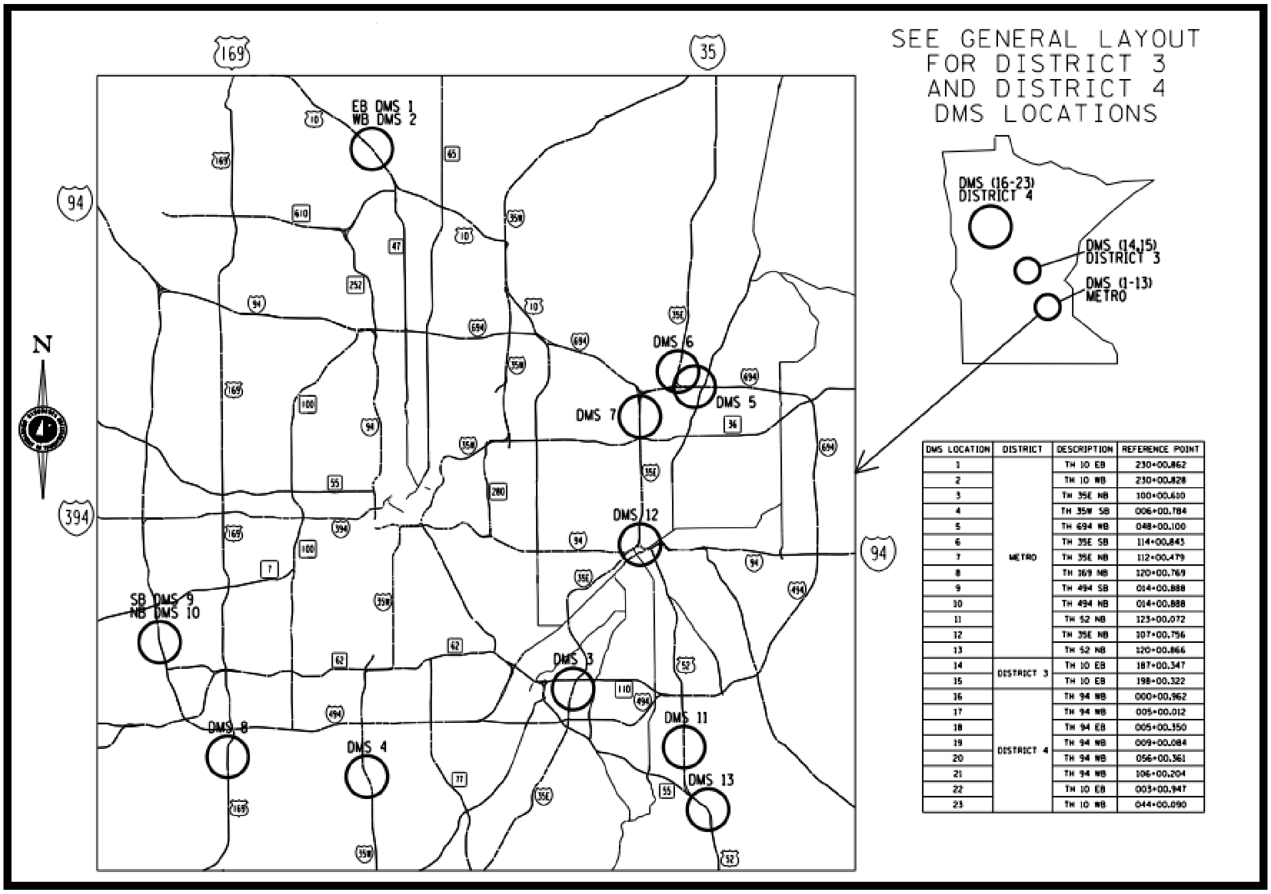
The general format for a SP number is "CCNN-A". CC is the county number in alphabetical order (i.e., Anoka County is 02). NN is the control section number within the county that is unique to the roadway in the county. A is the number of the project on that control section (i.e., 269 means that there have been 268 other projects on this section of roadway prior to this project).

The general format for a SAP number is CCC-NNN-A. CCC is a 3-digit city number and a two-digit number is a county number. NNN is a number related to the roadway and project type. A is the number of the project in that city or county of that type.

INDEX MAP

The index map is used to identify the location of the project(s) and/or project work areas. Provide leader lines from the beginning and end of the project limits to the appropriate points on the map. This is generally located near the center of the title sheet.

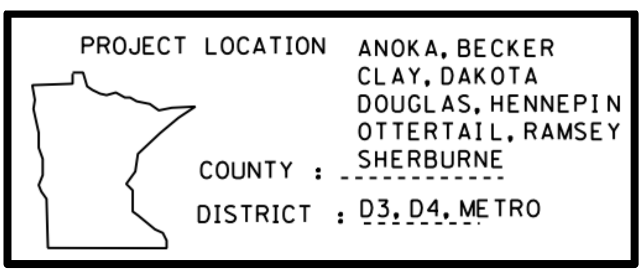
If appropriate, identify all SAP numbers applicable to the project. Also, label all individual device locations such as DMS, RWIS, video camera, etc. if it is a device-specific project.



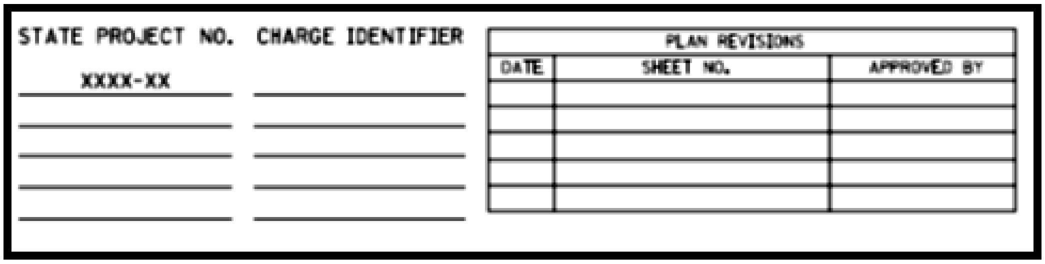
DMS LOCATION	DISTRICT	DESCRIPTION	REFERENCE POINT
1	METRO	TH 10 EB	230+00.862
2		TH 10 WB	230+00.828
3		TH 35E NB	100+00.610
4		TH 35W SB	006+00.784
5		TH 694 WB	048+00.100
6		TH 35E SB	114+00.843
7		TH 35E NB	112+00.479
8		TH 169 NB	120+00.769
9		TH 494 SB	014+00.888
10		TH 494 NB	014+00.888
11		TH 52 NB	123+00.072
12		TH 35E NB	107+00.756
13		TH 52 NB	120+00.866
14	DISTRICT 3	TH 10 EB	187+00.347
15		TH 10 EB	198+00.322
16	DISTRICT 4	TH 94 WB	000+00.962
17		TH 94 WB	005+00.012
18		TH 94 EB	005+00.350
19		TH 94 WB	009+00.084
20		TH 94 WB	056+00.361
21		TH 94 WB	106+00.204
22		TH 10 EB	003+00.947
23		TH 10 WB	044+00.090

PROJECT LOCATION

The information included in this block is the generalized location (county and city). This is generally located in the lower right part of the title sheet, left of the signature block, and above the project number block.



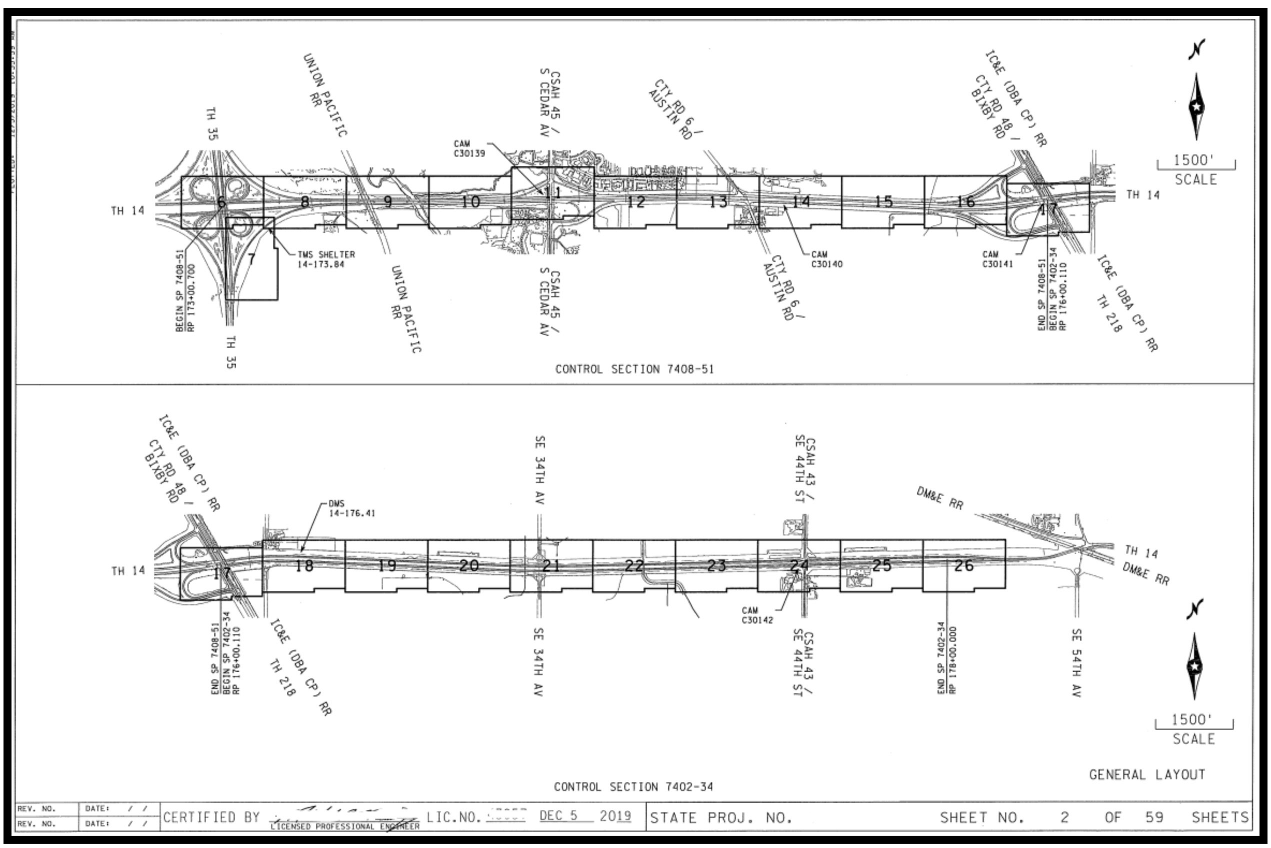
PLAN REVISIONS BLOCK



This block is included so that future revisions can be documented. This is generally located in lower center portion of the title sheet. Pencil in the charge identifier number. MnDOT plan processing will edit this as necessary.

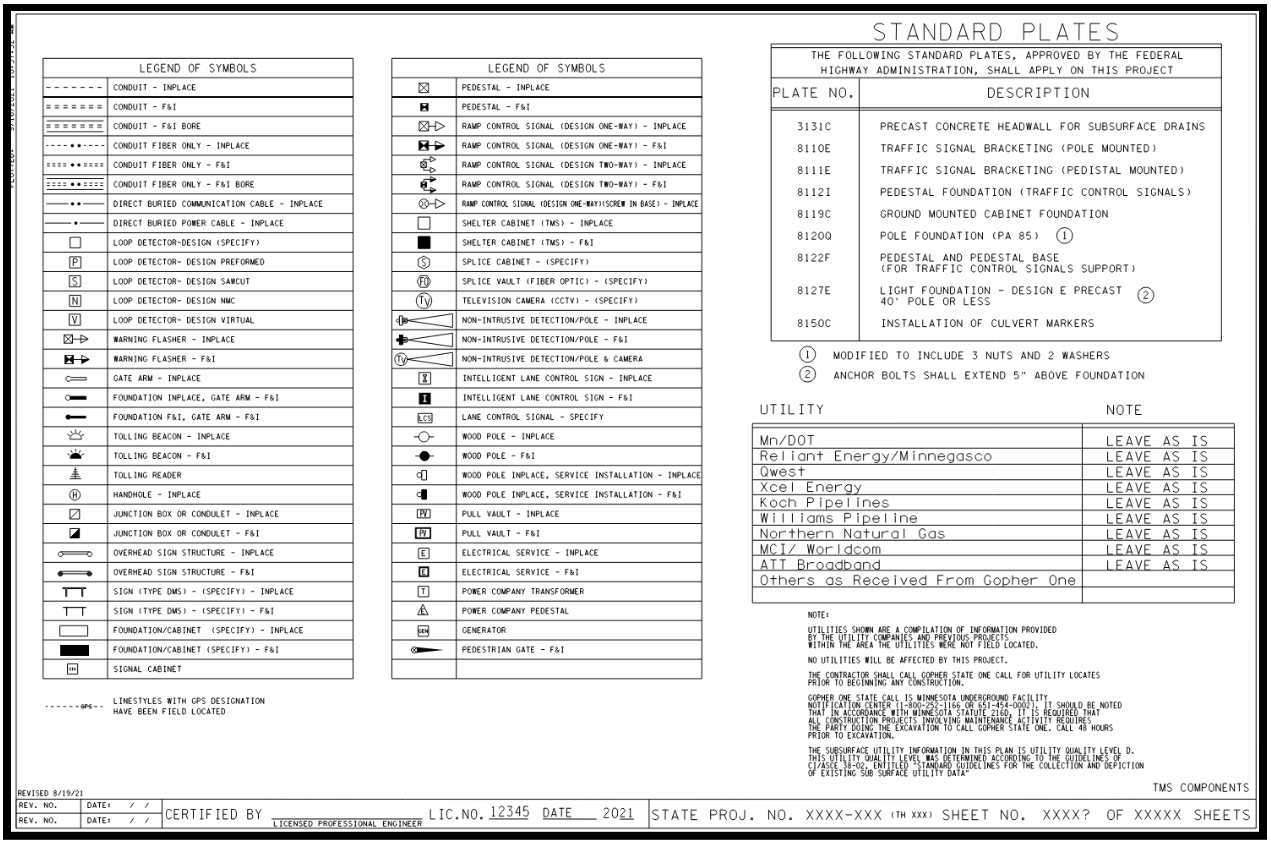
4.2.2. General Layout Sheets

The general layout sheets show the general orientation and location of the construction plan sheets and major TMS components within the project area.



4.2.3. TMS Components & Standard Plates Sheet

The TMS Components & Standard Plates sheet is required for all ITS plans. It includes information such as the legend of symbols and applicable standard plates. A sample TMS components sheet is shown below. Primary components of this sheet are further described later in this subsection.



	LEGEND OF SYMBOLS
	CONDUIT - INPLACE
	CONDUIT - F&I
	CONDUIT - F&I BORE
	CONDUIT FIBER ONLY - INPLACE
	CONDUIT FIBER ONLY - F&I
	CONDUIT FIBER ONLY - F&I BORE
	DIRECT BURIED COMMUNICATION CABLE - INPLACE
	DIRECT BURIED POWER CABLE - INPLACE
	LOOP DETECTOR-DESIGN (SPECIFY)
	LOOP DETECTOR- DESIGN PREFORMED
	LOOP DETECTOR- DESIGN SAWCUT
	LOOP DETECTOR- DESIGN NMC
	LOOP DETECTOR- DESIGN VIRTUAL
	WARNING FLASHER - INPLACE
	WARNING FLASHER - F&I
	GATE ARM - INPLACE
	FOUNDATION INPLACE, GATE ARM - F&I
	FOUNDATION F&I, GATE ARM - F&I
	TOLLING BEACON - INPLACE
	TOLLING BEACON - F&I
	TOLLING READER
	HANDHOLE - INPLACE
	JUNCTION BOX OR CONDULET - INPLACE
	JUNCTION BOX OR CONDULET - F&I
	OVERHEAD SIGN STRUCTURE - INPLACE
	OVERHEAD SIGN STRUCTURE - F&I
	SIGN (TYPE DMS) - (SPECIFY) - INPLACE
	SIGN (TYPE DMS) - (SPECIFY) - F&I
	FOUNDATION/CABINET (SPECIFY) - INPLACE
	FOUNDATION/CABINET (SPECIFY) - F&I
SIG	SIGNAL CABINET

GPS — LINESTYLES WITH GPS DESIGNATION HAVE BEEN FIELD LOCATED

	LEGEND OF SYMBOLS
	PEDESTAL - INPLACE
	PEDESTAL - F&I
	RAMP CONTROL SIGNAL (DESIGN ONE-WAY) - INPLACE
	RAMP CONTROL SIGNAL (DESIGN ONE-WAY) - F&I
	RAMP CONTROL SIGNAL (DESIGN TWO-WAY) - INPLACE
	RAMP CONTROL SIGNAL (DESIGN TWO-WAY) - F&I
	RAMP CONTROL SIGNAL (DESIGN ONE-WAY)(SCREW IN BASE) - INPLACE
	SHELTER CABINET (TMS) - INPLACE
	SHELTER CABINET (TMS) - F&I
S	SPLICE CABINET - (SPECIFY)
FO	SPLICE VAULT (FIBER OPTIC) - (SPECIFY)
TV	TELEVISION CAMERA (CCTV) - (SPECIFY)
	NON-INTRUSIVE DETECTION/POLE - INPLACE
	NON-INTRUSIVE DETECTION/POLE - F&I
TV	NON-INTRUSIVE DETECTION/POLE & CAMERA
I	INTELLIGENT LANE CONTROL SIGN - INPLACE
I	INTELLIGENT LANE CONTROL SIGN - F&I
LCS	LANE CONTROL SIGNAL - SPECIFY
	WOOD POLE - INPLACE
	WOOD POLE - F&I
	WOOD POLE INPLACE, SERVICE INSTALLATION - INPLACE
	WOOD POLE INPLACE, SERVICE INSTALLATION - F&I
PV	PULL VAULT - INPLACE
PV	PULL VAULT - F&I
E	ELECTRICAL SERVICE - INPLACE
E	ELECTRICAL SERVICE - F&I
T	POWER COMPANY TRANSFORMER
E	POWER COMPANY PEDESTAL
GEN	GENERATOR
	PEDESTRIAN GATE - F&I

STANDARD PLATES

THE FOLLOWING STANDARD PLATES, APPROVED BY THE FEDERAL HIGHWAY ADMINISTRATION, SHALL APPLY ON THIS PROJECT

PLATE NO.	DESCRIPTION
3131C	PRECAST CONCRETE HEADWALL FOR SUBSURFACE DRAINS
8110E	TRAFFIC SIGNAL BRACKETING (POLE MOUNTED)
8111E	TRAFFIC SIGNAL BRACKETING (PEDISTAL MOUNTED)
8112I	PEDESTAL FOUNDATION (TRAFFIC CONTROL SIGNALS)
8119C	GROUND MOUNTED CABINET FOUNDATION
8120Q	POLE FOUNDATION (PA 85) (1)
8122F	PEDESTAL AND PEDESTAL BASE (FOR TRAFFIC CONTROL SIGNALS SUPPORT)
8127E	LIGHT FOUNDATION - DESIGN E PRECAST 40' POLE OR LESS (2)
8150C	INSTALLATION OF CULVERT MARKERS

(1) MODIFIED TO INCLUDE 3 NUTS AND 2 WASHERS

(2) ANCHOR BOLTS SHALL EXTEND 5" ABOVE FOUNDATION

UTILITY	NOTE
Mn/DOT	LEAVE AS IS
Reliant Energy/Minnegasco	LEAVE AS IS
Qwest	LEAVE AS IS
Xcel Energy	LEAVE AS IS
Koch Pipelines	LEAVE AS IS
Williams Pipeline	LEAVE AS IS
Northern Natural Gas	LEAVE AS IS
MCI/ Worldcom	LEAVE AS IS
ATT Broadband	LEAVE AS IS
Others as Received From Gopher One	

NOTE:

UTILITIES SHOWN ARE A COMPILATION OF INFORMATION PROVIDED BY THE UTILITY COMPANIES AND PREVIOUS PROJECTS WITHIN THE AREA THE UTILITIES WERE NOT FIELD LOCATED.

NO UTILITIES WILL BE AFFECTED BY THIS PROJECT.

THE CONTRACTOR SHALL CALL GOPHER STATE ONE CALL FOR UTILITY LOCATES PRIOR TO BEGINNING ANY CONSTRUCTION.

GOPHER ONE STATE CALL IS MINNESOTA UNDERGROUND FACILITY NOTIFICATION CENTER (1-800-252-1166 OR 651-454-0002). IT SHOULD BE NOTED THAT IN ACCORDANCE WITH MINNESOTA STATUTE 216D, IT IS REQUIRED THAT ALL CONSTRUCTION PROJECTS INVOLVING MAINTENANCE ACTIVITY REQUIRES THE PARTY DOING THE EXCAVATION TO CALL GOPHER STATE ONE. CALL 48 HOURS PRIOR TO EXCAVATION.

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS UTILITY QUALITY LEVEL WAS DETERMINED ACCORDING TO THE GUIDELINES OF CI/ASCE 38-02, ENTITLED "STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUB SURFACE UTILITY DATA"

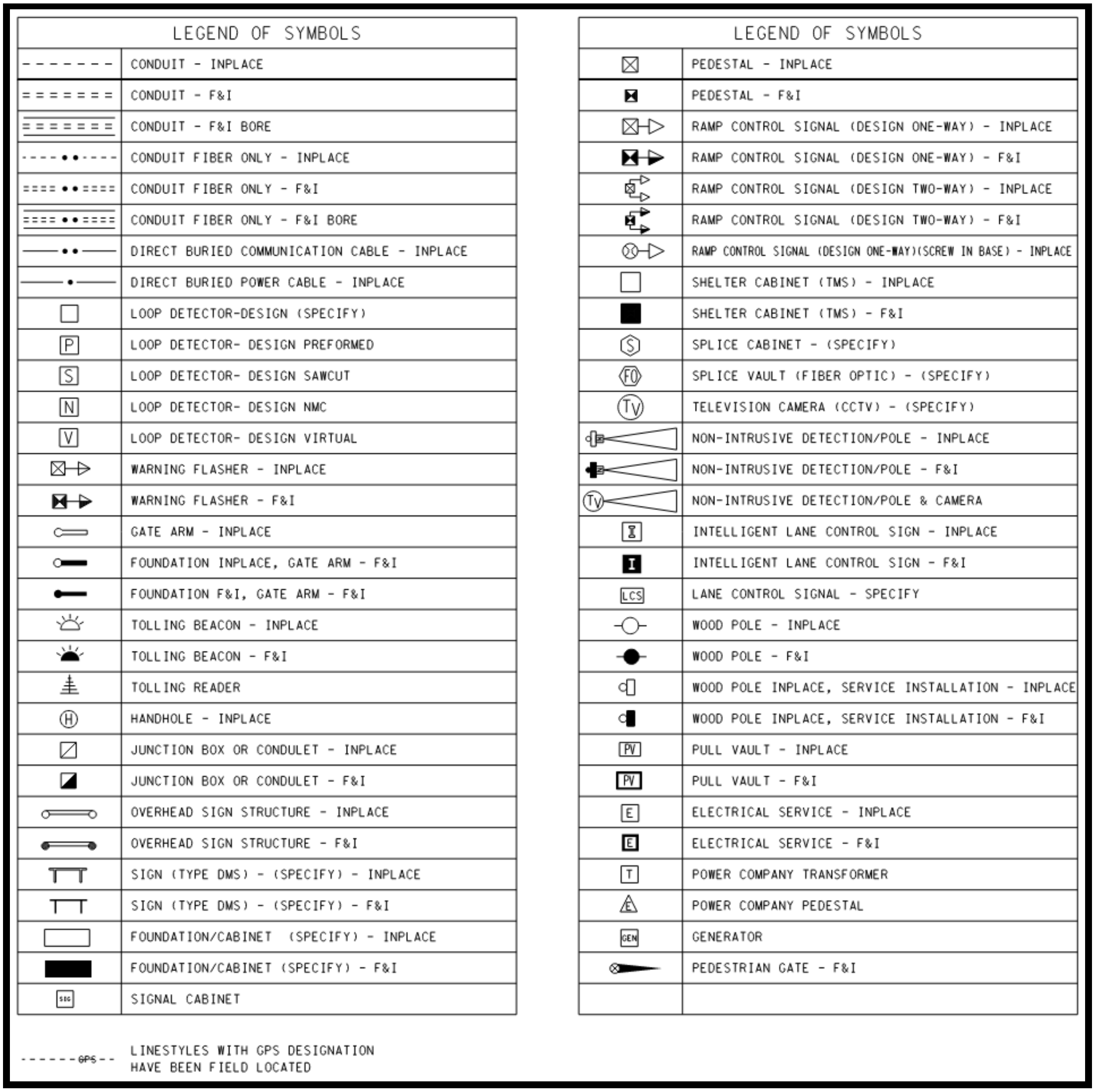
TMS COMPONENTS

REVISED 8/19/21

REV. NO.	DATE: / /	CERTIFIED BY ____ LICENSED PROFESSIONAL ENGINEER	LIC.NO. 12345	DATE ____ 2021	STATE PROJ. NO. XXXX-XXX (TH XXX)	SHEET NO. XXXX? OF XXXXX SHEETS
REV. NO.	DATE: / /					

LEGEND OF SYMBOLS

These are the standard symbols pertaining to TMS design.



LEGEND OF SYMBOLS
CONDUIT - INPLACE
CONDUIT - F&I
CONDUIT - F&I BORE
CONDUIT FIBER ONLY - INPLACE
CONDUIT FIBER ONLY - F&I
CONDUIT FIBER ONLY - F&I BORE
DIRECT BURIED COMMUNICATION CABLE - INPLACE
DIRECT BURIED POWER CABLE - INPLACE
LOOP DETECTOR-DESIGN (SPECIFY)
LOOP DETECTOR- DESIGN PREFORMED
LOOP DETECTOR- DESIGN SAWCUT
LOOP DETECTOR- DESIGN NMC
LOOP DETECTOR- DESIGN VIRTUAL
WARNING FLASHER - INPLACE
WARNING FLASHER - F&I
GATE ARM - INPLACE
FOUNDATION INPLACE, GATE ARM - F&I
FOUNDATION F&I, GATE ARM - F&I
TOLLING BEACON - INPLACE
TOLLING BEACON - F&I
TOLLING READER
HANDHOLE - INPLACE
JUNCTION BOX OR CONDULET - INPLACE
JUNCTION BOX OR CONDULET - F&I
OVERHEAD SIGN STRUCTURE - INPLACE
OVERHEAD SIGN STRUCTURE - F&I
SIGN (TYPE DMS) - (SPECIFY) - INPLACE
SIGN (TYPE DMS) - (SPECIFY) - F&I
FOUNDATION/CABINET (SPECIFY) - INPLACE
FOUNDATION/CABINET (SPECIFY) - F&I
SIGNAL CABINET

LEGEND OF SYMBOLS
PEDESTAL - INPLACE
PEDESTAL - F&I
RAMP CONTROL SIGNAL (DESIGN ONE-WAY) - INPLACE
RAMP CONTROL SIGNAL (DESIGN ONE-WAY) - F&I
RAMP CONTROL SIGNAL (DESIGN TWO-WAY) - INPLACE
RAMP CONTROL SIGNAL (DESIGN TWO-WAY) - F&I
RAMP CONTROL SIGNAL (DESIGN ONE-WAY)(SCREW IN BASE) - INPLACE
SHELTER CABINET (TMS) - INPLACE
SHELTER CABINET (TMS) - F&I
SPLICE CABINET - (SPECIFY)
SPLICE VAULT (FIBER OPTIC) - (SPECIFY)
TELEVISION CAMERA (CCTV) - (SPECIFY)
NON-INTRUSIVE DETECTION/POLE - INPLACE
NON-INTRUSIVE DETECTION/POLE - F&I
NON-INTRUSIVE DETECTION/POLE & CAMERA
INTELLIGENT LANE CONTROL SIGN - INPLACE
INTELLIGENT LANE CONTROL SIGN - F&I
LANE CONTROL SIGNAL - SPECIFY
WOOD POLE - INPLACE
WOOD POLE - F&I
WOOD POLE INPLACE, SERVICE INSTALLATION - INPLACE
WOOD POLE INPLACE, SERVICE INSTALLATION - F&I
PULL VAULT - INPLACE
PULL VAULT - F&I
ELECTRICAL SERVICE - INPLACE
ELECTRICAL SERVICE - F&I
POWER COMPANY TRANSFORMER
POWER COMPANY PEDESTAL
GENERATOR
PEDESTRIAN GATE - F&I

LINESTYLES WITH GPS DESIGNATION HAVE BEEN FIELD LOCATED

STANDARD PLATES SUMMARY

This identifies the list of Standard Plates that are applicable to this project.

STANDARD PLATES

THE FOLLOWING STANDARD PLATES, APPROVED BY THE FEDERAL HIGHWAY ADMINISTRATION, SHALL APPLY ON THIS PROJECT

PLATE NO.	DESCRIPTION
3131C	PRECAST CONCRETE HEADWALL FOR SUBSURFACE DRAINS
8110E	TRAFFIC SIGNAL BRACKETING (POLE MOUNTED)
8111E	TRAFFIC SIGNAL BRACKETING (PEDISTAL MOUNTED)
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8122F	PEDESTAL AND PEDESTAL BASE (FOR TRAFFIC CONTROL SIGNALS SUPPORT)
8127E	LIGHT FOUNDATION - DESIGN E PRECAST 40' POLE OR LESS (2)
8150C	INSTALLATION OF CULVERT MARKERS

(1) MODIFIED TO INCLUDE 3 NUTS AND 2 WASHERS

(2) ANCHOR BOLTS SHALL EXTEND 5" ABOVE FOUNDATION

4.2.4. Utility Listings & Construction Notes Sheet

The Utility Listings & Construction Notes sheet is required for all ITS plans. It includes information such as the utility listing for each work area, utility notes, and general construction notes. A sample Utility Listings & Construction Notes sheet is shown below. Primary components of this sheet are further described later in this subsection.

DMS LOCATION 21: ALEXANDRIA TH 94 WB R.P. 106+00.204	
UTILITY	NOTE
MINNESOTA INFORMATION TECHNOLOGY SERVICES	LEAVE AS IS
MNDOT	LEAVE AS IS
NORTHERN NATURAL GAS COMPANY	LEAVE AS IS
NUSTAR ENERGY, LP	LEAVE AS IS
RUNESTONE ELECTRIC ASSOCIATION	LEAVE AS IS
SPRINT COMMUNICATIONS COMPANY, LP	LEAVE AS IS

DMS LOCATION 22: DILWORTH TH 10 WEST OF 12TH ST	
UTILITY	NOTE
702 COMMUNICATIONS	LEAVE AS IS
CABLE ONE, INCORPORATED	LEAVE AS IS
CENTURYLINK	LEAVE AS IS
CITY OF DILWORTH	LEAVE AS IS
CONSOLIDATED COMMUNICATIONS	LEAVE AS IS
MIDCONTINENT COMMUNICATIONS	LEAVE AS IS
MOORHEAD PUBLIC SERVICE UTILITY	LEAVE AS IS
XCEL ENERGY	LEAVE AS IS

DMS LOCATION 23: DETROIT LAKES TH 10 WEST OF TH 59	
UTILITY	NOTE
ARVIG COMMUNICATIONS SYSTEMS	LEAVE AS IS
CENTURYLINK	LEAVE AS IS
DETROIT LAKES PUBLIC UTILITIES	LEAVE AS IS
CONSOLIDATED COMMUNICATIONS	LEAVE AS IS
MINNESOTA ENERGY RESOURCES CORPORATION	LEAVE AS IS
MNDOT	LEAVE AS IS
ROGERS TELECOM US INCORPORATED	LEAVE AS IS

UTILITY NOTES:

UTILITIES SHOWN ARE A COMPILATION OF INFORMATION PROVIDED BY THE UTILITY COMPANIES AND PREVIOUS PROJECTS WITHIN THE AREA THE UTILITIES WERE NOT FIELD LOCATED.

NO UTILITIES WILL BE AFFECTED BY THIS PROJECT.

THE CONTRACTOR SHALL CALL GOPHER STATE ONE CALL FOR UTILITY LOCATES PRIOR TO BEGINNING ANY CONSTRUCTION.

GOPHER STATE ONE CALL IS MINNESOTA UNDERGROUND FACILITY NOTIFICATION CENTER (1-800-252-1166 OR 651-454-0002). IT SHOULD BE NOTED THAT IN ACCORDANCE WITH MINNESOTA STATUTE 216D, IT IS REQUIRED THAT ALL CONSTRUCTION PROJECTS INVOLVING MAINTENANCE ACTIVITY REQUIRES THE PARTY DOING THE EXCAVATION TO CALL GOPHER STATE ONE CALL. CALL 48 HOURS PRIOR TO EXCAVATION.

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS UTILITY QUALITY LEVEL WAS DETERMINED ACCORDING TO THE GUIDELINES OF CI/ASCE 38-02, ENTITLED "STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUB SURFACE UTILITY DATA"

GENERAL CONSTRUCTION NOTES:

1. BURIED FIBER OPTIC CABLE SHALL BE PLACED AT LEAST 20 FEET FROM CULVERTS OUTLETS, UNLESS OTHERWISE SPECIFIED OR DIRECTED BY THE ENGINEER. IN MEDIANS, PLACE HALFWAY UP SLOPE BETWEEN DRAINAGE DITCH AND EXISTING OR POTENTIAL FUTURE CABLE BARRIER.
2. BORED FIBER OPTIC CABLE LOCATIONS SHALL BE VERIFIED BY THE ENGINEER PRIOR TO PERFORMING WORK.
3. BORED FIBER OPTIC CABLE AT CULVERT LOCATIONS SHALL BE PLACED UNDER CULVERTS UNLESS OTHERWISE SPECIFIED OR DIRECTED BY THE ENGINEER.
4. POLES SHALL BE PLACED BEHIND EXISTING GUARDRAIL, WHERE GUARDRAIL EXISTS, OR OUTSIDE OF THE CLEAR ZONE. POLES IN OPEN AREAS SHALL BE PLACED ON UPPER SIDE OF BACKSLOPE, WHERE POSSIBLE. POLE LOCATIONS SHALL BE AS DIRECTED BY THE ENGINEER.
5. CO-LOCATION (JOINT TRENCH) OF CONDUITS SHALL BE USED WHENEVER POSSIBLE AND NOTED ON AS-BUIT PLANS.
6. EMPTY CONDUITS, NOT PLACED IN JOINT TRENCH WITH FILLED CONDUITS FOR ENTIRE LENGTH, SHALL HAVE A NO.12 TRACE WIRE FURNISHED AND INSTALLED WITH MINIMUM 3' COIL AT BOTH ENDS OF EMPTY CONDUITS AND TRACE WIRE SHALL BE INCIDENTAL. LABEL BOTH ENDS AS "LOCATE WIRE".
7. NO OPEN TRENCHING IN WETLAND AREAS.
8. WHEN FO CABLE INSTALLED IN MEDIAN, BURIED CABLE SIGNS TO BE AT 200' SPACING.
9. TURF ESTABLISHMENT & EROSION CONTROL FOR TRAFFIC MANAGEMENT SYSTEM PLACEMENT SHALL BE CONSIDERED INCIDENTAL, APPLIED TO ALL DISTURBED AREAS, IN ACCORDANCE WITH MNDOT 2575.1, 2575.2, 2575.3, AND THE FOLLOWING
   - SEED MIXTURE 25-141
   - FERTILIZER TYPE 3, ANALYSIS 22-5-10 (NPK) APPLIED AT A RATE OF 350 POUNDS/ACRE.
   - ROLLED EROSION PREVENTION CATEGORY 20 PER MNDOT 2575.3
10. ALL DRAINAGE INLETS WITHIN 200 FEET OF ANY DISTURBED SOIL IN THE MEDIAN SHALL BE PROVIDED WITH APPROPRIATE INLET PROTECTION PRIOR TO DISTURBANCE. INLET PROTECTION SHALL BE INCIDENTAL UNLESS OTHERWISE SPECIFIED IN THE CONTRACT.
11. ALL MATERIAL REMOVED AND NOT REUSED ON THIS PROJECT SHALL BECOME THE PROPERTY OF THE CONTRACTOR AND BE DISPOSED OF OUTSIDE MNDOT RIGHT OF WAY IN ACCORDANCE WITH SPEC. 2106.
12. SALVAGE AND INSTALLATION OF CULVERT MARKER POSTS ARE INCIDENTAL.
13. ANY REQUIRED GRADING SHALL BE DONE BEFORE GUARDRAIL POSTS ARE SET.

NO	DATE	BY	CKD	APPR	REVISION

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.
Print Name:
Date 11/01/2019 License #

STATE PROJ. NO.

DESIGN TEAM
DRAWN BY:
DESIGNER:
CHECKED BY:

Kimley»Horn

MINNESOTA DEPARTMENT OF TRANSPORTATION
UTILITY LISTINGS & CONSTRUCTION NOTES
SHEET 6 OF 104

UTILITY NOTES

These are the general Utility Notes.

UTILITY NOTES:

UTILITIES SHOWN ARE A COMPILATION OF INFORMATION PROVIDED BY THE UTILITY COMPANIES AND PREVIOUS PROJECTS WITHIN THE AREA THE UTILITIES WERE NOT FIELD LOCATED.

NO UTILITIES WILL BE AFFECTED BY THIS PROJECT.

THE CONTRACTOR SHALL CALL GOPHER STATE ONE CALL FOR UTILITY LOCATES PRIOR TO BEGINNING ANY CONSTRUCTION.

GOPHER STATE ONE CALL IS MINNESOTA UNDERGROUND FACILITY NOTIFICATION CENTER. IT SHOULD BE NOTED THAT IN ACCORDANCE WITH MINNESOTA STATUTE 216D, IT IS REQUIRED THAT ALL CONSTRUCTION PROJECTS INVOLVING MAINTENANCE ACTIVITY REQUIRES THE PARTY DOING THE EXCAVATION TO CALL GOPHER STATE ONE CALL. CALL 48 HOURS PRIOR TO EXCAVATION.

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS UTILITY QUALITY LEVEL WAS DETERMINED ACCORDING TO THE GUIDELINES OF CI/ASCE 38-02, ENTITLED "STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUB SURFACE UTILITY DATA"

Utility quality level is a professional opinion about the quality and reliability of utility information. There are four levels of utility quality information, ranging from the most precise and reliable, level A, to the least precise and reliable, level D. The utility quality level must be determined in accordance with guidelines established by the Construction Institute of the American Society of Civil Engineers in document CI/ASCE 38-02 entitled "Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data."

According to Minnesota Statutes, section 216D.04, subdivision 1a, all plans for projects with excavation must depict the utility quality level of the utility information. Unless there is proof that the utility information in the plan is more accurate, MnDOT assumes that it is Utility Quality Level D. The project manager must use the following note, filling in the appropriate utility quality level, on the utility tabulation sheets for projects involving excavation:

> The subsurface utility information in this plan is utility quality level ___. This utility quality level was determined according to the guidelines of CI/ASCE 38- 02, entitled "Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data."

The Minnesota statute on utilities can be found at the following web site:

https://www.revisor.mn.gov/statutes/cite/216D.04

The plans and/or specifications should call for GPS locating of as-built installed equipment and underground cables to support future one-call locating requirements, as well as provisions for how the contractor should mark their dig locations and what level of locating they must agree to when digging.

LIST OF UTILITY OWNERSHIP

This is the list of the utility ownership in the project area. The table includes a note of how the utilities should be impacted (e.g., LEAVE AS IS).

DMS LOCATIONS 1 & 2: TH 10 1/4 MI NORTH OF EGRET BLVD	
UTILITY	NOTE
CENTERPOINT ENERGY MINNESOTA GAS	LEAVE AS IS
CENTURYLINK	LEAVE AS IS
CITY OF COON RAPIDS	LEAVE AS IS
COMCAST CABLE, LLC.	LEAVE AS IS
CONNEXUS ENERGY	LEAVE AS IS
MNDOT	LEAVE AS IS

DMS LOCATION 3: TH 35E NORTH OF WAGON WHEEL TR	
UTILITY	NOTE
CITY OF MENDOTA HEIGHTS	LEAVE AS IS
COMCAST CABLE, LLC.	LEAVE AS IS
MNDOT	LEAVE AS IS
SAINT PAUL PUBLIC WORKS	LEAVE AS IS
SAINT PAUL REGIONAL WATER SERVICES	LEAVE AS IS
XCEL ENERGY	LEAVE AS IS

DMS LOCATION 4: TH 35W AT 94TH ST	
UTILITY	NOTE
ARVIG COMMUNICATIONS SYSTEMS	LEAVE AS IS
CENTERPOINT ENERGY MINNESOTA GAS	LEAVE AS IS
CENTURYLINK	LEAVE AS IS
CITY OF BLOOMINGTON UTILITIES	LEAVE AS IS
COMCAST CABLE, LLC.	LEAVE AS IS
CONSOLIDATED COMMUNICATIONS	LEAVE AS IS
MCI COMMUNICATIONS SERVICES, INCORPORATED	LEAVE AS IS
MNDOT	LEAVE AS IS
SPRINT COMMUNICATIONS COMPANY, LP	LEAVE AS IS
WINDSTREAM COMMUNICATIONS	LEAVE AS IS
XCEL ENERGY	LEAVE AS IS

GENERAL CONSTRUCTION NOTES

These are the general construction notes.

GENERAL CONSTRUCTION NOTES:

1. BURIED FIBER OPTIC CABLE SHALL BE PLACED AT LEAST 20 FEET FROM CULVERTS OUTLETS, UNLESS OTHERWISE SPECIFIED OR DIRECTED BY THE ENGINEER. IN MEDIANS, PLACE HALFWAY UP SLOPE BETWEEN DRAINAGE DITCH AND EXISTING OR POTENIAL FUTURE CABLE BARRIER.

2. BORED FIBER OPTIC CABLE LOCATIONS SHALL BE VERIFIED BY THE ENGINEER PRIOR TO PERFORMING WORK.

3. BORED FIBER OPTIC CABLE AT CULVERT LOCATIONS SHALL BE PLACED UNDER CULVERTS UNLESS OTHERWISE SPECIIFIED OR DIRECTED BY THE ENGINEER.

4. POLES SHALL BE PLACED BEHIND EXISTING GUARDRAIL, WHERE GUARDRAIL EXISTS, OR OUTSIDE OF THE CLEAR ZONE. POLES IN OPEN AREAS SHALL BE PLACED ON UPPER SIDE OF BACKSLOPE, WHERE POSSIBLE. POLE LOCATIONS SHALL BE AS DIRECTED BY THE ENGINEER.

5. CO-LOCATION (JOINT TRENCH) OF CONDUITS SHALL BE USED WHENEVER POSSIBLE AND NOTED ON AS-BUIT PLANS.

6. EMPTY CONDUITS, NOT PLACED IN JOINT TRENCH WITH FILLED CONDUITS FOR ENTIRE LENGTH, SHALL HAVE A NO.12 TRACE WIRE FURNISHED AND INSTALLED WITH MINIMUM 3' COIL AT BOTH ENDS OF EMPTY CONDUITS AND TRACE WIRE SHALL BE INCIDENTAL. LABEL BOTH ENDS AS "LOCATE WIRE".

7. NO OPEN TRENCHING IN WETLAND AREAS.

8. WHEN FO CABLE INSTALLED IN MEDIAN, BURIED CABLE SIGNS TO BE AT 200' SPACING.

9. TURF ESTABLISHMENT & EROSION CONTROL FOR TRAFFIC MANAGEMENT SYSTEM PLACEMENT SHALL BE CONSIDERED INCIDENTAL, APPLIED TO ALL DISTURBED AREAS, IN ACCORDANCE WITH MNDOT 2575.1, 2575.2, 2575.3, AND THE FOLLOWING
   - SEED MIXTURE 25-141
   - FERTILIZER TYPE 3, ANALYSIS 22-5-10 (NPK) APPLIED AT A RATE OF 350 POUNDS/ACRE.
   - ROLLED EROSION PREVENTION CATEGORY 20 PER MNDOT 2575.3

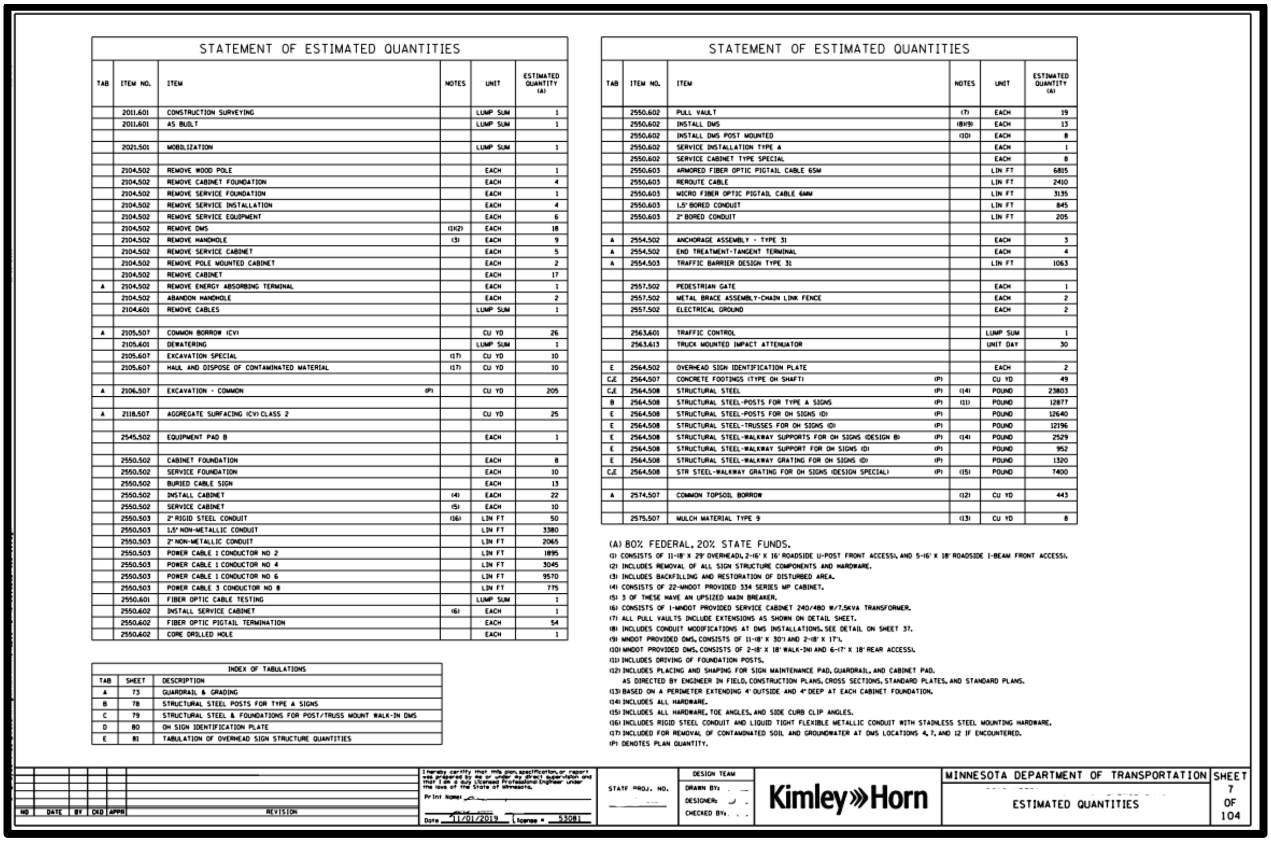
10. ALL DRAINAGE INLETS WITHIN 200 FEET OF ANY DISTURBED SOIL IN THE MEDIAN SHALL BE PROVIDED WITH APPROPRIATE INLET PROTECTION PRIOR TO DISTURBANCE. INLET PROTECTION SHALL BE INCIDENTAL UNLESS OTHERWISE SPECIFIED IN THE CONTRACT.

11. ALL MATERIAL REMOVED AND NOT REUSED ON THIS PROJECT SHALL BECOME THE PROPERTY OF THE CONTRACTOR AND BE DISPOSED OF OUTSIDE MNDOT RIGHT OF WAY IN ACCORDANCE WITH SPEC. 2106.

12. SALVAGE AND INSTALLATION OF CULVERT MARKER POSTS ARE INCIDENTAL.

13. ANY REQUIRED GRADING SHALL BE DONE BEFORE GUARDRAIL POSTS ARE SET.

4.2.5. Estimated Quantities Sheet



STATEMENT OF ESTIMATED QUANTITIES

TAB	ITEM NO.	ITEM	NOTES	UNIT	ESTIMATED QUANTITY (A)
	2011.601	CONSTRUCTION SURVEYING		LUMP SUM	1
	2011.601	AS BUILT		LUMP SUM	1
	2021.501	MOBILIZATION		LUMP SUM	1
	2104.502	REMOVE WOOD POLE		EACH	1
	2104.502	REMOVE CABINET FOUNDATION		EACH	4
	2104.502	REMOVE SERVICE FOUNDATION		EACH	1
	2104.502	REMOVE SERVICE INSTALLATION		EACH	4
	2104.502	REMOVE SERVICE EQUIPMENT		EACH	6
	2104.502	REMOVE DMS	(1)(2)	EACH	18
	2104.502	REMOVE HANDHOLE	(3)	EACH	9
	2104.502	REMOVE SERVICE CABINET		EACH	5
	2104.502	REMOVE POLE MOUNTED CABINET		EACH	2
	2104.502	REMOVE CABINET		EACH	17
A	2104.502	REMOVE ENERGY ABSORBING TERMINAL		EACH	1
	2104.502	ABANDON HANDHOLE		EACH	2
	2104.601	REMOVE CABLES		LUMP SUM	1
A	2105.507	COMMON BORROW (CV)		CU YD	26
	2105.601	DEWATERING		LUMP SUM	1
	2105.607	EXCAVATION SPECIAL	(17)	CU YD	10
	2105.607	HAUL AND DISPOSE OF CONTAMINATED MATERIAL	(17)	CU YD	10
A	2106.507	EXCAVATION - COMMON (P)		CU YD	205
A	2118.507	AGGREGATE SURFACING (CV) CLASS 2		CU YD	25
	2545.502	EQUIPMENT PAD B		EACH	1
	2550.502	CABINET FOUNDATION		EACH	8
	2550.502	SERVICE FOUNDATION		EACH	10
	2550.502	BURIED CABLE SIGN		EACH	13
	2550.502	INSTALL CABINET	(4)	EACH	22
	2550.502	SERVICE CABINET	(5)	EACH	10
	2550.503	2" RIGID STEEL CONDUIT	(16)	LIN FT	50
	2550.503	1.5" NON-METALLIC CONDUIT		LIN FT	3380
	2550.503	2" NON-METALLIC CONDUIT		LIN FT	2065
	2550.503	POWER CABLE 1 CONDUCTOR NO 2		LIN FT	1895
	2550.503	POWER CABLE 1 CONDUCTOR NO 4		LIN FT	3045
	2550.503	POWER CABLE 1 CONDUCTOR NO 6		LIN FT	9570
	2550.503	POWER CABLE 3 CONDUCTOR NO 8		LIN FT	775
	2550.601	FIBER OPTIC CABLE TESTING		LUMP SUM	1
	2550.602	INSTALL SERVICE CABINET	(6)	EACH	1
	2550.602	FIBER OPTIC PIGTAIL TERMINATION		EACH	54
	2550.602	CORE DRILLED HOLE		EACH	1

INDEX OF TABULATIONS

TAB	SHEET	DESCRIPTION
A	73	GUARDRAIL & GRADING
B	78	STRUCTURAL STEEL POSTS FOR TYPE A SIGNS
C	79	STRUCTURAL STEEL & FOUNDATIONS FOR POST/TRUSS MOUNT WALK-IN DMS
D	80	OH SIGN IDENTIFICATION PLATE
E	81	TABULATION OF OVERHEAD SIGN STRUCTURE QUANTITIES

STATEMENT OF ESTIMATED QUANTITIES

TAB	ITEM NO.	ITEM	NOTES	UNIT	ESTIMATED QUANTITY (A)
	2550.602	PULL VAULT	(7)	EACH	19
	2550.602	INSTALL DMS	(8)(9)	EACH	13
	2550.602	INSTALL DMS POST MOUNTED	(10)	EACH	8
	2550.602	SERVICE INSTALLATION TYPE A		EACH	1
	2550.602	SERVICE CABINET TYPE SPECIAL		EACH	8
	2550.603	ARMORED FIBER OPTIC PIGTAIL CABLE 6SM		LIN FT	6815
	2550.603	REROUTE CABLE		LIN FT	2410
	2550.603	MICRO FIBER OPTIC PIGTAIL CABLE 6MM		LIN FT	3135
	2550.603	1.5" BORED CONDUIT		LIN FT	845
	2550.603	2" BORED CONDUIT		LIN FT	205
A	2554.502	ANCHORAGE ASSEMBLY - TYPE 31		EACH	3
A	2554.502	END TREATMENT-TANGENT TERMINAL		EACH	4
A	2554.503	TRAFFIC BARRIER DESIGN TYPE 31		LIN FT	1063
	2557.502	PEDESTRIAN GATE		EACH	1
	2557.502	METAL BRACE ASSEMBLY-CHAIN LINK FENCE		EACH	2
	2557.502	ELECTRICAL GROUND		EACH	2
	2563.601	TRAFFIC CONTROL		LUMP SUM	1
	2563.613	TRUCK MOUNTED IMPACT ATTENUATOR		UNIT DAY	30
E	2564.502	OVERHEAD SIGN IDENTIFICATION PLATE		EACH	2
C,E	2564.507	CONCRETE FOOTINGS (TYPE OH SHAFT) (P)		CU YD	49
C,E	2564.508	STRUCTURAL STEEL (P)	(14)	POUND	23803
B	2564.508	STRUCTURAL STEEL-POSTS FOR TYPE A SIGNS (P)	(11)	POUND	12877
E	2564.508	STRUCTURAL STEEL-POSTS FOR OH SIGNS (D) (P)		POUND	12640
E	2564.508	STRUCTURAL STEEL-TRUSSES FOR OH SIGNS (D) (P)		POUND	12196
E	2564.508	STRUCTURAL STEEL-WALKWAY SUPPORTS FOR OH SIGNS (DESIGN B) (P)	(14)	POUND	2529
E	2564.508	STRUCTURAL STEEL-WALKWAY SUPPORT FOR OH SIGNS (D) (P)		POUND	952
E	2564.508	STRUCTURAL STEEL-WALKWAY GRATING FOR OH SIGNS (D) (P)		POUND	1320
C,E	2564.508	STR STEEL-WALKWAY GRATING FOR OH SIGNS (DESIGN SPECIAL) (P)	(15)	POUND	7400
A	2574.507	COMMON TOPSOIL BORROW	(12)	CU YD	443
	2575.507	MULCH MATERIAL TYPE 9	(13)	CU YD	8

(A) 80% FEDERAL, 20% STATE FUNDS.
(1) CONSISTS OF 11-18' X 29' OVERHEAD, 2-16' X 16' ROADSIDE U-POST FRONT ACCESS, AND 5-16' X 18' ROADSIDE I-BEAM FRONT ACCESS.
(2) INCLUDES REMOVAL OF ALL SIGN STRUCTURE COMPONENTS AND HARDWARE.
(3) INCLUDES BACKFILLING AND RESTORATION OF DISTURBED AREA.
(4) CONSISTS OF 22-MNDOT PROVIDED 334 SERIES MP CABINET.
(5) 3 OF THESE HAVE AN UPSIZED MAIN BREAKER.
(6) CONSISTS OF 1-MNDOT PROVIDED SERVICE CABINET 240/480 W/7.5KVA TRANSFORMER.
(7) ALL PULL VAULTS INCLUDE EXTENSIONS AS SHOWN ON DETAIL SHEET.
(8) INCLUDES CONDUIT MODIFICATIONS AT DMS INSTALLATIONS. SEE DETAIL ON SHEET 37.
(9) MNDOT PROVIDED DMS, CONSISTS OF 11-(8' X 30') AND 2-(8' X 17').
(10) MNDOT PROVIDED DMS, CONSISTS OF 2-(8' X 18' WALK-IN) AND 6-(7' X 18' REAR ACCESS).
(11) INCLUDES DRIVING OF FOUNDATION POSTS.
(12) INCLUDES PLACING AND SHAPING FOR SIGN MAINTENANCE PAD, GUARDRAIL, AND CABINET PAD.
AS DIRECTED BY ENGINEER IN FIELD, CONSTRUCTION PLANS, CROSS SECTIONS, STANDARD PLATES, AND STANDARD PLANS.
(13) BASED ON A PERIMETER EXTENDING 4' OUTSIDE AND 4" DEEP AT EACH CABINET FOUNDATION.
(14) INCLUDES ALL HARDWARE.
(15) INCLUDES ALL HARDWARE, TOE ANGLES, AND SIDE CURB CLIP ANGLES.
(16) INCLUDES RIGID STEEL CONDUIT AND LIQUID TIGHT FLEXIBLE METALLIC CONDUIT WITH STAINLESS STEEL MOUNTING HARDWARE.
(17) INCLUDED FOR REMOVAL OF CONTAMINATED SOIL AND GROUNDWATER AT DMS LOCATIONS 4, 7, AND 12 IF ENCOUNTERED.
(P) DENOTES PLAN QUANTITY.

NO | DATE | BY | CKD | APPR | REVISION

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.
Print Name:
Date 11/01/2019 License # 53081

STATE PROJ. NO.

DESIGN TEAM
DRAWN BY:
DESIGNER:
CHECKED BY:

Kimley»Horn

MINNESOTA DEPARTMENT OF TRANSPORTATION
ESTIMATED QUANTITIES

SHEET 7 OF 104

This sheet shows the estimated quantities for the project. The total quantity and the quantity by project number shall be shown.

The appropriate specification item numbers, item descriptions, and units using the State's pay item list shall be included.

Refer to the AASHTOWare Project Item List website (http://transport.dot.state.mn.us/Reference/refItem.aspx) for a listing of the following:

- Item number and extension
- Long description
- Short description
- Unit name
- Plan unit description

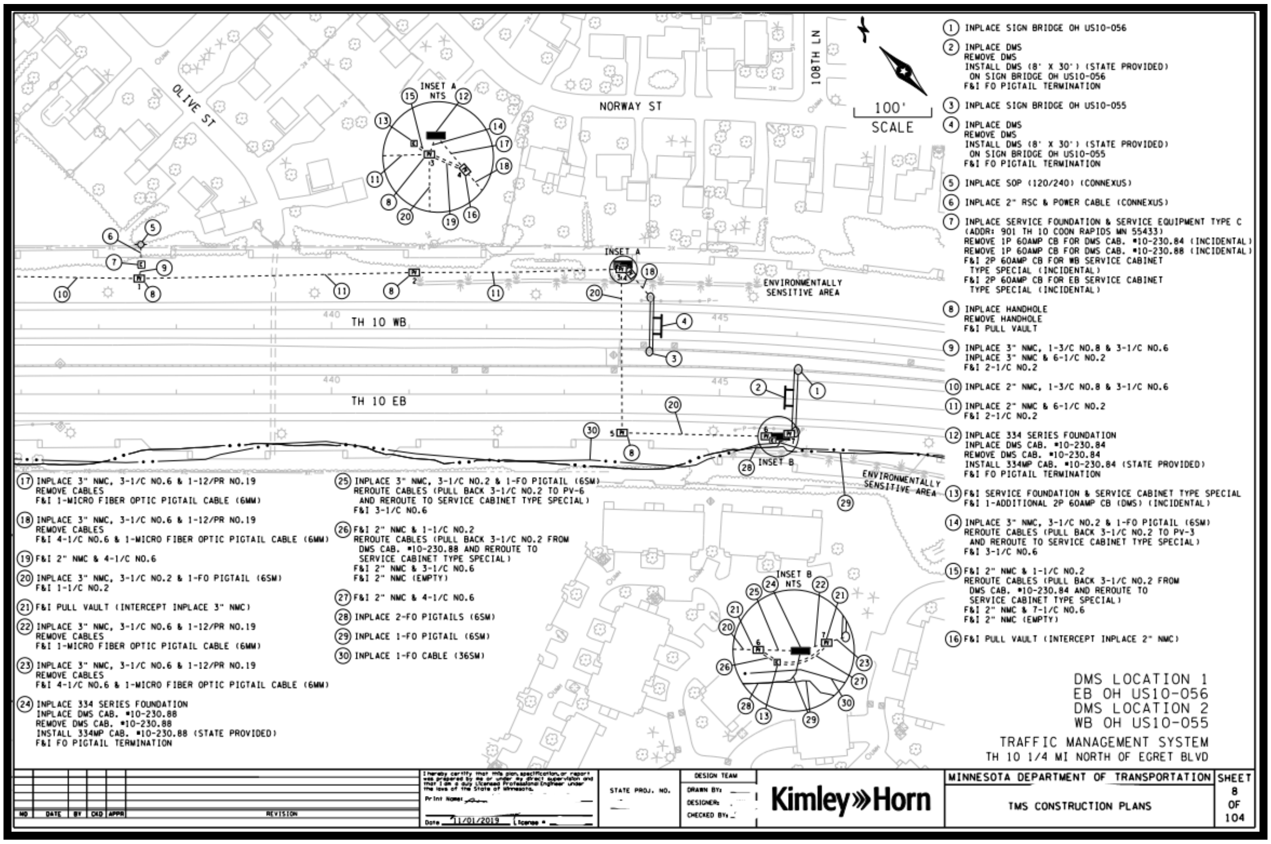
State Aid participation should be clearly identified for each item. The funding split note(s) should be larger than the rest of the pay item notes as shown below for increased visibility. The pay item notes should provide additional details that will assist the contractor with bidding on a plan set, such as describing what a quantity consists of and if any service cabinets include circuit breakers that differ from what is included in the APL.

(A) 80% FEDERAL, 20% STATE FUNDS.
(1) CONSISTS OF 11-(8' X 29' OVERHEAD), 2-(6' X 16' ROADSIDE U-POST FRONT ACCESS), AND 5-(6' X 18' ROADSIDE I-BEAM FRONT ACCESS).
(2) INCLUDES REMOVAL OF ALL SIGN STRUCTURE COMPONENTS AND HARDWARE.
(3) INCLUDES BACKFILLING AND RESTORATION OF DISTURBED AREA.
(4) CONSISTS OF 22-MNDOT PROVIDED 334 SERIES MP CABINET.
(5) 3 OF THESE HAVE AN UPSIZED MAIN BREAKER.
(6) CONSISTS OF 1-MNDOT PROVIDED SERVICE CABINET 240/480 W/7.5KVA TRANSFORMER.
(7) ALL PULL VAULTS INCLUDE EXTENSIONS AS SHOWN ON DETAIL SHEET.
(8) INCLUDES CONDUIT MODIFICATIONS AT DMS INSTALLATIONS. SEE DETAIL ON SHEET 37.
(9) MNDOT PROVIDED DMS, CONSISTS OF 11-(8' X 30') AND 2-(8' X 17').
(10) MNDOT PROVIDED DMS, CONSISTS OF 2-(8' X 18' WALK-IN) AND 6-(7' X 18' REAR ACCESS).
(11) INCLUDES DRIVING OF FOUNDATION POSTS.
(12) INCLUDES PLACING AND SHAPING FOR SIGN MAINTENANCE PAD, GUARDRAIL, AND CABINET PAD.
AS DIRECTED BY ENGINEER IN FIELD, CONSTRUCTION PLANS, CROSS SECTIONS, STANDARD PLATES, AND STANDARD PLANS.
(13) BASED ON A PERIMETER EXTENDING 4' OUTSIDE AND 4" DEEP AT EACH CABINET FOUNDATION.
(14) INCLUDES ALL HARDWARE.
(15) INCLUDES ALL HARDWARE, TOE ANGLES, AND SIDE CURB CLIP ANGLES.
(16) INCLUDES RIGID STEEL CONDUIT AND LIQUID TIGHT FLEXIBLE METALLIC CONDUIT WITH STAINLESS STEEL MOUNTING HARDWARE.
(17) INCLUDED FOR REMOVAL OF CONTAMINATED SOIL AND GROUNDWATER AT DMS LOCATIONS 4, 7, AND 12 IF ENCOUNTERED.
(P) DENOTES PLAN QUANTITY.

4.2.6. Construction Plans

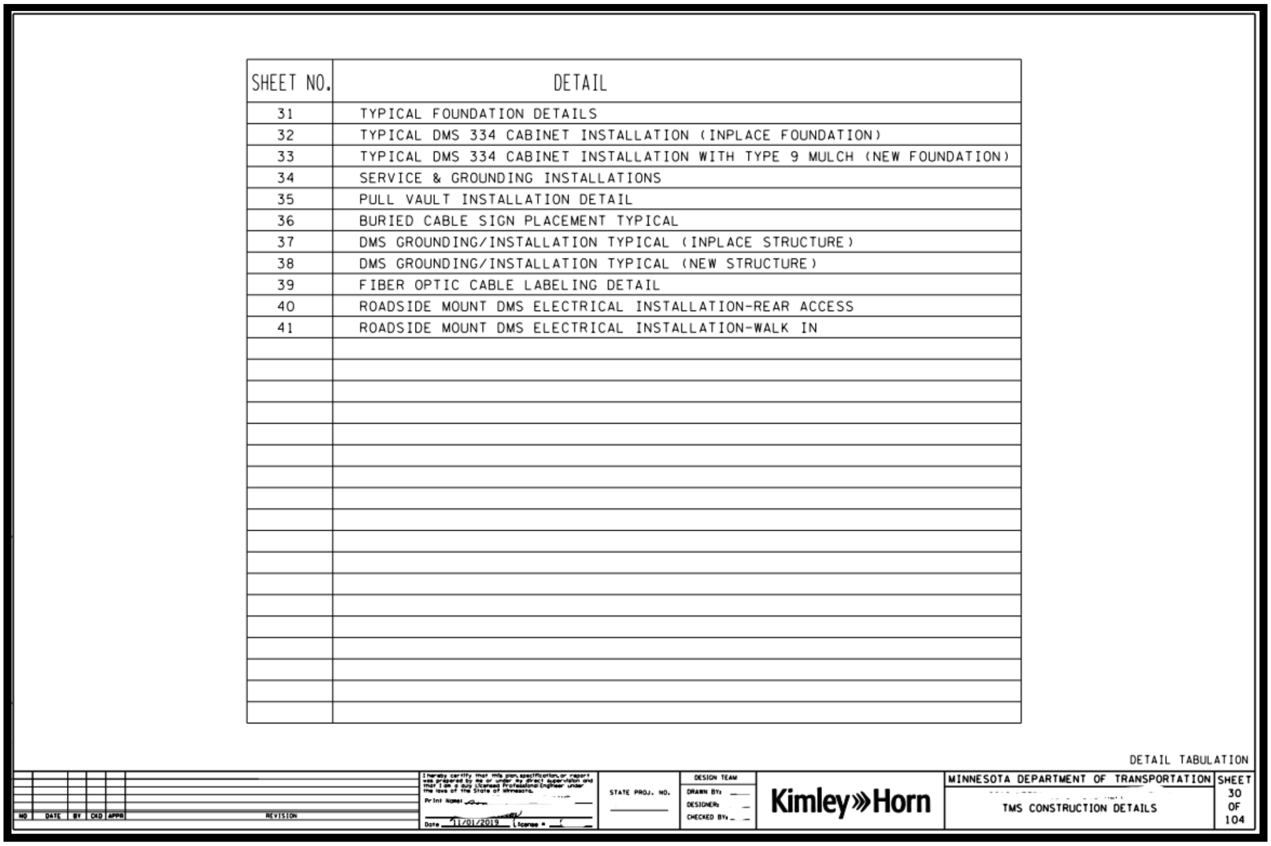
At a minimum, the construction plan sheet(s) should include the following:

- Roadway geometrics (to scale)
- Background topography (grayscale)
- All graphics depicting ITS components
- Component installation notes
- Cabinet/equipment pad detail and notes
- Source of power notes (when applicable)
- Plan sheet title and revision block (on all sheets)
- A bar scale
- A north arrow
- Highway and/or street names
- Show utilities on the plan sheets on a case-by-case basis
- Blow-up of details, as needed, to clarify the area around video camera poles, NID poles, cabinets, etc.
- Separate removal/proposed construction sheets in areas with highly congested linework to clarify intent
- Staged projects than span several construction seasons may require individual staging plan sheets. MnDOT requires a final plan set that shows a comprehensive view of the completed TMS.



4.2.7. Detail Tabulation

The detail tabulation sheet is a table of contents for the details included in the plans.



SHEET NO.	DETAIL
31	TYPICAL FOUNDATION DETAILS
32	TYPICAL DMS 334 CABINET INSTALLATION (INPLACE FOUNDATION)
33	TYPICAL DMS 334 CABINET INSTALLATION WITH TYPE 9 MULCH (NEW FOUNDATION)
34	SERVICE & GROUNDING INSTALLATIONS
35	PULL VAULT INSTALLATION DETAIL
36	BURIED CABLE SIGN PLACEMENT TYPICAL
37	DMS GROUNDING/INSTALLATION TYPICAL (INPLACE STRUCTURE)
38	DMS GROUNDING/INSTALLATION TYPICAL (NEW STRUCTURE)
39	FIBER OPTIC CABLE LABELING DETAIL
40	ROADSIDE MOUNT DMS ELECTRICAL INSTALLATION-REAR ACCESS
41	ROADSIDE MOUNT DMS ELECTRICAL INSTALLATION-WALK IN

4.2.8. Detail Sheets

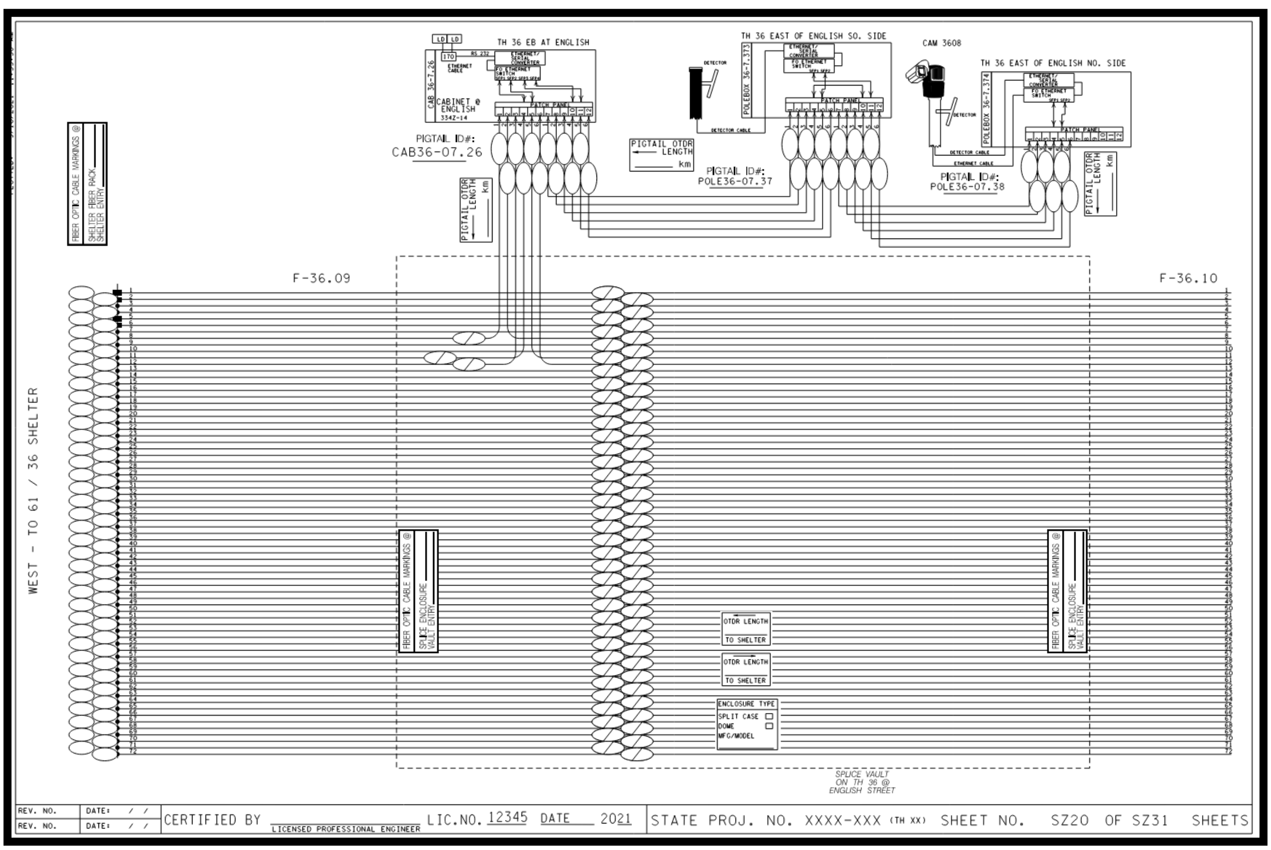
The detail sheets show the standard details that are applicable to the project. They may include the following details. Details are available here: http://www.dot.state.mn.us/rtmc/designplansheets.html

- Cabinet, Loop Detectors, Misc.
    - Typical 334 Cabinet Installation
    - Conduit Hanger Bracket
    - Typical DMS 334 Cabinet Installation
    - DMS Grounding/Installation
    - Fiber Optic Cable Encasement
    - Generator Connections
    - Loop Detectors
    - Pull Vault Installation
    - Service & Grounding Installations
    - Typical Foundations
- Cameras & NID
    - Video Camera Pole Cabinet at Inplace Pole
    - Video Camera Pole Installation
    - NID Pole Installation
    - NID Pole Cabinet

- Fiber Optic Materials
  - Proposed 10’x12’ TMS Shelter
  - Proposed 12’x18’ TMS Shelter
  - Buried Cable Sign Placement
  - Fiber Optic Cable Labeling
  - Fiber Optic Splice Vault Installation
  - Fiber Optic Pull Vault at Splicing Locations Installation
- Ramp Meters
  - Advance Flasher Signal
  - Ramp Control Signals (One-Way and Two-Way)
  - Ramp Control Signal Cable Termination Guide
  - RCS Signing Layouts (With and Without HOV)
- Sign Structural Details
- Guardrail Installations
- End Treatment Details
- Other(s)

4.2.9. Communications Schematics/Testing

The Communications Schematics/Testing sheets include the schematic legend sheet and all communications schematics that are required.



4.3. MnDOT Standard Specifications for Construction

The MnDOT Standard Specifications for Construction (Spec Book) (see Figure 4-1) contains standard specifications to be used and referred to in the design of plans and in the preparation of the Special Provisions. Designers need to be aware of the specifications contained in the Spec Book that may apply to their individual project.

The Spec Book is available online at http://www.dot.state.mn.us/pre-letting/spec/index.html. The Spec Book is an online document that is typically updated every five years. The current version is the 2020 (lettings through 1/27/2022 use 2018). Also available online are the 2018, 2016, 2014, 2005, and 2000 editions.

Figure 4-1: MnDOT Standard Specifications for Construction


DEPARTMENT OF TRANSPORTATION

STANDARD

SPECIFICATIONS

FOR

CONSTRUCTION

2020 EDITION

VOLUME 1

Minnesota 2020 Standard Specifications

2550 TRAFFIC MANAGEMENT SYSTEM

2550.1 DESCRIPTION

This Work consists of providing and installing Intelligent Transportation System (ITS) and Traffic Management System (TMS) components, including electrical service, for communications, traffic control, surveillance, and motorist information.

4.3.1. Format of the Spec Book

The Spec Book contains three divisions:

- Division I - General Requirements and Covenants
- Division II - Construction Details
- Division III - Materials

A section of Division I that all designers need to be particularly aware of, Section 1504, is shown in Figure 4-2**.** That is because the order of precedence amongst contract documents is established in that section.

Figure 4-2: Spec Book 1504, Coordination of Contract Documents

1504 COORDINATION OF CONTRACT DOCUMENTS

A requirement appearing in one of the Contract documents is as binding as though the requirement appears in all. If discrepancies exist between the Contract documents, the following order of precedence applies:

(1) Addenda
(2) Special Provisions
(3) Project-Specific Plan Sheets
(4) Supplemental Specifications
(5) Standard Plans and Standard Plates
(6) Standard Specifications

If discrepancies exist between dimensions in the Contract documents, the following order of precedence applies:

(1) Plan dimensions
(2) Calculated dimensions
(3) Scaled dimensions

The Department and Contractor shall inform each other as to any discrepancy or defect they discover. Neither the Contractor nor the Engineer shall take advantage of any discrepancy or defect. The Engineer will review the alleged discrepancy or defect to determine if a Contract revision is necessary in accordance with 1402, "Contract Revisions." The Engineer will decide all issues concerning a discrepancy or defect.

4.3.2. Format of MnDOT 2550 (Traffic Management System)

Division II contains MnDOT 2550 (Traffic Management System).

The format of MnDOT 2550 is as follows:

- Description:
  - List of acronyms
- Materials:
  - General information section
  - Specifies various materials, including references to Division III of the Spec Book
- Construction Requirements:
  - Specifies the requirements for constructing a TMS
- Method of Measurement:
  - Traffic Management Systems are measured by the various system components by the units of measure required by the contract
- Basis of Payment:
  - There is a payment schedule listed in this section that shows the Item No., Item, and Unit

Division III includes a section entitled "Electrical Systems Materials" that contains various material specifications for TMS. Many of these material specifications are referred to by MnDOT 2550. The format of these material specifications is divided into Scope, Requirements, and Inspection and Testing.

4.3.3. Other Standards

There are other national and local standards which are applicable to ITS plans and specifications. The following are some of the standards specified in the Spec Book:

- American Association of State Highway and Transportation Officials (AASHTO)
- American Society of Testing and Materials (ASTM)
- Institute of Transportation Engineers (ITE)
- Insulated Cable Engineers Association (ICEA)
- National Electrical Code (NEC)
- National Electrical Manufacturers Association (NEMA)
- National Electrical Safety Code (NESC)
- Rural Utilities Service (RUS)
- Underwriter Laboratories, Inc. (UL)

4.3.4. MnDOT Contract Proposal

CONTENTS

Each MnDOT project has a proposal. The proposal contains items such as:

- Addendums
- Notices to Bidders
- Appendices
- Special Provisions (by division, e.g. Divisions S, Division SS, Division SL, Division ST, Division SZ, etc.)
- Attachments
- Contract Schedule (Bid Prices)

SPECIAL PROVISIONS

Special Provisions are defined as "Additions and revisions to the Standard and Supplemental Specifications covering conditions peculiar to an individual project."

Special Provisions are just that: **"SPECIAL"** provisions. If an item(s) is adequately addressed or specified in the Spec Book, Standard Plates, Plan, or other contract documents, then that item(s) should not be duplicated within the Special Provisions. All pay items that end in the 600s (i.e. ####.6##) will require a Special Provision.

Division SZ covers Traffic Management Systems. Special Provisions will be formatted into several SZ sections since there is an individual section for each pay item and several other categories. The Division SZ base specification includes all boilerplate sections, and the designer needs to delete the sections that do not apply to the project and, as needed, modify the sections that do apply to the project. The Division SZ base specification is available on the RTMC design website at the link below:
http://www.dot.state.mn.us/rtmc/designplansheets.html

Division S is the overall Special Provision section that is included for all projects. The following describes the typical Metro District process for completing Division S, so for all Greater MN districts the designer should coordinate with the district to determine their requirements. The traffic group provides input on the Traffic portion of Time & Traffic within Division S for every project, and the construction group is responsible for writing the Time & Traffic portion of Division S with input from the traffic group. The construction group also provides input on contract duration, liquidated damages, and certain quantities such as the need for truck mounted impact attenuators and construction surveying. The Central Office is responsible for writing Division S and incorporates input from the traffic and construction groups. There are a variety of pay items that need to be included in Division S for an ITS project. The Division S sections required vary depending on the components (i.e. structural steel, concrete, erosion control, etc.) included in the ITS project.

Other Special Provisions sections are only included if design in other functional areas require their addition. They are typically completed by the functional group completing that portion of the design. A list of other Special Provisions sections that may need to be included are:

- Division SB (Bridge)
- Division SL (Lighting)
- Division SS (Signals)
- Division ST (Signing)

ADDENDUM

At times it may become necessary to provide additional information, corrections, additions, or deletions to the Special Provisions, plans, and/or Spec Book after the project is advertised but before the actual letting of the project. This information is provided to bidders via an addendum. This addendum is then sent out to contractors, suppliers, etc. that have purchased the contract documents for the specific project. This addendum is sent out with enough lead time to allow bidders the opportunity to consider the addendum as they prepare their bid.

SUPPLEMENTAL AGREEMENTS

It is important that plans and Special Provisions are clear, accurate, and adequately indicate the work that the contractor is required to perform. However, when that does not happen, or if some item(s) is inadvertently omitted from the project documents, MnDOT will negotiate a supplemental agreement with the contractor to rectify the situation. There are occasions when supplemental agreements are necessary due to field conditions that were not apparent at the time of the project design. It is, however, in the best interest of everyone to try and keep supplemental agreements to a minimum.

4.4. Approved/Qualified Products List

The MnDOT APL/QPL for Traffic Management Systems/ITS can be found by visiting http://www.dot.state.mn.us/products/trafficmgtsystems/index.html.

4.5. Pay Items

Information on Pay Items can be obtained from the AASHTOWare Project Item List website: https://transport.dot.state.mn.us/reference/refItem.aspx.

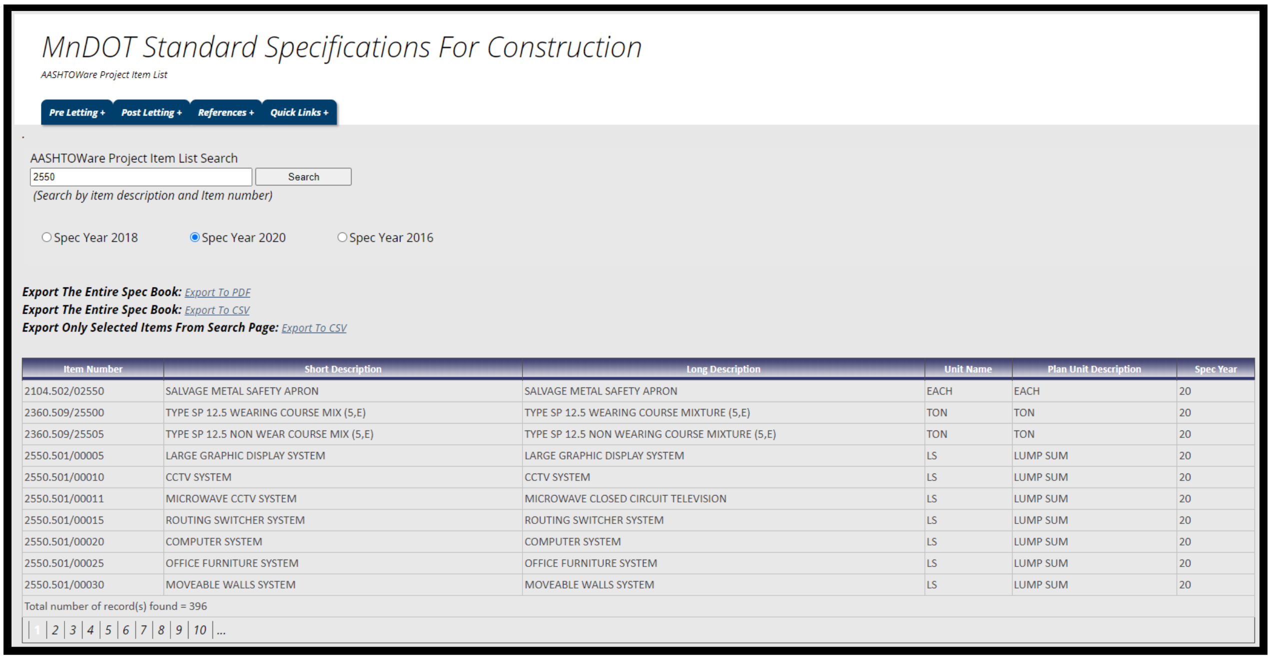
The website includes a search box to look for individual items (see Figure 4-3). The results will list the item by:

- Item Number

- Short Description
- Long Description
- Unit Name
- Plan Unit Description
- Specification Year

The results, or the entire AASHTOWare list, can be export to PDF and CSV formats.

Figure 4-3: AASHTOWare Website



Item Number	Short Description	Long Description	Unit Name	Plan Unit Description	Spec Year
2104.502/02550	SALVAGE METAL SAFETY APRON	SALVAGE METAL SAFETY APRON	EACH	EACH	20
2360.509/25500	TYPE SP 12.5 WEARING COURSE MIX (5,E)	TYPE SP 12.5 WEARING COURSE MIXTURE (5,E)	TON	TON	20
2360.509/25505	TYPE SP 12.5 NON WEAR COURSE MIX (5,E)	TYPE SP 12.5 NON WEARING COURSE MIXTURE (5,E)	TON	TON	20
2550.501/00005	LARGE GRAPHIC DISPLAY SYSTEM	LARGE GRAPHIC DISPLAY SYSTEM	LS	LUMP SUM	20
2550.501/00010	CCTV SYSTEM	CCTV SYSTEM	LS	LUMP SUM	20
2550.501/00011	MICROWAVE CCTV SYSTEM	MICROWAVE CLOSED CIRCUIT TELEVISION	LS	LUMP SUM	20
2550.501/00015	ROUTING SWITCHER SYSTEM	ROUTING SWITCHER SYSTEM	LS	LUMP SUM	20
2550.501/00020	COMPUTER SYSTEM	COMPUTER SYSTEM	LS	LUMP SUM	20
2550.501/00025	OFFICE FURNITURE SYSTEM	OFFICE FURNITURE SYSTEM	LS	LUMP SUM	20
2550.501/00030	MOVEABLE WALLS SYSTEM	MOVEABLE WALLS SYSTEM	LS	LUMP SUM	20

Total number of record(s) found = 396

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ...

4.6. Tabulation/Statement of Estimated of Quantities

In order to develop a cost estimate for the TMS, the designer needs to develop a "Tabulation/Statement of Estimated Quantities" for all system component parts. This section is a Tabulation of Estimated Quantities if the system is part of a larger plan and a Statement of Estimated Quantities if it is a stand-alone TMS plan. When determining TMS quantities, the designer should determine quantities on a by-sheet/by-location basis in order for discrepancies to be more easily checked. Certain pay items require adjustment to increase quantities to appropriately consider factors such as wire slack and changes in grade on conduit length. When developing the Engineer's Estimate, even though they are not listed in the Statement of Estimated Quantities, the designer must include State-provided materials (i.e. back-sheet item) since they are project costs.

4.7. General Design Steps

This section covers the general design process for all ITS infrastructure, and design guidance for each ITS component is discussed in detail in their respective sections which are linked below:

- Supporting Infrastructure Design: Section 3
    - Power Distribution: Section 3.1
    - Communications: Section 3.2

- Conduit: Section 3.3
- Conduit Access: Section 3.4
- Equipment and Service Cabinets and Shelters: Section 3.5
- Additional Supporting Infrastructure (Posts and Poles, Foundations, Guardrails, Pull Off Areas and Grading): Section 3.6
- ITS Device Design: Section 3.7
    - Vehicle Detection: Section 3.7.1
    - Video Cameras: Section 3.7.2
    - Dynamic Message Signs: Section 3.7.3
    - HOT Lanes: Section 3.7.4
    - Ramp Meters: Section 3.7.5

Detailed design steps for the ITS devices are discussed in the following sections of this manual:

- Vehicle Detection: Section 4.8.1
- Video Cameras: Section 4.8.2
- Dynamic Message Signs: Section 4.8.3
- HOT Lanes: Section 4.8.4
- Ramp Meters: Section 4.8.5

Table 4-1: General Design Steps

Design Step	Design Consideration
Design Step 1: Determine device-specific details for all proposed ITS components, and determine preliminary device locations	• See the relevant ITS Device Design sections referenced above to determine device-specific details and preliminary locations for all devices.
Design Step 2: Get accurate drawings of the proposed ITS design locations	• Obtain all as-built TMS plan sheets, structure inspection reports, and structural shop drawings for the proposed ITS design locations from Georilla, eDIGS, and as-built books at the MnDOT RTMC design office. • Request or obtain base mapping for the proposed ITS design locations. Files that may be available are existing topographic survey files, proposed design files, existing utility files, and the overall TMS base file. Retain coordinates within the CADD file (if possible). • MnDOT uses MicroStation and all plans are to be produced using MicroStation. The use of “Models” within MicroStation will not be accepted. If there are multiple phases of TMS construction, each phase of design must be contained in individual files.
Design Step 3: Refine locations of the proposed ITS devices	• Review all as-built TMS plan sheets for the proposed ITS design locations to identify any possible issues, and to gain a better understanding of existing conditions prior to the site visit. • See the relevant ITS Device Design sections linked above to refine locations of the proposed ITS devices. There are various design considerations that need to be made for each device.

Design Step	Design Consideration
Design Step 4: Conduct a site visit	• Plan details of the site visit prior to going into the field. Are two staff required for safety? Are there site-specific elements that would affect where you should park (bridges, continuous guardrail, narrow shoulders, etc.)? Are any specialized tools required? Do you need access into existing ITS cabinets, handholes, or pull vaults? Is traffic control or a bucket truck needed to safely access the site? • Notify MnDOT in advance of the site visit. For shorter duration visits with minimal impact to traffic, notify the MnDOT project manager and RTMC. For longer duration or if traffic disruptions are required, the 511 Coordinator needs to be contacted. • Review the site to determine where existing power and a connection to inplace communications infrastructure is available. The review of existing conditions is often simpler in rural areas as opposed to urban areas although there are locations in rural areas that are very challenging to obtain power or a connection to inplace communications infrastructure. • Review all inplace components in the field. Will any existing ITS infrastructure need to be removed or relocated due to their condition, possible conflicts with proposed ITS infrastructure, etc.? • Review terrain at proposed component location, site drainage, line of sight, etc. • Take photos of everything and make sketches to confirm cable routing and component locations, etc. Create notes that identify the locations and view of each photo in the field.
Design Step 5: Revise ITS device locations as needed, determine the source of power location, and identify where the connection to existing communications infrastructure will occur	• Review site visit information and as-built information and revise ITS device locations. At this point locations are driven primarily by obtaining reasonable access to power and communications and adjustments that are warranted based on findings during the site visit. • See the relevant ITS Device Design sections linked above for various design considerations that need to be made for each device. • Finalize locations of ITS devices. • Request any additional survey, geotechnical data, or other information needed. Survey is required at locations where there is not accurate base mapping. Soil borings are required at all proposed overhead sign structure footing locations. • When there is excavation, start the MnDOT Utility Coordination Process. If this design is being included as part of a larger roadway design project, MnDOT Utilities may handle this process.
Design Step 6: Lay out the proposed ITS devices and supporting infrastructure in MicroStation	• Lay out all proposed ITS devices and supporting infrastructure in MicroStation. Supporting infrastructure that may be required includes control cabinet, service cabinet, source of power, communications, pull vaults, and conduit runs.

<table>
<tr><th>Design Step</th><th>Design Consideration</th></tr>
<tr><td></td><td>Determine which components are State-provided.
See the relevant ITS Device Design sections linked above for typical layouts and design considerations for each device installation. A general description of what may be required is listed below:
Structure for ITS device
ITS device (there can be multiple ITS devices at each site)
334 series cabinet
Service cabinet (with a meter) located near the source of power (SOP)
Service cabinet type special (without a meter) located near the pole cabinet or 334 series cabinet if there is a long distance from the service cabinet (with a meter), access road, or if physical barriers are present
SOP (coordinated by designer, installed by power company, power company costs are a project cost) after SOP location and type is determined
Some general items to consider when placing cabinets are:
Place within right-of-way
Place higher than adjacent pull vaults to keep water from running into cabinet
Locate to avoid interference with pedestrians
Consider snow storage so access can be maintained during the winter
If the 334 series cabinet is not near the service cabinet, a service cabinet type special should be installed near the 334 series cabinet to facilitate more efficient and safe access to shut off power to devices
The 334 series cabinet should be located behind a guardrail or outside the clear zone
Consider access to potential fiber optic trunk line and existing splice points</td></tr>
<tr><td>Design Step 7: Determine SOP and coordinate with utility company</td><td>See Section 3.1.3 for detailed design guidance on power services.</td></tr>
<tr><td>Design Step 8: Add conduit runs, pull vaults, and cables</td><td>See Sections 3.3 and 3.4 for details on conduits and conduit access.
See Section 3.1.8 for details on load requirements, breaker sizing, and voltage drops to determine the size of power cables needed for the circuits serving each ITS device and from the SOP.
See Section 3.2 for more information on communications and each ITS device section linked above for device-specific design guidance.</td></tr>
<tr><td>Design Step 9: Size conduits</td><td>See Sections 3.3.2 and 3.3.3 for design guidance.</td></tr>
<tr><td>Design Step 10: Annotate plans</td><td>See each ITS device section linked above for device-specific plan sheet annotations. The designer needs to coordinate with the</td></tr>
</table>

Design Step	Design Consideration
	project manager to assign device names for all the proposed ITS devices. Cabinet and pole names are based on roadway and location relative to the reference point.

4.8. Detailed Design Steps

4.8.1. Vehicle Detection

Table 4-2: Vehicle Detection Design Steps

Design Step	Design Consideration

Design Step 1: Determine all required detection locations	• What is the condition of the existing roadway? For existing mainline loop detectors, depending on the existing roadway condition and the number of mainline loops being replaced, the designer may choose to abandon the existing loops and install microwave detection.
	• Inductive loops and microwave detection:
	    • Project may require repairs/replacement of existing detection or that new detection be installed, whether it is inductive loops or microwave detection
	    • Input from RTMC operations is required
	    • Designer should determine the location of all required detection based on the design considerations above and the RTMC standard detail sheets available online at: http://www.dot.state.mn.us/rtmc/designplansheets.html.
	• Microwave detection:
	    • Determine if the detector can be mounted on an existing pole or if it will require its own pole

Design Step 2: Get accurate drawings of the proposed detection locations	• See General Design Step 2, Section 4.7.

Design Step 3: Refine location of microwave detection	Microwave detection:
	• Modify the location of the proposed detector(s) based on the following:
	    • Can the detector be mounted on a video camera pole or will it require its own pole? It must be serviceable.
	    • If a new pole is needed, calculate the clear zone distance at the proposed detection location. The pole should be sufficiently outside the clear zone, but if this isn't possible it must be placed behind guardrail.
	    • Obtain a cross section at the proposed detection location to determine the detector mounting height and pole height based on Table 3-11. MnDOT typically chooses a mounting height between the recommended and maximum whenever possible.

Design Step	Design Consideration
	◦ Review Section 3.7.1 design guidelines and check for potential conflicts. • Review the modified location one final time to make sure there are no major concerns that justify another adjustment to the detector location.
Design Step 4: Conduct a site visit	• See General Design Step 4, Section 4.7.
Design Step 5: Refine detection locations, source of power, and connection to existing communications infrastructure.	Inductive loops and microwave detection: • Review site visit information and as-built information and refine detector location(s). At this point, the detector locations will typically not be modified much as they are determined primarily by the standard details. The 334 series cabinet (if required) should be located close to the detectors, and power and communications (if required) should be brought to the control cabinet location whenever possible. Solar power and cellular modems may be used as a last resort for some rural locations. Approval from the MnDOT ITS project manager must be obtained if solar power or cellular modems are used. • If a cellular modem or solar power are selected: 1) check cellular signal strength in the area for the provider MnDOT uses and 2) make sure the proposed site is clear of vegetation over-canopy, so the solar panels will receive unimpeded sunlight. • Finalize detector locations.
Design Step 6: Lay out proposed detection and any related TMS components	Inductive loops: • The following components are typically required as part of a new or existing inductive loop detection installation: inductive loops, 334 series cabinet, service cabinet, and SOP. • A typical layout for a loop detector installation includes the following TMS components: ◦ Inductive loops in pavement, either sawcut or preformed depending on pavement conditions ◦ SOP (coordinated by designer, installed by power company, power company costs are a project cost) after SOP location and type is determined ◦ Service cabinet (with a meter) located near the SOP ◦ Service cabinet type special (without a meter) located near the pole cabinet if there is a long distance from the service cabinet (with a meter), access road, or if physical barriers are present ◦ 334 series cabinet • Position components in the design file. Microwave detection: • The following components are typically required as part of a new detection installation: NID device, NID pole, pole cabinet, service cabinet, and SOP.

Design Step	Design Consideration

	• The microwave detector is State-provided and installed, and the pole cabinet and pole are furnished and installed by the contractor.
	• A typical layout for a new detector installation includes the following TMS components:
	    ◦ NID pole or mounting support to attach the detector to an existing structure
	    ◦ Non-intrusive detector
	    ◦ SOP (coordinated by designer, installed by power company, power company costs are a project cost) after SOP location and type is determined
	    ◦ Service cabinet (with a meter) located near the SOP
	    ◦ Service cabinet type special (without a meter) located near the pole cabinet if there is a long distance from the service cabinet (with a meter), access road, or if physical barriers are present
	    ◦ Pole cabinet
	• Position components in the design file.
	• Guardrail may be required to protect the NID pole and provide a safe work area. Incorporate into the design, or if part of a larger project coordinate with the roadway designer. If guardrail is added, review grades as often additional grading is required.

Design Step 7: Determine SOP and coordinate with utility company	Inductive loops: • See General Design Steps, Section 4.7. • See Table 3-2 for the amp load for a 334 series cabinet. • 120 VAC is required for a 334 series cabinet. • See subsection Breaker Sizing for the circuit breaker size to be used in a service cabinet for a 334 series cabinet. Microwave detection: • See General Design Steps, Section 4.7. • See Table 3-2 for the amp load for a pole cabinet serving a NID. • 120 VAC is required for a pole cabinet serving a NID. • See subsection Breaker Sizing for the circuit breaker size to be used in a pole cabinet serving a NID.

Design Step 8: Add conduit runs, pull vaults, and cables	See General Design Steps, Section 4.7.
	• Inductive loops:
	    ◦ Inductive loops use a 2/C No. 14 cable
	• Microwave detection:
	    ◦ Detectors typically use an armored fiber optic pigtail cable (6SM) for communications to the pole cabinet
	    ◦ Power cable is typically 1-3/C No. 14 from the service cabinet to the pole cabinet, with a separate circuit breaker installed in the service cabinet for the pole cabinet. Wire size will need to

Design Step	Design Consideration

	be increased if distances increase and voltage drops are too high.
	• The typical layout of conduit runs and pull vaults are as follows:
	  ◦ Pull vault installed within 25’ of detector pole
	  ◦ Two non-metallic conduits (NMC) between the pull vault near the base of the detector support and the detector pole cabinet with the detector power cables and fiber pigtail
	  ◦ One empty NMC between the pull vault near the base of the detector support and the detector pole cabinet for future needs.
	  ◦ One NMC between the pull vault near the base of the detector pole and the service cabinet with power cables for the pole cabinet
	  ◦ One NMC between the service cabinet and SOP with power cables
	  ◦ One NMC between the control cabinet (if required) and the pull vault near the base of the detector support that includes the fiber pigtail.
	  ◦ One NMC between the pull vault near the pole cabinet or 334 series cabinet (if required) and the nearest splice vault with a fiber pigtail to connect to the fiber optic trunk line. Additional pull vaults may be needed along this conduit path if the distance or route to the fiber optic trunk line necessitate additional locations.

Design Step 9: Size conduits	• See General Design Step 9, Section 4.7.
Design Step 10: Annotate plans	• A plan example where the detection related components and annotations are shown is available at: http://www.dot.state.mn.us/its/design.html. • Detectors are numbered/labeled according to the RTMC standard details at: http://www.dot.state.mn.us/rtmc/designplansheets.html.

4.8.2. Video Cameras

Table 4-3: Video Camera Design Steps

Design Step	Design Consideration
Design Step 1: Determine general video camera purpose and location	• Is an existing video camera being replaced or is it a new location? • The designer should obtain the primary purpose of the video camera and approximate location and highway where the video camera is to be located from RTMC operations. • If available, review preliminary design documents, project scoping reports, and ideally the detailed scope of the project. • Determine the following based on the video camera purpose and highway characteristics: ◦ Video camera spacing

Design Step	Design Consideration
	- Available structure types for mounting - Discuss and review proposed video camera locations with RTMC operations staff to confirm that the design intent is achieved - Selection of video camera locations are based on operational and maintenance requirements along with local topography. Desired coverage dictates the general camera location. - Camera locations require a clear line of site to the desired coverage area (consider tree canopy cover during the summer). If necessary, use a camera-equipped vehicle to validate video camera placement as a part of design development. • The following items should be considered when locating a video camera in both urban and rural conditions: - Typical spacing is 0.5-1 mile in urban areas. In rural areas, longer distances are typically used; if using 1-2 mile spacing the shorter pole should be used, and if up to 2-mile spacing is desired the longer pole should be used. At longer distances, wind has a more significant effect on camera movement and can cause the video to bounce excessively. Some corridors will not have video cameras while others will just place video cameras at interchanges. In the Metro District, the standard is a 50-foot pole and 1-mile spacing. - Place on the outside of the curve - Check for blind spots caused by other structures - Locate so a maintenance vehicle can park safely near the video camera and that a level area is available to use a ladder (if applicable). A pull-off may be required. - Avoid locations that require a lane closure to obtain access to the video camera - If being mounted on a folding pole, ensure the camera will lower into an area where work can occur - In rural areas, place on a higher elevation location such as on bridge crossings to maximize view - Galloping at longer distances is less of a concern with modern image stabilization - There is usually more flexibility in rural areas - Pole height depends on topography - Combining a video camera and NID on the same pole can be considered
Design Step 2: Get accurate drawings of the proposed video camera location	• See General Design Step 2, Section 4.7.

<table>
<tr><th>Design Step</th><th>Design Consideration</th></tr>
<tr><td>Design Step 3: Refine location of video camera</td><td>The goal of this step is to refine the location of the video camera provided initially to within 200 feet of its final design location prior to completing the field visit.
Modify the location of the proposed video camera considering the following:
Is the video camera located near an existing source of power or communications connection? If it isn’t, can the video camera be moved closer to the existing infrastructure to reduce cost?
Is there existing infrastructure that can be used to mount the video camera (e.g. NID pole of appropriate height)?
If the video camera is roadside mounted, can it be placed outside the clear zone or is it possible/necessary to place behind guardrail?
If near a DMS, locate the video camera so the DMS can be viewed by the video camera
Plans must indicate which direction the folding pole should fall. The pole cabinet needs to be downstream so the pole folds over the cabinet.
Review the modified location one final time to make sure there are not any major concerns that justify another adjustment to the video camera location (e.g., roadside mount would be in a pond, steep slopes make video camera location impractical, etc.).</td></tr>
<tr><td>Design Step 4: Conduct a site visit</td><td>See General Design Step 4, Section 4.7.
To verify video camera sight lines, a drone may be used. If there are sight obstructions, use the drone to determine a better video camera location.</td></tr>
<tr><td>Design Step 5: Refine video camera location, source of power, and connection to existing communications infrastructure</td><td>Review site visit information and as-built information and refine video camera location. At this point, the location refinement is driven primarily by reasonable access to power and communications.
If there is not a source of power located within a reasonable distance (less than 1,200 feet) from the proposed video camera location, consider relocating the video camera. Solar power is an option for some rural locations.
If there is not an existing communications connection located within a reasonable distance (less than 1,200 feet) from the video camera, consider relocating the video camera. Cellular modems are an option for some rural location depending on video camera use and if there is a reliable cell phone signal.
If a cell phone modem or solar power are selected: 1) check cell signal in the area for the provider MnDOT utilizes for cell service and 2) make sure the proposed site is clear of vegetation over-canopy, so the solar panels will receive unimpeded sunlight
Finalize the location of the video camera.</td></tr>
</table>

Design Step	Design Consideration

Design Step 6: Lay out proposed video camera related TMS components	• The following components are typically required as part of a new video camera installation: video camera, mounting support (video camera folding pole, NID folding pole, or traffic signal pole), pole cabinet, service cabinet, and SOP
	• The video camera is State-provided
	• A typical layout for a new video camera installation requires the following TMS components:
	    • Mounting support to attach the video camera
	    • Video camera
	    • SOP (coordinated by designer, installed by power company, power company costs are a project cost) after SOP location and type is determined
	    • Service cabinet (with a meter) located near the SOP
	    • Service cabinet type special (without a meter) located near the pole cabinet if there is a long distance from the service cabinet (with a meter) or access road, or if physical barriers are present
	    • Pole cabinet
	• Position components into the design file.
	• Guardrail may be required to protect the video camera pole and provide a safe work area. Incorporate guardrail into the design, or if part of a larger project coordinate with roadway designer. If guardrail is added, review grades as often grading is required.

Design Step 7: Determine SOP and coordinate with utility company	• See General Design Steps, Section 4.7. • See Table 3-2 for the amp load for a pole cabinet serving a video camera. • 120 VAC power is required for the video camera. • See subsection Breaker Sizing for the circuit breaker size to be used in service cabinet for a pole cabinet serving a video camera.
Design Step 8: Add conduit runs, pull vaults, and cables	• See General Design Steps, Section 4.7. • Video cameras typically utilize Cat 5E cable for communications and power between the pole cabinet to the video camera. If a 334 series cabinet is required in addition to the pole cabinet and it is located close to video camera pole (less than 50 feet), then Cat 5E cable is run to the video camera from the 334 series cabinet. In cases where the 334 series cabinet is located more than 50 feet from the video camera, a fiber pigtail is run to the pole cabinet and an Ethernet switch is placed in the pole cabinet. • Power cable is typically 1-3/C No. 14 from the service cabinet to the pole cabinet, with a separate circuit breaker in the service cabinet for the pole cabinet. Wire size will need to be increased if distances increase and voltage drops are too large. • The typical layout of conduit runs and pull vaults are as follows: • Pull vault within 25 feet of video camera pole

Design Step	Design Consideration
	• Two non-metallic conduits (NMC) between the pull vault near the base of the video camera support and the video camera pole cabinet with video camera power cables and fiber pigtail • One empty NMC between the pull vault near the base of the video support and the video camera pole cabinet for future needs • One NMC between the pull vault near the base of the video camera pole and the service cabinet with power cables for the video camera • One NMC between the service cabinet and SOP with power cables • One NMC between the 334 series cabinet (if required) and the pull vault near the base of the video camera support that includes the fiber pigtail • One NMC between the pull vault near the pole cabinet or 334 series cabinet (if required) and the nearest splice vault with a fiber pigtail to connect to the fiber optic trunk line. Additional pull vaults may be needed along this conduit path if the distance or route to the fiber optic trunk line necessitate additional locations.
Design Step 9: Size conduits	• See General Design Step 9, Section 4.7.
Design Step 10: Annotate plans	• A plan example where the video camera related components and annotations are shown is available at: http://www.dot.state.mn.us/its/design.html. • Video cameras are labeled in order from west to east and south to north. • The designer needs to coordinate with the project manager to determine camera numbers that may required coordination with RTMC Operations.

4.8.3. Dynamic Message Signs

Table 4-4: DMS Design Steps

Design Step	Design Consideration
Design Step 1: Determine general DMS purpose and location	• Is an existing DMS being replaced, or is it a new location? • Input from RTMC operations is required. • Designer should obtain the primary purpose of the DMS and approximate location and highway where the DMS is to be located. • If available, review preliminary design documents, project scoping reports, and ideally the detailed scope of the project. • Determine the following based on the DMS purpose and highway characteristics: • Mounting position (overhead or roadside mount)

<table>
<tr><th>Design Step</th><th>Design Consideration</th></tr>
<tr><td></td><td>Size and model of DMS
Available structure types for mounting
Is the DMS overhead and is it located on an oversize/overweight (OSOW) permit route? If it is, the required minimum clearance over the road needs to be reviewed. Maps for MnDOT OSOW routes are available at the following link: https://www.dot.state.mn.us/cvo/oversize/resources.html</td></tr>
<tr><td>Design Step 2: Get accurate drawings of the proposed DMS location</td><td>See General Design Step 2, Section 4.7.</td></tr>
<tr><td>Design Step 3: Refine location of DMS</td><td>The goal of this step is to refine the location of the DMS provided initially to within 200 feet of its final design location prior to completing the field visit.
Modify the location of the proposed DMS considering the following:
A DMS should not be located where roadway geometrics reduce sight distance below 800 feet
If the sign is on a horizontal curve with a radius of 5,500’ or less, the sign should be moved off the curve
Is the proposed DMS location far enough in advance of the location being signed or the intersection or interchange where traffic may need to exit based on the message on the DMS?
Ideally a DMS is placed a minimum of 1 mile in advance of the location of concern or intersection/interchange where traffic would exit to avoid a signed condition
Review distances to adjacent guide signs. Typical sign spacing of 800 feet in each direction of the DMS to adjacent standard guide signs must be maintained.
If the DMS will be overhead, is there an existing bridge or standard signing truss that could be utilized?
If the DMS is roadside mounted, can it be placed outside the clear zone or will it need to be placed behind guardrail? If DMS location is near an at-grade intersection, the designer needs to ensure that it does not negatively impact intersection sight distances.
The angle of skew needs to be reflected in the plans
Review the modified location one final time to make sure there are not any major concerns that justify another adjustment to the sign location (e.g., roadside mount would be in a pond, steep slopes make sign location impractical, etc.).</td></tr>
<tr><td>Design Step 4: Conduct a site visit</td><td>See General Design Step 4, Section 4.7.</td></tr>
<tr><td>Design Step 5: Refine DMS location, source of power, and connection to existing communications infrastructure</td><td>Review site visit information and as-built information and refine the DMS location. At this point, the location refinement is driven primarily by reasonable access to power and communications.</td></tr>
</table>

Design Step	Design Consideration
	• If there is not a source of power located within a reasonable distance (less than 1,200 feet) from the proposed DMS, consider relocating the DMS. If the DMS cannot be relocated, power should still be installed from the nearest SOP if possible. • If there is not an existing communications connection location within a reasonable distance (less than 1,200 feet) from the DMS, consider relocating the DMS. Cellular modems are an option for some rural location depending on DMS use and if there is a reliable cell phone signal. • If a cellular modem is selected check the cell signal in the area for the provider MnDOT utilizes for cell service. • Finalize the location of the DMS.

Design Step 6: Lay out proposed DMS-related TMS components	• The following components are typically required as part of a new DMS installation: DMS, sign structure, 334 series cabinet, service cabinet, and SOP.
	• The DMS and 334 series cabinet are State-provided.
	• A typical layout for a new DMS installation requires the following TMS components:
	    ◦ Sign structure to mount the DMS to
	    ◦ DMS
	    ◦ SOP (coordinated by designer, installed by power company, power company costs are a project cost) after SOP location and type is determined
	    ◦ Service cabinet (with meter) located near the SOP
	    ◦ Service cabinet type special (without a meter) located near the pole cabinet if there is a long distance from the service cabinet (with a meter) or access road, or if physical barriers are present
	    ◦ 334 series cabinet
	• Position components into the design file.
	• Some general items to consider when placing cabinets are:
	    ◦ Place within right-of-way
	    ◦ Place outside the clear zone or behind guardrail
	    ◦ Place higher than adjacent pull vaults to keep water from running into cabinet
	    ◦ Locate to avoid interference with pedestrians
	    ◦ Ensure the front of DMS is visible from cabinet
	    ◦ Consider snow storage so access can be maintained during the winter
	    ◦ 334 series cabinet should be relatively close to the service cabinet, or a service cabinet type special should be considered near 334 series cabinet
	    ◦ Consider access to the fiber optic trunk line if applicable
	• When ladder access is required to maintain ground-mounted signs, the area must meet OSHA requirements. Pull-offs may also

Design Step	Design Consideration
	be required in some situations to allow for maintenance vehicles to safely park to access the sign without significantly impacting traffic. These need to be incorporated into the design by the ITS designer, or if part of a larger project a roadway designer may incorporate this into the design, but coordination is required. • Guardrail is required for sign structures that are not breakaway. It is often desired to protect cabinets and provide a safe work area. The ITS designer needs to incorporate this into the design, or if part of a larger project a roadway designer may incorporate this into the design, but coordination is required.
Design Step 7: Determine SOP and coordinate with utility company	• See General Design Steps, Section 4.7. • See Table 3-2 for the amp load for the DMS model being used. • 120/240 VAC power is usually required for DMS. Smaller DMSs may only require 120 VAC. • See subsection Breaker Sizing for the circuit breaker size to be used in the service cabinet serving a DMS.

Design Step 8: Add conduit runs, pull vaults, and cables	• See General Design Steps, Section 4.7.
	• Communication cable between the DMS and the 334 series cabinet is micro fiber optic cable (6-strand multimode).
	• The power cable size serving the DMS varies based on the amp load of the particular DMS and whether the DMS requires 120 or 120/240 VAC. The power cable size serving the 334 series cabinet varies based on the proximity of the cabinet to the service cabinet. See the Wire Gauge subsection for minimum wire size for the various DMS sizes and 334 series cabinet. Wire size will need to be increased if distances increase and voltage drops are too large. Three cables are utilized for signs that require 120 VAC and four cables are utilized for signs that required 120/240 VAC.
	• The typical layout of conduit runs and pull vaults are as follows:
	  ◦ Pull vault within 25 feet of the sign structure
	  ◦ One non-metallic conduit (NMC) between a pull vault near the base of the sign structure and sign structure with power cables and communication cable
	  ◦ One NMC between the pull vault near the base of the sign structure and the service cabinet with power cables for the DMS
	  ◦ One NMC between the service cabinet and 334 series cabinet with power cables for the 334 series cabinet
	  ◦ One NMC between the 334 series cabinet and the pull vault near the base of the sign structure that includes the communication cables from the fiber optic trunk line to the 334 series cabinet, and from the 334 series cabinet to the DMS
	  ◦ One NMC between the pull vault near the base of the sign structure and the nearest splice vault with a fiber optic pigtail to connect the 334 series cabinet to the fiber optic

Design Step	Design Consideration
	trunk line. Additional pull vaults may be needed along this conduit path if the distance or route to the fiber optic trunk line necessitate additional locations. • One NMC between the service cabinet and SOP with power cables
Design Step 9: Size conduits	• See General Design Step 9, Section 4.7.
Design Step 10: Annotate plans	• A plan example where the DMS related components and annotations are shown is available at: http://www.dot.state.mn.us/its/design.html.

4.8.4. HOT Lanes

Table 4-5: HOT Lane Design Steps

Design Step	Design Consideration
Design Step 1: Determine general locations for all required HOT lane facility components	• Is an existing HOT lane being modified or is it a new location? • If available, review preliminary design documents, project scoping reports, and ideally the detailed scope of the project. • Create a high-level layout depicting all inplace or proposed sign bridges, roadway bridges, and entrance ramps. • Significant collaboration between the RTMC and signing groups will be required. • Coordination may be needed between roadway design and ITS design regarding placement of tolling antennas and enforcement beacons, as the location of wide shoulders may change depending on where tolling antennas need to be placed.
Design Step 2: Get accurate drawings of the proposed HOT lane location	• See General Design Step 2, Section 4.7.
Design Step 3: Refine location of HOT lane components	• Based on the as-builts, adjust the placement of the HOT lane components to avoid conflicts with existing infrastructure.
Design Step 4: Conduct a site visit	• See General Design Step 4, Section 4.7.
Design Step 5: Refine HOT lane component locations, sources of power, and connections to existing communications infrastructure	• Finalize locations of HOT lane components. Each component has different placement considerations as detailed in Section 3.7.4.

Design Step	Design Consideration
Design Step 6: Lay out proposed HOT lane related TMS components	• The following components are required as part of a new HOT lane installation: ◦ DMS pricing signs ◦ Tolling antennas (need two for bi-directional HOT lanes) ◦ Enforcement shoulder ◦ Enforcement devices (ADEC TDC3 detector and enforcement beacon) ◦ Controller cabinet (if the toll reader is in the cabinet, the length of the LMR600 cable needs to be considered) ◦ Conduit ◦ Pull vaults ◦ Pavement markings and signing • Complete an FCC filing for the tolling antenna (Part 90). See Section 3.2.3 for more information.
Design Step 7: Determine SOP and coordinate with utility company	• See General Design Step 7, Section 4.7. • See Table 3-2 for the amp loads for the various tolling components. • 120 VAC power is required for the controller cabinet. • See subsection Breaker Sizing for the circuit breaker size to be used in the service cabinet serving a HOT lane.
Design Step 8: Add conduit runs, pull vaults, and cables	• See General Design Step 8, Section 4.7. • The power cable size serving the 334 series cabinet varies based on the proximity of the cabinet to the service cabinet. See the Wire Gauge subsection for minimum wire size for the 334 series cabinet. Wire size will need to be increased if distances increase and voltage drops are too large. • Power cable for HOT lane TMS components are: ◦ DMS: see Wire Gauge subsection ◦ Tolling antenna: LMR600 cable (100’ maximum recommended distance) ◦ Enforcement beacon lights: 6/C No. 14 ◦ Detector/trigger: 3/PR No. 22 • The typical layout of conduit runs and pull vaults are as follows: ◦ Two pull vaults within 25 feet of 334 series cabinet, one for power and one for communications ◦ One non-metallic conduit (NMC) between the power pull vault and the 334 series cabinet with power cables ◦ One NMC between the communications pull vault and the 334 series cabinet with communication cables ◦ One NMC between the service cabinet and 334 series cabinet with power cables for the 334 series cabinet ◦ One NMC between the service cabinet and SOP with power cables ◦ One NMC between the 334 series cabinet and the nearest splice vault with a fiber optic pigtail to connect to the fiber

Design Step	Design Consideration
	optic trunk line. Additional pull vaults may be needed along this conduit path if the distance or route to the fiber optic trunk line necessitate additional locations.
Design Step 9: Size conduits	• See General Design Step 9, Section 4.7.
Design Step 10: Annotate plans	• A plan example where the HOT lane related components and annotations are shown is available at: http://www.dot.state.mn.us/its/design.html.

4.8.5. Ramp Meters

Table 4-6: Ramp Meter Design Steps

Design Step	Design Consideration
Design Step 1: Determine proposed ramp metering location(s) and/or existing ramp metering location(s) to be modified	• Is an existing ramp meter being replaced or is it a new location? • If available, review preliminary design documents, project scoping reports, and ideally the detailed scope of the project. • Evaluate geometric requirements and potential modifications for the location. The MnDOT Road Design Manual provides guidance related to ramp geometrics at ramp meter locations (see sections 6-2.07, 6-2.08, and 6-2.09). • Determine if advance warning signs "Ramp Metered When Flashing" should be included.
Design Step 2: Get accurate drawings of the proposed ramp meter location	• See General Design Step 2, Section 4.7.
Design Step 3: Refine location of ramp meter	• Based on the as-builts, adjust the placement of the ramp meters to avoid conflicts with existing infrastructure.
Design Step 4: Conduct a site visit	• See General Design Step 4, Section 4.7.
Design Step 5: Refine ramp meter location, source of power, and connection to existing communications infrastructure	• Finalize the location of ramp meter signals. The ramp meter location is driven by the ramp geometrics, so the source of power and communications will always need to come to the ramp meter cabinet location.

Design Step 6: Lay out proposed ramp meter related TMS components	• The following components are required as part of a new ramp meter installation:
	  • Ramp meter signals
	  • Controller cabinet
	  • Detection:
	    • Queue loop(s)
	    • Passage loop(s)
	  • Conduit
	  • Pull vaults
	  • Pavement markings and signing
	  • Advanced warning signs and beacons (if required)

Design Step 7: Determine SOP and coordinate with utility company	• See General Design Step 7, Section 4.7. • See Table 3-2 for the amp loads for the ramp meter components. • 120 VAC power is required for the controller cabinet.

Design Step	Design Consideration
	• See subsection Breaker Sizing for the circuit breaker size to be used in the service cabinet for a 334 series cabinet serving a ramp meter site.

Design Step 8: Add conduit runs, pull vaults, and cables	• See General Design Step 8, Section 4.7.
	• The power cable size serving the 334 series cabinet varies based on the proximity of the cabinet to the service cabinet. See the Wire Gauge subsection for minimum wire size for the 334 series cabinet. Wire size will need to be increased if distances increase and voltage drops are too large.
	• Power cable used for each ramp meter signal is 1-6/C No. 14.
	• For power cable runs longer than 1000 feet, use 2-6/C No.14 per ramp meter signal.
	• The typical layout of conduit runs and pull vaults are as follows:
	  ○ Two pull vaults within 25 feet of 334 cabinet, one for power and one for communications
	  ○ One non-metallic conduit (NMC) between the power pull vault and the 334 series cabinet with power cables
	  ○ One NMC between the communications pull vault and the 334 series cabinet with communication cables
	  ○ One NMC between the service cabinet and 334 series cabinet with power cables for the 334 series cabinet
	  ○ One NMC between the service cabinet and SOP with power cables
	  ○ One NMC between the 334 series cabinet and the nearest splice vault with a fiber pigtail to connect to the fiber optic trunk line. Additional pull vaults may be needed along this conduit path if the distance or route to the fiber optic trunk line necessitate additional locations.
	  ○ Conduits connecting loop detector lead-ins to the 334 cabinet

Design Step 9: Size conduits	• See General Design Step 9, Section 4.7.
Design Step 10: Annotate plans	• A plan example where the ramp meter related components and annotations are shown is available at: http://www.dot.state.mn.us/its/design.html.