Systems Engineering Analysis for Standard Traffic Signal

System Requirements

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Revision History

This document will be used for design of MnDOT's new standard traffic signal. As the system is developed, changes to requirements will be tracked and this document will be revised as needed. The following table provides the date and a brief description of each revision to document revision history.

Revision Number	Date of Revision	Description of Revision
1.0	8/30/2019	Initial version
1.1	11/19/2019	Minor revisions per FHWA comments
1.2	5/13/2020	Revisions per MnDOT comments
1.3	5/28/2020	Final version

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Introduction

This report provides ***Functional Requirements*** (*FRs*) for a standard traffic signal and for optional features that may or may not apply to this particular project. Please see the corresponding *Minnesota Statewide Regional ITS Architecture and Systems Engineering Checklist* (*Checklist)* for the project to identify which specific features apply and other pertinent site details. Regardless of the selected options, all traffic signals include the *FR* for the Basic Traffic Signal. Following are the name identifiers for the various features that may apply:

- Basic Traffic Signal (common to all)
- Flashing Yellow Arrow (FYA)
- Advance Warning Flasher (AWF)
- Railroad Preemption (RRP)
- Emergency Vehicle Preemption (EVP)
- Transit Signal Priority (TSP)
- Enforcement Lights
- Traffic Signal Interconnect
- Connected and Automated Vehicle (CAV) Infrastructure Systems and CAVs
- Other

The *FRs* are categorized by the above Traffic Signal features.

The concept of operations developed for this project presents an overview of the current environment, identifies the relevant stakeholders, translates current challenges into specific needs, outlines the envisioned operational concept, suggests likely roles and responsibilities, describes scenarios for operation of the new standard traffic signal, and presents potential risks and recommended mitigation strategies associated with this effort.

This system requirements document contains the requirements necessary for addressing the needs identified in the concept of operations. The requirements describe what a standard traffic signal must do as the basis for further design, procurement, installation, testing and operation. It also presents an assessment of how the standard traffic signal fits within the Minnesota Statewide Regional ITS Architecture.

ITS Architecture Assessment

As an Intelligent Transportation System, it is necessary to assess where the standard traffic signal system fits within the Minnesota Statewide Regional ITS Architecture (Version 2018). As it is envisioned in the concept of operations, the standard traffic signal is part of the Traffic Management Service Package Area (Volume 3). The system addresses numerous needs/potential solutions identified in the architecture and are noted below.

- ATMS01: Provide efficient signal timing
- ATMS02: Implement red-light running technology
- ATMS03: Use archived data for traffic management strategy development and long-range planning

- ATMS14: Monitor operation and performance of traffic signals
- ATMS28: Provide railroad flashing light signals and gates
- ATMS33: Provide intersection collision avoidance systems
- ATMS37: Provide safe signal phase transition
- ATMS38: Provide health monitoring of rail crossings
- APTS15: Optimize schedule efficiency and schedule coordination
- APTS17: Coordinate transit vehicle movements with traffic control devices

The standard traffic signal system is further identified in Traffic Management bundle as a series of existing architecture elements within several service packages. Service packages represent slices of the Physical View that address specific services (i.e. traffic signal control). A service package collects together several different physical objects (systems and devices) and their functional objects and information flows that provide the desired service. Individual service packages and the system functions they perform can be found in the U.S. Department of Transportation (USDOT) National ITS Reference Architecture (ARC-IT). Standard traffic signal system service packages are provided in Table 1 below.

Table 1. Applicable Service Packages from Minnesota Statewide Regional ITS Architecture

System/Element	Service Package	Description
Advance Warning Flasher Roadside Equipment	• TM03: Traffic Signal Control	Advance Warning Flasher Roadside Equipment is located upstream from traffic signal roadside equipment on approaches to warn drivers of changes in signal phases from green to red.
Traffic Signal Roadside Equipment	• TM03: Traffic Signal Control • TM04: Connected Vehicle Traffic Signal System • PT09: Transit Signal Priority • PS03: Emergency Vehicle Preemption	This element represents traffic signals in Minnesota. This element supports surface street control and arterial traffic management. It represents traffic signal systems ranging from fixed-schedule control systems to fully traffic responsive systems that dynamically adjust control plans and strategies based on current traffic conditions and priority requests.
Transit Vehicle Equipment	• PT09: Transit Signal Priority	This element represents vehicle equipment on transit vehicles that communicates with traffic signals or transit management centers and requests transit signal priority at traffic signals.
Emergency Vehicle Equipment	• PS03: Emergency Vehicle Preemption	This element represents vehicle equipment on emergency vehicles that communicates with traffic signals and requests emergency vehicle pre-emption at traffic signals throughout Minnesota.

System/Element	Service Package	Description
RTMC	• TM03: Traffic Signal Control	MnDOT RTMC is located in the Waters Edge Building in Roseville. The RTMC is where State Patrol, MnDOT Maintenance, and MnDOT Freeway Operations work together to quickly detect, respond to and remove incidents off of the freeway systems. The RTMC is responsible for managing traffic on the Twin Cities metro freeways with the use of ramp meters, variable message signs, lane control signals and loop detectors. Additional RTMC components include the HOV system, MnPASS, and airborne monitoring systems. The RTMC monitors traffic conditions, assists in incident management and provides traveler information. Traffic Operations staff also continually perform systems analysis of field equipment, the ramp meter algorithm and Operations Center equipment. They also analyze and research traffic flow trends, new technologies and other issues that affect congestion.
Local TMCs	• TM03: Traffic Signal Control	This element represents local centers that facilitate traffic management on a roadway network from a central location that provides roadway monitoring, signal system control, remote equipment control, and communications with field personnel and other agencies.

Based on the architecture references identified, it is confirmed that the standard traffic signal system is adequately addressed in the *Minnesota Statewide Regional ITS Architecture.*

Functional Requirements

Functional requirements are verifiable details that define what the standard traffic signal system will do, how well it will perform or what conditions it must perform under. The requirements presented in this section are defined in relation to the needs that were identified in the concept of operations for the standard traffic signal system.

There are a series of functional requirements presented in Table 2 to describe the environment the system must operate within.

Table 2. Functional Requirements for Standard Traffic Signal

ID	Functional Requirement
TS-BTS	**Basic Traffic Signal Requirements**
TS-BTS-1	The field element shall control traffic using actuated timing as specified in the plans, and under central control where specified. The signal shall use standard red-yellow-green indications with design and operation in conformance with the latest version of the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) to optimize efficiency and safety.
TS-BTS-2	The field element shall include wiring for emergency vehicle preemption (EVP).
TS-BTS-3	The field element shall include a local interface that provides operational status and fault data for connected field equipment to field personnel.
TS-BTS-4	The field element shall include a local interface that allows field personnel to conduct diagnostic tests on connected field equipment.
TS-BTS-5	The field element design shall address Americans with Disability Act Accessibility Guidelines (ADAAG) as required in Sec 4D.33 of the latest version of the MN MUTCD and Public Rights-of-Way Accessibility Guidelines (PROWAG) as adopted by MnDOT.
TS-BTS-6	The field element shall include detection.
TS-BTS-7	The field element located in Metro Area shall include interconnect and communications back to central control.
	Pedestrian Aspects
TS-BTS: PED-1	When specified in the plans, the field element shall include pedestrian signal indications, push buttons, and timing.
TS-BTS: PED-2	Except when other requirements supersede it, the field element shall include Accessible Pedestrian Signals (APSs) that provide both audio and vibrotactile indication of "WALK/DON'T WALK" intervals wherever pedestrian signal indications are provided.
TS-BTS: PED-3	When specified in the plans, the field element shall include APS pushbutton detectors that are active or passive. Active detectors shall include a pushbutton locator tone.
TS-BTS: PED-4	The field element shall include Countdown Pedestrian Signal (CPS) indications that provide display of seconds remaining in the pedestrian change ("Flashing DON'T WALK") interval.
TS-BTS: PED-5	CPS indications shall be blank except when counting down in integer numbers to and through "0" during the pedestrian clearance interval.
TS-BTS: PED-6	When specified in the plans, the field element shall collect pedestrian images and pedestrian sensor data, and respond to pedestrian crossing requests via display, audio signal, or other manner.
	Detection Aspects
TS-BTS: DET-1	When specified in the plans, the field element shall include loop, video or other detection on identified approaches.
TS-BTS: DET-2	When specified in the plans, collected field data from the site shall be archived at a central location for use in traffic analysis, planning, studies, and performance measurement. Archived data at a minimum shall consist of volume, occupancy, and speed.
	Monitoring Aspects

ID	Functional Requirement
TS-BTS: MON-1	When specified in the plans, the field element shall monitor operation of the traffic signal controller(s) and report to the center any instances in which the indicator response does not match that expected from the indicator control information.
TS-BTS: MON-2	When specified in the plans, the field element shall monitor operation of traffic signal controllers and report to the center any instances in which the indicator response does not match that expected from known indicator preemptions.
TS-BTS: MON-3	When specified in the plans, the field element shall return traffic signal controller operational status to the control center.
TS-BTS: MON-4	When specified in the plans, the field element shall return traffic signal controller fault data to the maintenance center for repair.
	Interface Aspects
TS-BTS: IFC-1	When specified in the plans, the field element shall include detection that provides data and status information to other field element devices (such as other traffic signals, dynamic message signs, ramp meters, work zone intrusion alert systems), without center control.
TS-BTS: IFC-2	When specified in the plans, the field element shall include detection that receives control information from other field element devices, without center control.
TS-BTS: IFC-3	When specified in the plans, the field element shall include arterial signal controllers that provide data and status information to other field element devices (such as traffic controllers at adjacent intersections and dynamic message signs), without center control.
TS-BTS: IFC-4	When specified in the plans, the field element shall include arterial signal controllers that receive control information from other field element devices, without center control.
TS-FYA	**Flashing Yellow Arrow Requirements**
TS-FYA-1	When specified in the plans, the field element shall include Flashing Yellow Arrows (FYA) on the identified approaches that indicate permissive vehicle movement when activated.
TS-AWF	**Advanced Warning Flasher Requirements**
TS-AWF-1	When specified in the plans, the field element shall include Advanced Warning Flashers (AWF) on the identified approaches tied to signal phasing and timing for activation.
TS-AWF-2	AWF shall be set up and timed to flash a warning to approaching drivers that the signal has turned or is about to turn to red.
TS-RRP	**Railroad Preemption**
TS-RRP-1	When specified in the plans, the field element shall include Railroad Preemption (RRP) in which the adjacent railroad track circuit is interfaced with the traffic signal to provide grade crossing clearance and protection.
TS-RRP-2	RRP shall provide fail-safe operation in coordination with other protection devices, such as flashers and gates, to clear the tracks of conflicting objects and persons and hold the protection throughout the train crossing time.
TS-RRP-3	RRP shall revert to normal traffic signal operation through pre-determined signal phase sequencing and timing.

ID	Functional Requirement
TS-EVP	**Emergency Vehicle Preemption**
TS-EVP-1	When specified in the plans, the field element shall include Emergency Vehicle Preemption (EVP) in which green time is extended or red time is truncated to improve safety and expedite the movement of authorized emergency vehicles on the identified approach(es).
TS-EVP-2	EVP shall include confirmatory lights that indicate to emergency vehicle drivers whether or not preemption has been granted.
TS-EVP-3	EVP shall revert to normal traffic signal operation through pre-determined signal phase sequencing and timing.
TS-TSP	**Transit Signal Priority**
TS-TSP-1	When specified in the plans, the field element shall include Transit Signal Priority (TSP) in which green time is extended or red time is truncated to expedite the movement of transit vehicles on the identified approach(es). Preemption control for RRP or EVP shall take precedence over TSP.
TS-TSP-2	TSP shall include rules to negotiate competing calls for priority and allowed frequency of TSP operation.
TS-TSP-3	TSP shall revert to normal traffic signal operation through pre-determined signal phase sequencing and timing.
TS-EnL	**Enforcement Lights**
TS-EnL-1	When specified in the plans, the field element shall include Enforcement Lights (EnL) that provide confirming display of red signal indications to support red light running enforcement.
TS-EnL-2	EnL shall be placed in a location so that enforcement personnel can observe the EnL and the associated approach to allow the personnel to pull out and pursue a red-light running driver from a safe location.
TS-TSC	**Traffic Signal Coordination**
TS-TSC-1	When specified in the plans, the field element shall include Traffic Signal Coordination (TSC) that allows the signal to be sequenced and timed with adjacent signals to provide progressive traffic movement.
TS-CAV	**CAV Infrastructure Systems**
TS-CAV-1	In locations where CAV infrastructure systems broadcast messages to vehicle systems, the traffic signal controller shall communicate the signal status (e.g. SPaT data) to the CAV infrastructure system.
TS-CAV-2	In locations where CAV infrastructure systems acquire data from traffic signals and vehicle systems, CAV infrastructure systems shall warn drivers of potential violations of traffic signals.
TS-CAV-3	In situations where direct traffic signal to CAVs is operational, traffic signal shall generate a message conveying the status of the signal (e.g. SPaT data), in a format compatible with the two-way vehicle to roadside or cloud-based communication medium.
TS-Oth	**Other**
TS-Oth-1	[Develop as appropriate]

Table 3. Mapping of Standard Traffic Signal Needs/Services to Functional Requirements

Feature	Needs/Services	ITS Functional Requirements
Basic Traffic Signal	ATMS01: Provide efficient signal timing	TS-BTS-1, -5, -6, -7
	ATMS03: Use archived data for traffic management strategy development and long-range planning.	TS-BTS-DET-2
	ATMS14: Monitor operation and performance of traffic signals	TS-BTS-3, -4; TS-BTS: MON-1 thru -4
	ATMS37: Provide safe signal phase transition	TS-BTS-1
Pedestrian Aspects	--	TS-BTS: PED-1 thru -6
Detection Aspects	ATMS01: Provide efficient signal timing	TS-BTS-1, -6; TS-BTS: DET-1
	ATMS33: Provide intersection collision avoidance systems	TS-BTS-1
	ATMS37: Provide safe signal phase transition	TS-BTS-1
Monitoring Aspects	ATMS14: Monitor operation and performance of traffic signals	TS-BTS-3, -4; TS-BTS: MON-1 thru -4
Interface Aspects	ATMS01: Provide efficient signal timing	TS-BTS: IFC-1 thru -4
Flashing Yellow Arrow	ATMS01: Provide efficient signal timing	TS-BTS-1; TS-FYA-1
	ATMS37: Provide safe signal phase transition	TS-FYA-1
Advanced Warning Flasher	ATMS33: Provide intersection collision avoidance systems	TS-AWF-1, -2
	ATMS37: Provide safe signal phase transition	TS-AWF-1, -2
Railroad Preemption	ATMS28: Provide railroad flashing light signals and gates	TS-RRP-1 thru -3
	ATMS38: Provide health monitoring of rail crossings	TS-BTS: MON-2, -4
Emergency Vehicle Preemption	--	TS-BTS-2; TS-EVP-1 thru -3
Transit Signal Priority	APTS 15: Optimize schedule efficiency and schedule coordination	TS-TSP-1 thru -3
	APTS 17: Coordinate transit vehicle movements with traffic control devices	TS-TSP-1 thru -3
Enforcement Lights	ATMS02: Implement red-light running technology	TS-EnL-1, -2
Traffic Signal Coordination	ATMS01: Provide efficient signal timing	TS-TSC-1
CAV Infrastructure Systems	--	TS-CAV-1 thru -3
Other	[Develop as needed]	