Systems Engineering Analysis for Standard Traffic Signal

Concept of Operations

May 2020

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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 concept of operations 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 document provides a ***Concept of Operations*** *(ConOps)* for a standard traffic signal along with optional features that may apply to a 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. Regardless of the selected options, all traffic signals include the operational concepts for the Basic Traffic Signal. Following are the name identifiers for the various features that may apply:

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

For each section of this document where information is distinguished by optional feature, the section follows the naming scheme per the above list. For example, the Current Environment section covers the purpose and scope for Railroad Preemption as applies to the traffic signal. A separate document addresses Traffic Signal Preemption *ConOps* from the railroad system perspective. As operations of CAVs expand, several data exchanges between standard traffic signals and CAVs are anticipated, and these are presented in this document.

This concept of operations 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 standard traffic signals, and presents potential risks and recommended mitigation strategies associated with this effort. In addition to providing rationale for the replacement of current traffic signals, the concept of operations will be used to develop system requirements for standard traffic signals.

Current Environment

Basic Traffic Signal (BTS)

A traffic signal provides standard red-yellow-green operation to assign movement right-of-way, and will have actuated operation plus the following:

- Detection.
- Wiring for Emergency Vehicle Preemption (EVP).
- Design that follows the Americans with Disability Act Accessibility Guidelines for Buildings and Facilities (ADAAG), as cited in the *Minnesota Manual on Uniform Traffic Control Devices* (*MN*

MUTCD).

- Countdown Pedestrian Signal (CPS) faces that indicate time left in the pedestrian change interval (the flashing "don't walk").
- Accessible Pedestrian Signals that provide both audio and vibrating surface information in a non-visual format, except in certain circumstances.

A BTS shall include detection. A BTS in the Metro Area shall also include interconnect and communications back to the central control. Interconnects and communications back to the central control are optional for BTS in Greater Minnesota.

EVP wiring is included to allow for easy future addition of hardware and control software to facilitate safe and expeditious emergency vehicle movement on one or more approaches of the intersection (police, fire, ambulance).

Following the *ADAAG* requires appropriate design with respect to signal pole, cabinet, and pedestrian detector placement. Reference guidance is provided in Sections 4D and 4E of the *MN MUTCD*. MnDOT has adopted the 2005 version of the *Public Rights-of-Way Accessibility Guidelines (PROWAG)* for general use with regards to pedestrian treatments at traffic signals, with the exception for pedestrian signals at multi-lane roundabouts.

CPS faces provide second-by-second visual display of the number of seconds remaining in the pedestrian change interval, adjacent to the associated upraised hand ("Don't Walk"; see Figure 1). The display counts down only during display of the adjacent flashing upraised hand, displays zero when the upraised hand changes to steady display, then blanks out. Section 4E.7 of the *latest version of the MN MUTCD* spells out further details. The 2009 national *MUTCD* requires that CPS faces be provided on all new signals installed after December 22, 2013. MnDOT includes this feature on all new signal installations with pedestrian displays and is retrofitting or replacing existing pedestrian signal faces over the next two to three years.

Figure 1. Countdown Pedestrian Signal Display

(Source: Countdown Pedestrian Signals: A Comparison of Alternative Pedestrian Change Interval Displays, by Westat for FHWA, March 2005)

Accessible Pedestrian Signals (APSs) provide information in non-visual format using both audible messages and vibrating surfaces. APS detection may also be needed, which may be active or passive. If it is active, a pushbutton locator tone is provided. Specific requirements and guidance are spelled out in

Sections 4E.9 and .13 of the *MN MUTCD.* Of note, the pedestrian change interval timing may not be altered or omitted as part of a transition into a preemption sequence. Thus, APS inclusion at railroad grade crossings must be carefully weighed against absolute preemption requirements of a specific crossing.

The *PROWAG* discussed above could possibly mandate APS at all new or renovated pedestrian signal locations in the country. Once the U.S. Department of Justice adopts any future Access Board public right of way guidelines as a standard, the FHWA plans to reconsider the matter for future revisions of the national *MUTCD* (see *Federal Register* /Vol. 74, No. 240 /Wednesday, December 16, 2009 /Rules and Regulations, p66825, Item 408). Regardless of national developments, Minnesota intends to use APSs except in circumstances where other safety requirements take precedence.

Placement of APS devices is particularly important so that persons making use of them can readily recognize where they are, to what crossing they apply, and can easily activate associated detection when part of the design. Appropriate audible messages are defined in the *latest version of the MN MUTCD.* Automatic volume adjustment is provided within specified limits. Vibrotactile devices communicate information about pedestrian timing through a vibrating surface by touch and indicate that the walk interval is in effect. They also indicate to which direction they apply through a vibrating directional arrow or some other means.

Flashing Yellow Arrow (FYA)

The FYA was an optional feature in the 2009 national *MUTCD* (primarily Sections 4D.17-.30) that has been adopted by MnDOT*.* It is used to delineate permissive left or right turn movement, as opposed to protected left or right turn movement, see Figure 2. It may be selectively included on approaches on which there is a permissive left- or right- turn phase, due to conflicting movement with either opposing vehicular traffic, or pedestrian movement across a conflicting cross walk. Mast arm length may need to be adjusted to accommodate an FYA signal face.

Advanced Warning Flasher (AWF)

An AWF installation is the addition of a sign with flashing yellow sections to alert drivers approaching a signalized intersection that the light is about to turn from the green phase to red phase. While typically used on high speed roadways it may also be used at locations that have limited site distance of the signal indications. The purpose of a combination highway traffic signal and AWF system is to: 1) inform the driver in advance of a required drive decision (prepare to stop), and 2) minimize the number of drivers that will be required to make that decision in the dilemma zone. Application details are given in Section 4O of the *latest version of the MN MUTCD*.

AWF operation is implemented by use of a sign with yellow flashers, as illustrated on Figure 3. The yellow flashers are activated any time an approaching vehicle is likely to arrive at the signal during a red signal phase. The exact timing of when to flash is a detailed design aspect on an individual site basis, discussed in *latest version of the MN MUTCD* Section 4O. The overall goal is to alert drivers sufficiently in advance for maximum safety.

Figure 4D-12. Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Mode Left Turns

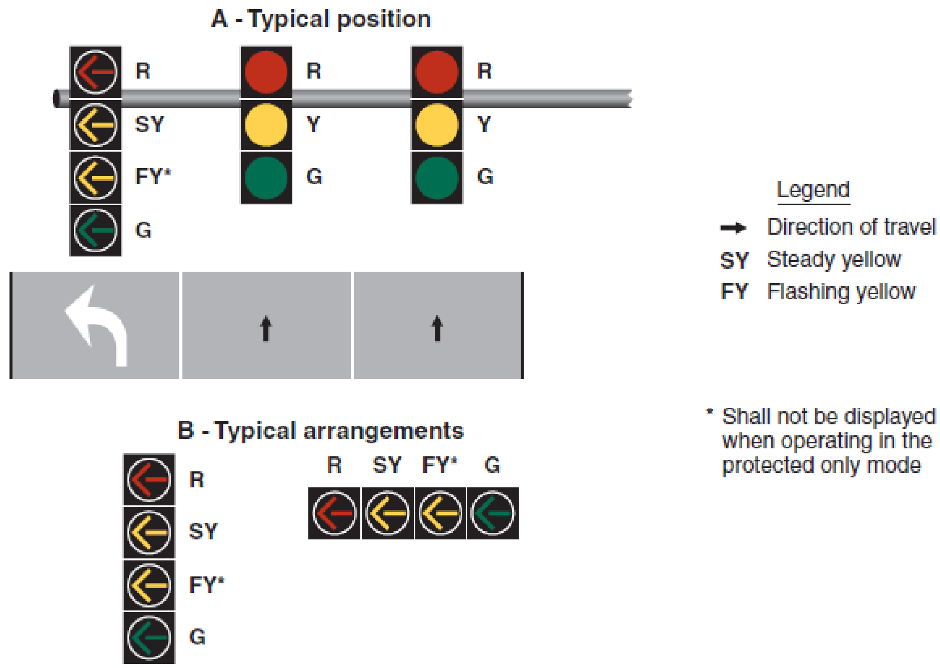

Figure 4D-14. Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Permissive Only Mode Right Turns

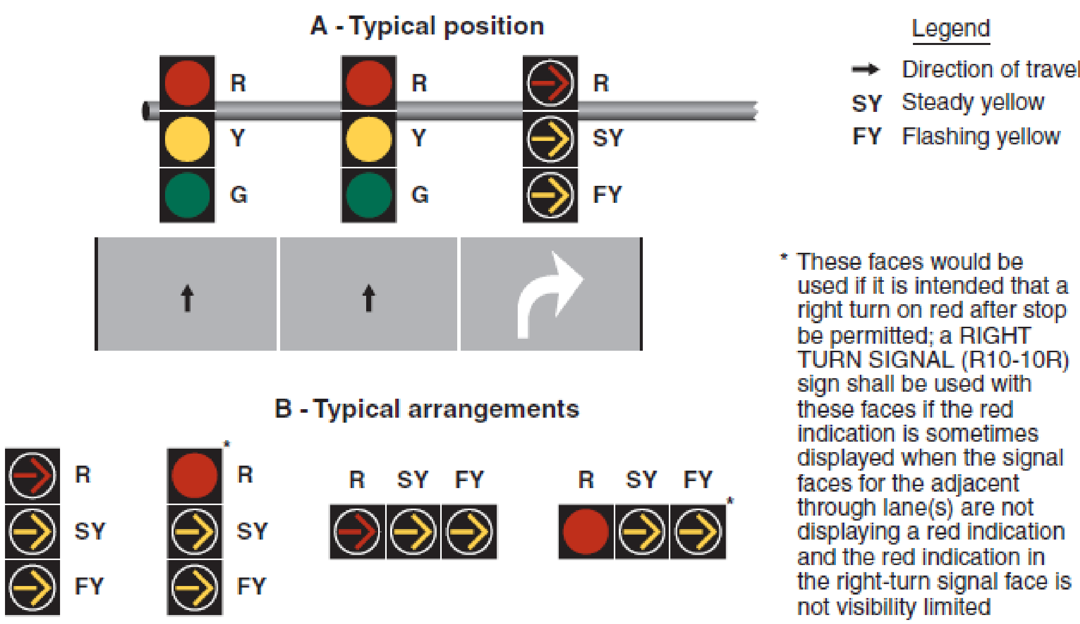

Figure 2. Illustration of Use of Flashing Yellow Arrow in 2009 National MUTCD – Section 4D Figures 4D-12 and 4D-14

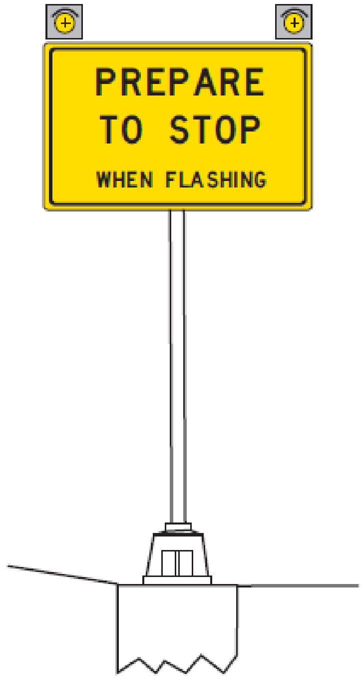

Figure 4O-1. Advance Warning Assembly

Figure 3. Minnesota AWF per MN MUTCD, Section 4O

Railroad Preemption (RRP) of Traffic Signal at Railroad-Highway Grade Crossing

RRP of a traffic signal is used to clear a railroad-highway grade crossing and maintain the clearance while the train passes to avoid a collision between the train(s) and vehicles or travelers including bicyclists and pedestrians (see Figure 4). The scope of RRP is heavy rail, i.e., operations in which the train cannot be expected to stop in time to avoid a collision with an object on the grade crossing. Light rail transit is considered a non-standard application that must be treated on a case-by-case basis. The approach of a train with RRP always preempts normal signal operation to clear the crossing and avoid a collision.

Two basic operational modes are used that affect traffic signal clearance timing. In the first mode, activation of crossing protection (flashing-light signals, or flashing-light signals and gates) is programmed to occur a fixed time before the arrival of the railroad vehicle at the crossing. Typical minimum activation time before the train arrives is 20 seconds or more per the *latest version of the MN MUTCD* but is set at a nearly uniform value of constant warning time. To accomplish this, track sensors must be able to accurately measure the speed of the approaching train and estimate the arrival time to the crossing. Traffic signal clearance timing must then be related to the constant warning time for activating crossing protection.

In the second mode, the approach of a train at the track sensor point unconditionally activates crossing protection (flashing-light signals, or flashing-light signals and gates), and pre-emption signal timing and speed of the train are not taken into account. Active crossing protection time thus is variable as a function of the speed of the approaching train.

Figure 4. Grade Crossing with Traffic Signal Preemption
(Source: AECOM)

Regardless of the operational mode, the pre-emption response of the traffic signal controller is site specific, depending on the physical configuration of the railroad-highway grade crossing and the location of adjacent traffic signals (see Figure 5). The control logic must clear vehicles, bicyclists and pedestrians off the railroad tracks by special pre-emption phasing and timing. Except where Accessible Pedestrian Signals are used, the *latest version of the MN MUTCD* (Section 4D.27) allows for shorter than normal pedestrian change intervals so that clearing of the grade crossing area changes can be completed in time. Signal sequencing may include quickly turning signals downstream of a crossing to green to allow queued vehicles to leave the crossing area. Once grade crossing clearance has occurred, parallel movements to the rail movement may be allowed, possibly augmented by “NO LEFT TURN” or “NO RIGHT TURN” blank-out signs. RRP treatment by traffic signals is complex and must be carefully considered and designed to provide the greatest possible protection for the individual site conditions.

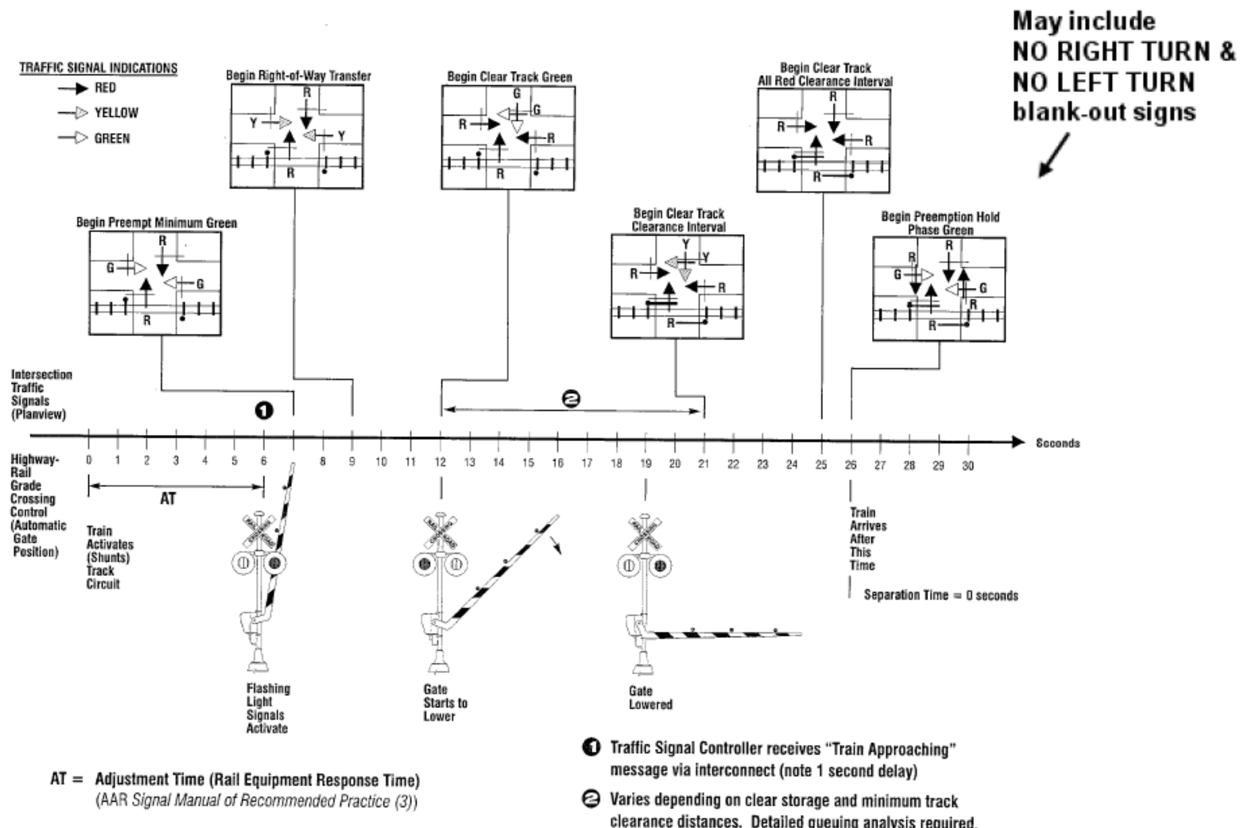

FIGURE 14 Sample simultaneous preemption time line (from (2)).

Figure 5. Traffic Signal Sequencing for Railroad Preemption

(Source: Traffic Signal Operations Near Highway-Rail Grade Crossings, NCHRP Synthesis 271)

If the highway traffic signal is interconnected with a four-quadrant gate system, backup or standby power should be considered for the signal. For signalized intersections in close proximity to a grade crossing, a supplemental pre-signal on the approach to the crossing is sometimes included so that drivers do not stop on normal red on the railroad tracks. In this case, additional track clearance sequencing and timing must be used.

Other related materials from the railroad viewpoint are presented in Systems Engineering Concept of Operations for: Railroad-Highway Grade Crossing.

Emergency Vehicle Preemption (EVP)

EVP is used to support safe and expeditious movement of police, fire, ambulance, or other critical emergency service vehicles through a signalized intersection. The basic concept (see Figure 6) is that an emergency vehicle that needs to travel as quickly as possible to or from an incident scene requests high priority movement through all or many of the signals on its travel route by either a call to a central control system, or by emitting an advance request for preemption service to each properly instrumented signal on its route. The continuous request is typically optical, audio (e.g., siren), or radio, and is sent well before the expected vehicle arrival time to the stop line. Each instrumented signal then attempts to service the call by either holding the green on the subject approach, or early terminating the green on a conflicting approach and granting right of way to the subject approach. Sometimes there may be conflicting calls for

EVP service on instrumented approaches, in which case controller software must have pre-established rules for "negotiating" which call is served, typically the first call received. A system that relies on central control, *not* vehicle emitters and receivers, requires that vehicle location be accurately tracked as it passes through each intersection by, for example, automatic vehicle location technology.

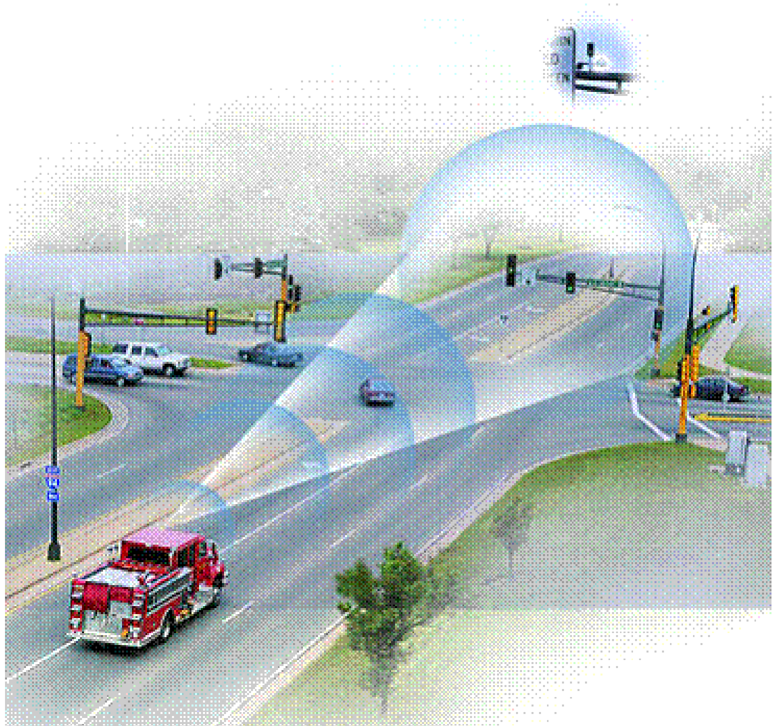

Figure 6. Emergency Vehicle Preemption Concept
Approaching emergency vehicle typically sends optical, audio, or radio signal requesting signal preemption. Unlike RRP, EVP is not usually absolute.
(Source: 3M/Global Traffic Technologies)

Unlike RRP, EVP is not absolute in the sense that preemption is not necessarily granted in all cases, for example, when EVP has already been granted for an emergency vehicle on a conflicting approach. Confirmatory white/clear indicator lights are required per the *latest version of the MN MUTCD* (Section 4D.27) to indicate to emergency vehicle drivers whether or not they have been granted preemption. The *latest version of the MN MUTCD* (Section 4D.27) allows for shorter than normal pedestrian change intervals so that the required clearing of the grade crossing area changes can be completed in time. The passage of the emergency vehicle through the intersection typically means that the call for service is no longer received by the signal controller, and it returns the signal to normal operational mode.

As noted earlier that wiring is included for all traffic signals to allow for easy future addition of EVP hardware and control software, if EVP is not installed at the time of construction. Minnesota State Law requires EVP wiring is included in the traffic signal design. Minnesota is also one of a few states that require the white/clear indicator lights for confirmation.

Transit Signal Priority (TSP)

TSP is similar to EVP but with a lower priority to force a green extension or early truncation of red (see Figure 7). Typical implementations are based on active tracking of bus passage times relative to scheduled passage times at route checkpoints. If a bus is running ahead of schedule, TSP activation is inappropriate because it may then put the bus further ahead of schedule. Usually a bus needs to be a few minutes or more behind schedule to justify putting in a call for priority service. Another consideration is that in more urbanized areas, requests for priority may occur on conflicting approaches of a given signalized intersection, so there must be a rule such as "first calling, first served." More sophisticated systems could theoretically keep track of number of passengers on board, and in the case of approximately same time requests on conflicting approaches, grant priority to the bus with significantly higher passenger count. Most US transit bus systems today, however, do not track number of passengers on board in real time**.**

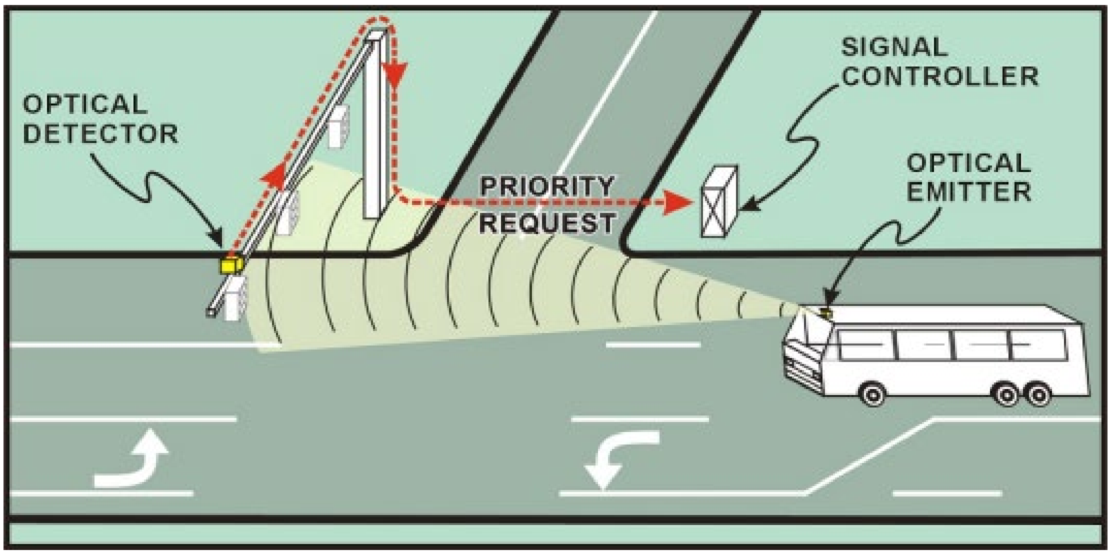

Figure 7. Transit Signal Priority Concept – with Optical Emitter

Approaching bus typically sends optical, audio, or radio signal requesting priority at signal if it is behind schedule a certain amount. This involves local intelligence to determine bus schedule performance. TSP operates at lower priority than both RRP and EVP.

(Source: "Bus Priority in Portland - Lessons Learned", by B. Kloos, http://www.docstoc.com/docs/DownloadDoc.aspx?doc_id=19006315)

The scope of TSP addressed here is operation in which all vehicle-tracking and priority decisions are made locally, that is, a transit system control center is *not* involved in monitoring bus position and schedule adherence to decide on whether or how to grant transit priority. The level of priority to grant must be determined on an individual route or site basis. The location of bus stop affects the determination of this, with near side stops having the additional complication that bus dwell time for boarding and alighting passengers is variable such that the true desired "green" time for the bus is not known very long in advance. Far side stop placement simplifies the control algorithm because a bus requesting priority is always requesting to make it through the signal at its expected arrival time to the stop line.

As with EVP, calls for priority can be accomplished by a number of methods including optical, audio, or radio emitters/receivers. In general, it is desirable that TSP along, or crossing, a progressively timed arterial be fit into the overall timing plan, not disrupting coordinated operations. In this way, servicing of the call should have the least adverse impact on normal signal operation, and in some cases may improve flow along the major traffic route.

Although bus TSP operation is shown in Figure 7, TSP also can support light rail transit operations where grade crossings with highways typically occur frequently. In this case, TSP may be combined with special traffic signal preemption depending on the needs of the site.

Enforcement Lights (EnL)

EnL are special displays placed on the back or the side of signal heads for the benefit of an enforcement officer to see when the red is displayed, as shown on Figure 8. This allows the enforcement officer to see whether or not a driver has illegally entered the intersection approach on red and should have a violation cited.

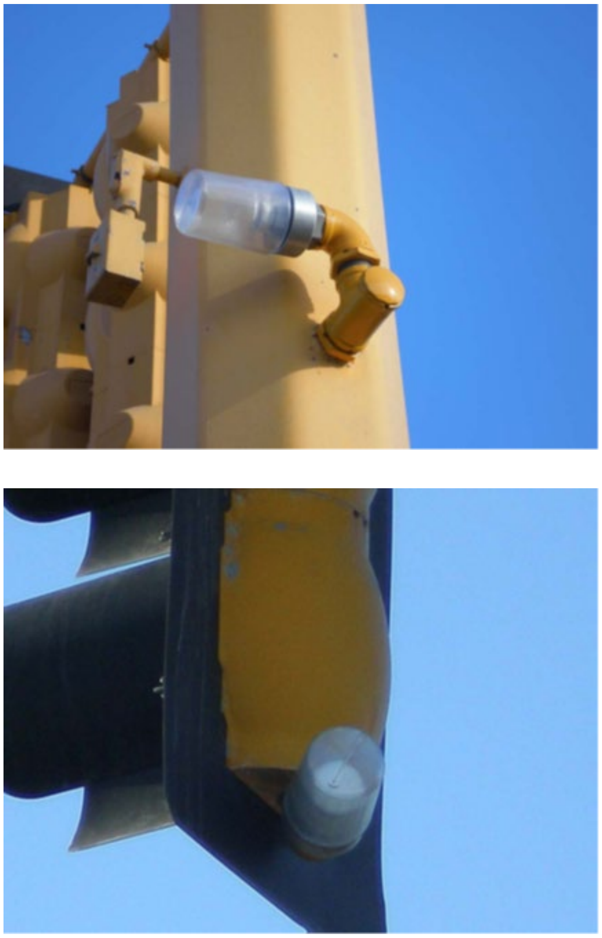

Figure 8. Enforcement Lights on Backside of Traffic Signal Face
(Source: MnDOT photo files)

Design of EnL is on a site basis, taking into account where a police officer can safely park to observe the light and then enter traffic to catch up to the offending vehicle. The need for EnL should be established based on crash records or observed patterns of red light running that tend to support the installation.

Traffic Signal Coordination (TSC)

TSC is the establishment of timed traffic flow between traffic signals on a progressively timed arterial or in a grid to minimize delays and stops. The *MnDOT Traffic Signal Timing and Coordination Manual* discusses signal timing and coordination, all of which is dependent on setting up coordination plans by time of day and day of week, or on use of traffic responsive/adaptive signal timing. The signals may be interconnected via wireline or wireless communications, or progressive timing may be established using time-based coordination in which very accurate internal clocks are used to maintain timing schedules. If signal interconnection is used, timing plan settings and parameters can be controlled remotely and the signals can be monitored to confirm signal operations in a closed loop configuration.

With interconnection, the remote location may be a traffic management center, an agency desktop computer, or possibly a technician's laptop computer via a secure connection over the internet. An on-street master may be part of the system supervising a defined arterial or small network, or the signals may connect directly to a central control location. The central control location may contact the on-street masters to provide oversight and direction. Intersection controllers may collect volume, occupancy, and occasionally speed data locally for performance monitoring and timing plan development. This information may be immediately conveyed to the central control location or locally stored for later retrieval.

System supervision and oversight may be by standard closed loop signal packages from established suppliers or may use custom software. Project design documents must clearly lay out the operational needs and constraints, and then define the supervisory and oversight software. Similarly, project design must define the technology and performance requirements of the communications subsystem that connects the signals. The TSC scope here is standard signal systems and not "smart" or "enhanced" corridors that in addition may have video, dynamic message signs (DMS), and other equipment.

CAV Infrastructure Systems and CAVs

CAV Infrastructure Systems and CAVs support connected and automated vehicle operations. They are external systems that include both CAV infrastructure (systems operated by MnDOT) and CAVs (vehicles and on-board units in the vehicles). The CAV Infrastructure Systems communicate with on-board units within CAVs. The vehicles and on-board applications communicate with CAV Infrastructure Systems and other CAVs. Standard traffic signal systems may communicate the signal status (e.g. Signal Phase and Timing or SPaT messages) with CAV Infrastructure Systems.

MnDOT may deploy CAV Infrastructure Systems that communicate with CAVs, either through roadside units (RSUs) or cloud-based communications. RSUs are ITS devices that function to facilitate real-time communication between CAVs and the devices by transferring information to the vehicles via wireless communications such as Dedicated Short-Range Communications (DSRC). CAV Infrastructure Systems may broadcast SPaT messages to CAVs and acquire data from traffic signals and CAVs. CAV Infrastructure Systems may also provide warnings to CAVs of potential traffic signal violations (e.g. red-light running vehicles).

Figure 9. Roadside Unit (RSU) Mounted on Light Pole

Users

The stakeholders, as per the *Minnesota Statewide Regional ITS Architecture* 2018 (*Statewide Architecture* for short) for the traffic signal(s) will be all or nearly all of the following, depending on the specific feature:

- Travelers: private vehicle drivers and passengers, transit operators and passengers, commercial operators, school bus operators and passengers, pedestrians (including those with disabilities), and bicyclists
- Minnesota Department of Transportation (MnDOT) and associated entities:
    - District Offices
    - RTMC (Regional Transportation Management Center), plus Southern Regional Communication Center (SRCC),
    - Office of Connected & Automated Vehicles (CAV-X)
    - Office of Traffic Engineering
    - Electrical Services Section (ESS)
    - Office of Transportation System Management
- Minnesota Department of Public Safety (DPS), plus Division of Driver and Vehicle Services (DVS)
- Local Agencies: counties, cities, towns, villages, and townships
- Local Traffic Management Centers
- Local Maintenance and Construction Management (MCM) Agencies
- Local Transit Providers such as Metro Transit and others
- Railroad Companies
- Minnesota State Patrol (MSP) and local law enforcement
- Local Emergency Response and Incident Management Agencies: police, fire, and ambulance
- Federal Highway Administration (FHWA)
- Federal Transit Administration (FTA)
- Federal Railroad Administration (FRA)

Notes to Stakeholder list:

- Only Travelers is listed in the *Statewide Architecture* but has been expanded above to explicitly list the various types of Travelers
- The list of Local Agencies has been similarly expanded from the *Statewide Architecture*

- Local law enforcement has been added in the MSP group

Challenges and Needs

The needs and functions of the signal for each of the stakeholders are presented in Table 1.

Table 1. Standard Traffic Signal Needs by Stakeholder

Stakeholder	Traffic Signal Needs
Travelers: private vehicle drivers and passengers, transit operators and passengers, commercial operators, school bus operators and passengers, and bicyclists	BTS-1 Safe and efficient assignment of vehicle right-of-way, with reliable and predictable service
	BTS-2 Clear, unambiguous display of red-yellow-green signal indications
	BTS-3 Minimum delay and stops, to the extent possible
	Additional Needs and Functions by traffic signal feature:
	AWF-1 Adequate warning of signalized approach ahead, preparing drivers to stop
	RRP-1 Fail-safe operation that minimizes the possibility of vehicles, objects or persons occupying grade crossing area when a train passes
	EVP-1 Safe and expeditious movement of emergency vehicles through traffic signals
	TSP-1 For Transit Operators and Passengers, better service by extension of green time or early truncation of red thus reducing delay, improving schedule reliability, and reducing run time
	TSC-1 Traffic Signal Coordination - Coordinated signal operation with adjacent signals
	CAV-1 Broadcast signal status (e.g. SPaT messages) from RSUs to CAVs.
Pedestrians (including disabled)	PED-1 Provide safe pedestrian crossings of signalized approaches in marked crosswalks
	PED-2 Clear and unambiguous pedestrian signal section displays
	PED-3 Pedestrian detection by push button when warranted
	PED-4 Adherence to *ADAAG* in design and construction
	PED-5 Adequate “start-up” WALK time, followed by sufficient clearance FLASHING DON’T WALK time
	PED-6 Pedestrian timing based on walking speed of 3.5 feet per second or less due to, for example, disabled or elderly population
	PED-7 For impaired or disabled populations, easy to find detection/push buttons and explicit communication of “WALK/DON’T WALK” message
All Stakeholders share in above to varying degree. Further specific Needs and Functions follow:	
MnDOT, MnDOT District Offices, RTMC, CAV-X, Office of Traffic Engineering, ESS and Office of Transportation System	BTS-4 Well-designed traffic signal that meet agency performance standards or guidelines for effective operations and safety

Stakeholder	Traffic Signal Needs
Management; Local Agencies, MCM units, and Traffic Management Centers; FHWA	BTS-5 Easily maintained and operated signal per agency standards using interoperable and easily replaced equipment and parts
	BTS-6 Data archiving of vehicle detection data and signal operations for use in planning and performance monitoring wherever and whenever possible
	CAV-2 Communicate signal status and other messages to and from CAVs through RSUs.
Railroad Companies, FRA	RRP-2 Reliable and easily maintained link between track circuit and nearby traffic signal(s) to provide safe and effective actuation of active grade crossing protection with flashing-light signals, or flashing-light signals and gates
SRCC, Local Emergency Response and Incident Management Agencies: police, fire and ambulance	EVP-2 Signal preemption on selected approaches, including verification via visual display
Local Transit Providers, FTA	TSP-2 More effective use of resources (buses and labor) by extension of green time or early truncation of red thus reducing run time
Minnesota DPS, DVS, MSP, and local law enforcement	EnL-1 Monitoring of red light running with an effective tool that facilitates enforcement and issuance of citations for driver violations

The Needs and Services plus associated ITS Development Objectives, per the *Statewide Architecture*, are presented in Table 2. It should be noted that some of the standard application groups meet an ITS Development Objective *without* an identified Need or Service in the *Statewide Architecture*. The Needs and Services are mapped to identified functional requirements in the companion *Functional Requirements for Standard Traffic Signal.*

Table 2. Traffic Signal Needs/Services and ITS Development Objectives by Standard Traffic Signal Feature

ID	Feature	Needs/Services [1] [2]	ITS Development Objectives
TS-BTS	Basic Traffic Signal	ATMS01: Provide efficient signal timing	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
		ATMS03: Use archived data for traffic management strategy development and long-range planning	G-1-01, G-1-02, G-1-03

[1] Needs/Services Key: ATMS - Traffic Management; APTS – Public Transportation

[2] Needs/Services and ITS Development Objectives per *Minnesota Statewide Regional ITS Architecture* (December 2018.

ID	Feature	Needs/Services [1 2]	ITS Development Objectives
		ATMS14: Monitor operation and performance of traffic signals	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
		ATMS37: Provide safe signal phase transition	A-1-05, A-1-10, A-2-05, A-2-11, A-2-26, A2-32
		--	A-1-04, A-1-13, A-1-14, A-1-15, H-1-06, H-1-07
TS-BTS: PED	Pedestrian Aspects	--	A-1-15
TS-BTS: DET	Detection Aspects	ATMS01: Provide efficient signal timing	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
		ATMS33: Provide intersection collision avoidance systems	A-1-01, A-1-08, A-1-10, A-1-11, A-1-16, A2-01, A-2-09, A-2-11, A-2-12, A-2-17, A-2-22, A-2-30, A-2-32, A2-33, A-2-38
		ATMS37: Provide safe signal phase transition	A-1-05, A-1-10, A-2-05, A-2-11, A-2-26, A2-32
TS-BTS: MON	Monitoring Aspects	ATMS14: Monitor operation and performance of traffic signals	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
		--	C-3-09, D-1-06, G-1-01, G-1-02, G-1-03
TS-BTS: IFC	Interface Aspects	ATMS01: Provide efficient signal timing	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
TS-FYA	Flashing Yellow Arrow	ATMS01: Provide efficient signal timing	B-1-01, B-1-03, B-1-04, B-1-06, B-1-07, B1-08, B-1-09, B-1-10, B-1-11, B-1-12, B-1-13, C-2-01, C-2-02
		ATMS37: Provide safe signal phase transition	A-1-05, A-1-10, A-2-05, A-2-11, A-2-26, A2-32
		--	A-1-13, A-1-14

ID	Feature	Needs/Services [1, 2]	ITS Development Objectives
TS-AWF	Advanced Warning Flasher	ATMS33: Provide intersection collision avoidance systems	A-1-01, A-1-08, A-1-10, A-1-11, A-1-16, A2-01, A-2-09, A-2-11, A-2-12, A-2-17, A-2-22, A-2-30, A-2-32, A2-33, A-2-38
		ATMS37: Provide safe signal phase transition	A-1-05, A-1-10, A-2-05, A-2-11, A-2-26, A2-32
		--	A-1-13, A-1-14
TS-RRP	Railroad Preemption	ATMS28: Provide railroad flashing light signals and gates	A-1-09, A-2-10, A-2-31
		ATMS38: Provide health monitoring of rail crossings	A-1-09, A-2-10, A-2-31
TS-EVP	Emergency Vehicle Preemption	--	B-1-16
TS-TSP	Transit Signal Priority	APTS 15: Optimize schedule efficiency and schedule coordination	B-2-15, E-4-01, E-4-07
		APTS 17: Coordinate transit vehicle movements with traffic control devices	B-2-15, C-3-08, E-1-01, E-1-02
TS-EnL	Enforcement Lights	ATMS02: Implement red-light running technology	A-1-05, A-1-10, A-2-05, A-2-11, A-2-26, A2-32
		--	A-1-13, A-1-14, A-2-43, A-2-44
TS-TSI	Traffic Signal Coordination	ATMS01: Provide efficient signal timing	A-1-10, A-1-11, B-1-01, B-1-03, B-1-07, B-1-10, B-1-11, B-1-12, B-1-13, B-1-14, B-1-04, B-1-08, B-1-09, B-2-23, B-2-24, B-2-25
TS-Oth	Other		

Operational Concept

Operational Description

Basic Traffic Signal (BTS)

Traffic signal installation and operation is justified based on an Intersection Control Evaluation (ICE). An important part of an ICE is consideration of traffic signal warrants in Chapter 4C of the *latest version of the MN MUTCD.* The warrants by name are:

- Warrant 1, Eight-Hour Vehicular Volume
- Warrant 2, Four-Hour Vehicular Volume
- Warrant 3, Peak Hour
- Warrant 4, Pedestrian Volume
- Warrant 5, School Crossing
- Warrant 6, Coordinated Signal System

- Warrant 7, Crash Experience
- Warrant 8, Roadway Network
- Warrant 9, Intersection Near a Grade Crossing

Traffic signals serve to provide safe and efficient movement of conflicting traffic flows by enforcing control discipline that balances demand for green time among the conflicting approaches. Traffic signals are more efficient than stop signs once traffic volumes reach a certain level because they remove the uncertainty regarding which approach has the assigned right of way (green time) at any moment. Properly designed and timed, they also tend to result in safer operations than stop signs at heavy traveled intersections for the same reason. At signalized locations with pedestrian indications and potentially push buttons, signals afford safe movement of pedestrians across the busy intersection approaches and roadways.

Flashing Yellow Arrow (FYA)

FYA was developed with support from research in the National Cooperative Highway Research Program (see http://www.trb.org/Main/Public/Blurbs/159759.aspx). The overall intent is to improve operational efficiency while maintaining safe permissive left- and right-turn movements. An FHWA study also shows that FYA is more understandable than the green ball to the public. The latest version of the *MN MUTCD* provides this as an option based on engineering judgment. MnDOT has made the installation of the FYA left turn arrow a standard at intersections with exclusive left turn lanes.

Advanced Warning Flasher (AWF)

The approaches selected for AWF installation are to have been identified based on field studies, plan review, or the fundamental nature of the site(s). Appropriate documentation needs to be on file and maintained by the implementing agency.

Railroad Preemption (RRP)

RRP, EVP, and TSP are all versions of signal preemption and priority, in decreasing order of application based on the relative order of importance or difficulty in stopping the type or class of vehicle. In all cases, traffic signal planning, design, and operation must be carefully executed to maximize safety and efficiency. The most complex situations are those in which all three types are present at the same signalized intersection. Appropriate documentation needs to be on file and maintained by the implementing agency in all cases.

Emergency Vehicle Preemption (EVP)

See RRP.

Transit Signal Priority (TSP)

See RRP.

Enforcement Lights (EnL)

EnL will be in use in Minnesota at least until such time that the State passes legislation allowing the use of automated red-light running cameras. Appropriate documentation needs to be on file and maintained by the implementing agency.

Traffic Signal Coordination (TSC)

For ConOps and functional requirements for more sophisticated levels of traffic control than basic on-street master, closed loop control, additional documentation should be prepared on a site-specific basis. Even in the case of basic closed loop control, planning, design, and operational documentation may be substantial.

CAV Infrastructure Systems and CAVs

MnDOT may deploy CAV Infrastructure Systems that communicate with CAVs, either through RSUs or cloud-based communications. CAV Infrastructure Systems may broadcast SPaT messages to CAVs and acquire data from traffic signals and CAVs. CAV Infrastructure Systems may also provide warnings to CAVs of potential traffic signal violations (e.g. red-light running vehicles).

Other

Other features generally can be expected to require substantial documentation to justify and explain new technologies and applications.

Operational Environment

The major operational aspects of signals are covered under *Basic Traffic Signal* subsection and apply to all signal features. A few additional aspects for some of the features are also identified.

Basic Traffic Signal (BTS)

Operations, management, and maintenance of the traffic signal(s) will be the responsibility of the owning or assigned operational agency. The primary actions will be to:

- Establish traffic signal timing based on site volumes, geometrics, signal phasing and controller capabilities,
- Periodically check and conduct routine maintenance on the road approaches,
- Promptly respond to trouble calls to maintain satisfactory operation in case of performance failure or knock-down,
- Review crash data periodically to assure that the signalized intersection is operating as safely as can be expected, and
- Review performance data periodically (e.g., stops, delays, queue lengths) to assure satisfactory levels are achieved, potentially resulting in signal timing adjustments and possible recommendations for geometric improvements.

Flashing Yellow Arrow (FYA)

No additional actions.

Advanced Warning Flasher (AWF)

- Establish AWF timing (initiation and termination times of flashing) based on signal phasing and controller capabilities.

Railroad Preemption (RRP)

- Establish RRP preemption sequencing, phasing, and timing based on site physical and control features, emphasizing “fail safe” operation.

Emergency Vehicle Preemption (EVP)

- Establish EVP preemption sequencing, phasing, and timing based on site physical and control features, and how competing requests for preemption on conflicting approaches will be resolved.

Transit Signal Priority (TSP)

- Establish TSP priority timing based on site physical and control features, including rules for servicing requests on conflicting approaches and limits on the frequency of priority grants allowed.

Enforcement Lights (EnL)

No additional actions.

Traffic Signal Coordination (TSC)

- Establish initial traffic signal timing plans based on system volumes and geometrics, potentially running traffic signal timing software. If traffic responsive signal operation included, establish plan selection parameters.

CAV Infrastructure Systems and CAVs

- Install CAV Infrastructure Systems to support connected and automated vehicle operations.
- Establish CAV support and management systems to enable CAV services. This may include support systems for CAV system monitoring and management, registration, security and credentials management, authorization, and device certification and enrollment.
- Establish policies for CAV operations and management.

Other

[Reserved for new features and their operational actions].

Support Environment

Basic Traffic Signal (BTS)

The operational support environment will use standard traffic signal timing and maintenance techniques that are well developed within MnDOT, or Local Agencies. Technicians will operate and maintain the traffic signal(s) using agency operational guidelines along with routine and emergency maintenance procedures that are well established. Signal operation is to be in conformance with the *latest version of the MN MUTCD.*

With respect to support environment, the most important maintenance aspect once signal timing has been prepared and implemented is defined procedures for trouble calls. Trouble calls will typically originate from various sources: the general public, police, and MnDOT or Local Agency personnel who drive through the subject approach*[es]* either as a part of assigned work, or as a private citizen, e.g., while commuting to and from work. MnDOT or Local Agency policy and contract requirements typically define required response times on weekdays, weekends, holidays, and overnight. Response time (time interval from initial fault notification until an on-site maintenance vehicle arrives or diagnosing from a remote location begins) varies by type and severity of fault, as well as intersection priority. Periodic operational and safety reviews need to be conducted.

Preventive maintenance on the intersection(s) will be scheduled to occur periodically as a part of routine traffic signal maintenance. Signal timing reviews can be expected to occur on a periodic schedule of every three to five years, depending on if the signal is on a major or minor corridor, or based on operational observations and citizen complaints. Review of site performance from a crash history viewpoint may be completed periodically by MnDOT or Local Agency personnel.

Flashing Yellow Arrow (FYA)

As presented in the Current Environment section, the FYA operating scenario is the display of a flashing yellow arrow when permissive vehicle movement is allowed, that is, the controlled left- or right-turn traffic must yield to opposing conflicting traffic or conflicting pedestrians.

Also, FYA operations typically are localized to each site with no communication of occurrences to a central location. As a result, FYA operations do not generate additional system architecture needs. Specialized maintenance may be required depending on how FYA operation is implemented.

Advanced Warning Flasher (AWF)

The AWF operational concept is relatively straightforward, as described in the Current Environment section above, in which the yellow flasher is activated to warn approaching drivers that the signal has turned, or is about to turn, to red. Each site is essentially an isolated operation that does not depend on information from other locations, nor does it typically communicate AWF operations to a central location. As a result, there are no additional system architecture needs. If central monitoring is included, a wireline or wireless connection between the site and the central location must be established. The system architecture to handle the required data flows must be included in detailed site design.

AWF operation is a special extension of standard traffic signal procedures. The critical aspect is determination of when to initiate and terminate flasher operation within the framework of normal signal phasing and timing, per *the latest version of the MN MUTCD* Section 4O. A minimum amount of training in this aspect may be required. Periodic operational reviews need to be conducted, potentially leading to adjustment in AWF activation and termination timing to maximize the safety benefit.

Railroad Preemption (RRP)

The interface between the track circuit and the traffic signal and the associated signal preemption timing are critical aspects that must be carefully developed and, if necessary, fine-tuned. RRP also requires regular routine maintenance and quick response in case of performance failure or trouble call within a few hours at most. Although the operations of each site are standalone, remote monitoring of the preemption circuitry that sends alarm messages to both the railroad and the highway authority in the case of a malfunction is desirable. The system architecture and associated communications for this are dependent on characteristics of both the rail system and the traffic signal operation. Specialized training is required to handle operations and maintenance. Periodic operational and safety reviews need to be conducted, potentially leading to adjustment in RRP activation timing.

Emergency Vehicle Preemption (EVP)
Appropriate rules for negotiating competing calls for EVP must be established, along with treatment of pedestrian phase timing that may be operational when a call is received. Initial set up and operation can be expected to require adjustment of sensitivity and range parameters that vary by the technology used. Most sites operate standalone, with no communications to a central oversight point. The exception is an EVP system that tracks emergency vehicles using automatic vehicle location technology and issues commands on the route to hold greens or truncate reds. In this case, the system architecture and associated communications are dependent on characteristics of the traffic signal system. Specialized training is required to handle operations and maintenance. Periodic operational and safety reviews need to be conducted, potentially leading to adjustment in EVP timing.

Transit Signal Priority (TSP)
Appropriate rules for negotiating competing calls for TSP must be established, along with limits on frequency of priority grants. Per the *latest version of the MN MUTCD*, shortening of pedestrian interval timing is generally *not* allowed for TSP. Most sites operate standalone, with no communications to a central oversight point. The exception is a TSP system that tracks transit vehicles using automatic vehicle location technology and issues requests along the route to hold greens or truncate reds if the transit vehicle is significantly behind schedule. In this case, the system architecture and associated communications are dependent on characteristics of the transit management and traffic signal systems. Specialized training is required to handle operations and maintenance. Periodic operational and safety reviews need to be conducted, potentially leading to adjustment in TSP operations and timing.

Enforcement Lights (EnL)
Sites with EnL operate standalone so there are no system architecture aspects. Maintenance is essentially the same as for standard signal sections, so no special training is required.

Traffic Signal Coordination (TSC)
The Current Environment and Operational Concept sections discuss the development of coordinated signal timing settings and parameters for interconnected traffic signals. Sites are by definition interconnected so that system architecture and communications configuration need to be developed based on physical characteristics and communications medium. Some specialized training in communications technology is generally required. Periodic operational reviews need to be conducted, potentially leading to adjustment in signal system timing.

CAV Infrastructure Systems and CAVs
Management, security and maintenance is essential for CAV applications to standard traffic signals. It is critical to establish systems to support CAV system monitoring and management, registration, security and credentials management, authorization, and device certification and enrollment. Specialized training in CAV and communications technology is required for operations, management and maintenance.

Roles and Responsibilities
Based on the interactions described in the operational concept, Table 3 briefly summarizes the anticipated roles and responsibilities of the stakeholder groups with operating and maintaining standard traffic signals.

Table 3. Operation and Maintenance Roles and Responsibilities

User Group	Role / Responsibility
MnDOT ESS	• Maintain traffic signals that meet agency performance standards or guidelines for effective operations and safety
MnDOT Office of Traffic Engineering	• Provide standards, guidelines, and policies for the design and operation of traffic signals considering ease of maintenance and effective operations and safety to all users
MnDOT District Offices	• Design traffic signals that meet agency performance standards or guidelines for effective operations and safety • Operate and maintain signals per agency standards • Collect, archive and analyze vehicle detection data and signal operations for use in planning and performance monitoring wherever and whenever possible
Local Agencies	• Design traffic signals that meet agency performance standards or guidelines for effective operations and safety • Operate and maintain signals per agency standards • Collect and archive vehicle detection data and signal operations for use in planning and performance monitoring wherever and whenever possible
Traffic Management Centers	• Operate signals per agency standards using interoperable and easily replaced equipment and parts • Collect and archive vehicle detection data and signal operations for use in planning and performance monitoring wherever and whenever possible
MnDOT RTMC and SRCC	• Operate signals per agency standards using interoperable and easily replaced equipment and parts • Collect and archive vehicle detection data and signal operations for use in planning and performance monitoring wherever and whenever possible
Local Emergency Response and Incident Management Agencies: police, fire and ambulance	• Signal preemption on selected approaches, including verification via visual display
Local Transit Providers	• Signal priority on selected approaches, including verification via visual display
MSP	• Monitor red light running with an effective tool that facilitates enforcement and issuance of citations for driver violations
Local Law Enforcement	• Monitor red light running with an effective tool that facilitates enforcement and issuance of citations for driver violations

Operational Scenarios

Scenarios are intended to help users understand how they may interact with standard traffic signals within the context of those situations that will most commonly require the use of standard traffic signals. The following scenarios briefly describe how users will be impacted and how they are expected to respond.

- Scenario A: Basic Traffic Signal Operations
- Scenario B: Flashing Yellow Arrow
- Scenario C: Advance Warning Flasher
- Scenario D: Railroad Preemption
- Scenario E: Emergency Vehicle Preemption
- Scenario F: Transit Signal Priority
- Scenario G: Enforcement Lights
- Scenario H: Traffic Signal Coordination
- Scenario I: CAV Instructure Systems and CAVs

Scenario A: Basic Traffic Signal (BTS) Operations

A vehicle traveling along a city street approaches an intersection with a BTS. The vehicle driver sees the red signal and stops the vehicle behind the stop bar. The cross-street vehicles pass through the intersection as those drivers see a green signal. The vehicle driver stopping behind the stop bar sees the traffic signal turning green 20 seconds later. After the traffic signal turns green, the vehicle proceeds moving forward, passes through the intersection safely, and continues traveling down the street.

Scenario B: Flashing Yellow Arrow (FYA)

The FYA signal first activates once all cross-traffic phases terminate into red signals. A driver approaching the intersection spots the FYA signal and scans the opposing thru-movement for oncoming vehicles. After waiting for a safe gap in oncoming traffic, the driver proceeds to make a permissive left turn movement at the intersection. The driver safely clears the intersection and travels onward.

Scenario C: Advance Warning Flasher (AWF)

A vehicle traveling along a high-speed arterial approaches a signalized intersection. An AWF sign on the approach prior to the intersection begins to flash, warning approaching drivers that the is about to turn to red. The driver notices the flashing warning lights and begins to slow down in anticipation of an upcoming red light signal. The driver slows to a comfortable speed and stops on the approach to the intersection. Cross-traffic waiting for a phase transition begins to travel through the intersection.

Scenario D: Railroad Preemption (RRP)

As the train approaches and passes over the circuit terminal point prior to the crossing, the crossing equipment sends a preempt message to the traffic signal controller equipped with Traffic Signal Preemption (TSPr). The crossing equipment also activates the railroad-highway grade crossing flashing light signals (FLS). Once the preemption request is received, traffic signal preemption is then activated to clear the crossing and hold the “crossing closed” preemption state. The FLS remain active until the train has left the grade crossing. After the train has cleared the crossing and passed over the circuit terminal point beyond the crossing, the crossing equipment sends a message to the traffic signal controller that the train has passed through and that normal signal operations can safely be resumed. The FLS stop flashing and the traffic signal turns green for the vehicles stopped at the crossing. Vehicles stopped at the crossing begin to travel through the crossing.

Scenario E: Emergency Vehicle Preemption (EVP)

An ambulance rushing to the site of a 911 call emits an advance request for EVP to upcoming traffic signals along its route. The preemption request is received by traffic signals within range and transferred to the traffic signal controller. No prior EVP requests have been received by the traffic signal, so preemption is granted to the ambulance at the approaching traffic signal via green extension. A steady confirmatory white light is activated, indicating to the ambulance driver that EVP has been granted.

A passenger vehicle approaches the intersection. The driver hears but does not see an ambulance approaching from a cross street near the intersection. The passenger vehicle driver sees the red signal phase and comes to a stop behind the stop bar. At the same time a pedestrian walking along the sidewalk approaches the intersection. The pedestrian hears but does not see an ambulance approaching from a cross street near the intersection. The pedestrian sees the red signal phase and stops prior to the curb line.

The ambulance safely passes through the intersection on the green extension. After the ambulance passes through the intersection, the signal cycle is reset and the signal resumes normal operational mode. The passenger vehicle and the pedestrian wait at the intersection for their respective green signals to safely travel through the intersection.

The ambulance continues to request preemption at additional traffic signals along its route until the ambulance reaches its destination.

Scenario F: Transit Signal Priority (TSP)

A bus traveling along a busy urban corridor during AM peak hour is running roughly 5 minutes behind its normal route schedule. As the bus approaches a signalized intersection, the bus sends out a request for TSP. The request is received by the traffic signal controller, where it is processed. No conflicting TSP requests from other buses or EVP requests from emergency vehicles are received by the controller. The controller grants the TSP request via red light truncation. After the bus passes through the intersection, the TSP process within the signal controller is terminated and the traffic signal resumes normal operations.

Scenario G: Enforcement Lights (EnL)

A vehicle approaches a signalized intersection and notices the signal has turned from green to yellow. The driver speeds up to get through the intersection. The driver enters the intersection as the traffic signal turns red and the enforcement light for the approach is activated concurrently with the red signal phase. The driver passes through the intersection well after the red signal. A law enforcement officer downstream of the traffic signal observes the active enforcement light and spots the offending vehicle. The officer flags down the driver and performs enforcement activities.

Scenario H: Traffic Signal Coordination (TSC)

A steady stream of vehicles travels along a high-volume signalized arterial during the PM peak hour. The corridor contains TSC in the form of progressive timing. All traffic signals along this particular stretch of corridor contain uniform spacing between signals. The vehicles pass through a signalized intersection on a green phase and continue toward the downstream traffic signal. The progressive timing mechanism maintains efficient signal timing using an internal clock that synchronizes major thru-movement signal phasing for vehicles traveling along the corridor. The vehicle stream begins approaching the downstream intersection. As the vehicles approach the intersection, the signal remains green or turns to green to allow the stream of vehicles to travel through the intersection without stopping.

Scenario I: CAV Instructure Systems and CAVs

At a time when a high number of CAVs are operational in Minnesota, MnDOT may deploy CAV Infrastructure Systems which can receive communications from CAVs with an array of information such as basic safety messages (BSMs). Standard traffic signal equipment may communicate signal status (e.g. SPaT messages) with CAV Infrastructure Systems. CAV Infrastructure Systems may broadcast traffic signal status, warnings and BSMs to CAVs. The CAVs receive these messages via RSUs or cloud-based communications.

Risks and Mitigation

Basic Traffic Signal (BTS)

Depending on site conditions, traffic signals should achieve less vehicle delay, fewer stops, and less fuel consumption and emissions than alternate methods of traffic control such as stop signs, roundabouts, or manual police control. The impacts will vary across stakeholders, since stakeholder interests and objectives almost always need to be balanced against one another. For example, providing adequate pedestrian crossing time of a major arterial at a signal will often result in increased stops and delay to major arterial traffic. Thus, it is important that the competing objectives be identified at the outset of signal concept and detailed design, and that periodic performance evaluation be conducted to assure that the objectives are reasonably achieved. Overall agency goals and objectives may be reconsidered and redirected from time to time as well, and such redirection may affect periodic performance evaluation.

APS operation focuses on providing the same information to disabled persons as to others to help them make the correct crossing decision. One potential metric is safety performance, along with the degree to which drivers properly observe the rights of pedestrians in cross walks. This may require special studies of “challenged” crossings in which pedestrians are threatened by vehicles. A second potential metric is the comprehensibility of the APS to the target population, that is, the effectiveness and clarity in conveying the “WALK/DON’T WALK” message. The two metrics should be related to one another.

CPS installations should improve pedestrian safety by removing uncertainty about remaining crossing clearance time. Quantifying the benefit, however, may be difficult because of the many factors that affect pedestrian safety at intersections. It is likely that pedestrian involvement in crashes will need to be aggregated over several crossings and fairly long time periods to demonstrate benefits.

Flashing Yellow Arrow (FYA)

The primary benefit of FYA installation is flexibility in signal operation that should yield more efficient vehicle movement with reduced delay. Studies also show that FYA is more understandable than the green ball to the public. Ideally, time-and-delay studies are conducted to verify the results while accident occurrence is also reviewed to confirm that safe turn operations are maintained. Based on these assessments, site modifications may be appropriate, such as relocation of signal heads or conversion to protected only turn operation.

Advanced Warning Flasher (AWF)

The primary impact associated with AWF installation is reduction or prevention of adverse crash occurrence. It also provides benefits to larger vehicles as they need a longer stopping distance. The key metric will be annual crash data in terms of absolute number, severity, and rate, relative to similar signalized approaches that do not have AWF. Based on this assessment, alternate timing parameters may be implemented, to be more prominent or to provide additional stopping time for approaching drivers.

Railroad Preemption (RRP)

RRP is focused on safe operation of this critical interface between rail and highway systems, given the likely severity of any crashes that occur. Accident records need to be reviewed on a regular basis. Every grade crossing crash should be evaluated to see if further design or operational treatments might be employed to reduce the potential for future incidents.

Emergency Vehicle Preemption (EVP)

EVP aims to provide the fastest possible incident response time in the safest manner. The implementing agency should track response times and attempt to provide reasonable metrics for evaluating EVP performance. The difficulty in this is the variability in emergency conditions, in terms of route, time of day, traffic, and weather conditions. EVP also needs to be safe, that is, not result in increase in, and ideally reduce, collisions between emergency vehicles and other traffic. Presumably the “base case” will involve few such accidents, but emergency agencies should track safety trends.

Transit Signal Priority (TSP)

TSP has two primary benefits: reduced travel time/increased schedule reliability for passengers, and more efficient use of equipment by transit operating agencies. The transit operator should conduct before and after studies to determine the degree to which these benefits are achieved. Improved passenger service may attract additional ridership, so this aspect should be considered as well.

Enforcement Lights (EnL)

The primary goal of ENL is reduction in red light running occurrence and associated crashes. The lights also provide a safer environment for enforcement officers who no longer have to follow an offending vehicle through a red light. Crash data should thus be carefully tracked to see if in fact a safety benefit is realized. A secondary benefit may be a reduction in red light running at *all* signalized intersections, based on the positive benefits of active enforcement. Thus, evaluation should consider both specific installation site and general area performance with respect to those crashes that may be affected by reduction in red light running.

Traffic Signal Coordination (TSC)

TSC should result in reduced stops and delay on the road system by improved synchronization of signals. This may be measured through before and after time-and-delay studies of travel time that quantify effects of improved coordination. Stop and delay reductions can be translated into fuel and emissions savings. Interconnected signals may also provide quicker notification of malfunctioning than might otherwise occur.

CAV Infrastructure Systems and CAVs

Management, security and maintenance is essential for CAV applications to standard traffic signals. Privacy is another concern related to CAV applications. It is critical to establish systems to support CAV system monitoring and management, registration, security and credentials management, authorization, and device certification and enrollment. Specialized training in CAV and communications technology needs to be provided to appropriate agency staff for proper operations, management and maintenance of CAV systems.

Other

[Reserved for new feature impacts.]

Appendix A. ITS Development Objectives

Source: Minnesota Statewide Regional ITS Architecture (December 2018)

General Purpose: Create a system that enhances transportation through the safe and efficient movement of people, goods, and information, with greater mobility and fuel efficiency, less pollution, and increased operating efficiency in Minnesota.

DM:	Data Management
PT:	Public Transportation
TI:	Traveler Information
TM:	Traffic Management
PM:	Parking Management
SU:	Support
VS:	Vehicle Safety
CVO:	Commercial Vehicle Operations
PS:	Public Safety
MC:	Maintenance and Construction
WX:	Weather
ST:	Sustainable Travel

A. Improve the Safety of the State's Transportation System

A-1 Reduce crash frequency *(TI, TM, PT, CVO, PS, MC, VS & WX)*

- A-1-01 Reduce number of vehicle crashes
- A-1-02 Reduce number of vehicle crashes per VMT
- A-1-03 Reduce number of crashes due to road weather conditions
- A-1-04 Reduce number of crashes due to unexpected congestion
- A-1-05 Reduce number of crashes due to red-light running
- A-1-06 Reduce number of crashes involving large trucks and buses
- A-1-07 Reduce number of crashes due to commercial vehicle safety violations
- A-1-08 Reduce number of crashes due to inappropriate lane departure, crossing and merging
- A-1-09 Reduce number of crashes at railroad crossings
- A-1-10 Reduce number of crashes at signalized intersections
- A-1-11 Reduce number of crashes at un-signalized intersections
- A-1-12 Reduce number of crashes due to excessive speeding
- A-1-13 Reduce number of crashes related to driving while intoxicated
- A-1-14 Reduce number of crashes related to driver inattention and distraction
- A-1-15 Reduce number of crashes involving pedestrians and non-motorized vehicles
- A-1-16 Reduce number of crashes at intersections due to inappropriate crossing
- A-1-17 Reduce number of crashes due to roadway/geometric restrictions
- A-1-18 Reduce number of crashes involving younger drivers (under 21)
- A-1-19 Reduce number of all secondary crashes

A-2 Reduce fatalities and life changing injuries *(TI, TM, PT, CVO, PS, MC, VS & WX)*

- A-2-01 Reduce number of roadway fatalities
- A-2-02 Reduce number of roadway fatalities per VMT
- A-2-03 Reduce number of fatalities due to road weather conditions
- A-2-04 Reduce number of fatalities due to unexpected congestion
- A-2-05 Reduce number of fatalities due to red-light running
- A-2-06 Reduce number of fatalities involving large trucks and buses
- A-2-07 Reduce number of fatalities due to commercial vehicle safety violations
- A-2-08 Reduce number of transit fatalities
- A-2-09 Reduce number of fatalities due to inappropriate lane departure, crossing and merging
- A-2-10 Reduce number of fatalities at railroad crossings
- A-2-11 Reduce number of fatalities at signalized intersections
- A-2-12 Reduce number of fatalities at un-signalized intersections
- A-2-13 Reduce number of fatalities due to excessive speeding
- A-2-14 Reduce number of fatalities related to driving while intoxicated
- A-2-15 Reduce number of fatalities related to driver inattention and distraction
- A-2-16 Reduce number of fatalities involving pedestrians and non-motorized vehicles

A-2-17 Reduce number of fatalities at intersections due to inappropriate crossing
A-2-18 Reduce number of fatalities due to roadway/geometric restrictions
A-2-19 Reduce number of fatalities involving younger drivers (under 21)
A-2-20 Reduce number of fatalities involving unbelted vehicle occupants
A-2-21 Reduce number of hazardous materials transportation incidents involving fatalities
A-2-22 Reduce number of roadway injuries
A-2-23 Reduce number of roadway injuries per VMT
A-2-24 Reduce number of injuries due to road weather conditions
A-2-25 Reduce number of injuries due to unexpected congestion
A-2-26 Reduce number of injuries due to red-light running
A-2-27 Reduce number of injuries involving large trucks and buses
A-2-28 Reduce number of injuries due to commercial vehicle safety violations
A-2-29 Reduce number of transit injuries
A-2-30 Reduce number of injuries due to inappropriate lane departure, crossing and merging
A-2-31 Reduce number of injuries at railroad crossings
A-2-32 Reduce number of injuries at signalized intersections
A-2-33 Reduce number of injuries at un-signalized intersections
A-2-34 Reduce number of injuries due to excessive speeding
A-2-35 Reduce number of injuries related to driving while intoxicated
A-2-36 Reduce number of injuries related to driver inattention and distraction
A-2-37 Reduce number of injuries involving pedestrians and non-motorized vehicles
A-2-38 Reduce number of injuries at intersections due to inappropriate crossing
A-2-39 Reduce number of injuries due to roadway/geometric restrictions
A-2-40 Reduce number of injuries involving younger drivers (under 21)
A-2-41 Reduce number of injuries involving unbelted vehicle occupants
A-2-42 Reduce number of hazardous materials transportation incidents involving injuries
A-2-43 Reduce number of speed violations
A-2-44 Reduce number of traffic law violations

A-3 Reduce crashes in work zones *(TI, TM, PS, MC & VS)*
A-3-01 Reduce number of crashes in work zones
A-3-02 Reduce number of fatalities in work zones
A-3-03 Reduce number of motorist injuries in work zones
A-3-04 Reduce number of workers injured by vehicles in work zones

B. Increase Operational Efficiency and Reliability of the Transportation System

B-1 Reduce overall delay associated with congestion *(TI, TM, MC & VS)*
B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F
B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods
B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected

B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
B-1-15 Reduce mean incident notification time
B-1-16 Reduce mean time for needed responders to arrive on-scene after notification
B-1-17 Reduce mean incident clearance time per incident
B-1-18 Reduce mean incident clearance time for Twin Cities urban freeway incidents

B-2 Increase average vehicle passenger occupancy and facility throughput *(TM, PT & ST)*
B-2-01 Increase annual transit ridership
B-2-02 Increase annual express bus ridership
B-2-03 Increase annual light rail ridership
B-2-04 Increase annual commuter rail ridership
B-2-05 Maintain agency pre-defined performance targets for rides per hour of transit service
B-2-06 Maintain transit passengers per capita rate for service types
B-2-07 Maintain the cost efficiency of the statewide public transit network
B-2-08 Maintain the service effectiveness of the statewide public transit network in terms of passengers/service hour and passengers/mile
B-2-09 Maintain the cost effectiveness of the statewide public transit network in terms of cost per service hour, cost per passenger trip, and revenue recovery percentage
B-2-10 Maintain the availability of the statewide public transit network in terms of hours (span) of service and frequency
B-2-11 Reduce per capita single occupancy vehicle commute trip rate
B-2-12 Increase the percentage of major employers actively participating in transportation demand management programs
B-2-13 Reduce commuter vehicle miles traveled (VMT) per regional job
B-2-14 Create a transportation access guide, which provides concise directions to reach destinations by alternative modes (transit, walking, bike, etc.)
B-2-15 Improve average on-time performance for specified transit routes/facilities
B-2-16 Increase use of automated fare collection system per year
B-2-17 Increase the percent of transfers performed with automated fare cards
B-2-18 Increase the miles of bus-only shoulder lanes in the metro area
B-2-19 Increase the number of carpools
B-2-20 Increase use of vanpools
B-2-21 Provide carpool/vanpool matching and ridesharing information services
B-2-22 Reduce trips per year in region through carpools/vanpools
B-2-23 Increase vehicle throughput on specified routes
B-2-24 Increase AM/PM peak hour vehicle throughput on specified routes
B-2-25 Increase AM/PM peak hour person throughput on specified routes

B-3 Reduce delays due to work zones *(TI, TM, PS, MC & VS)*
B-3-01 Reduce total vehicle hours of delay by time period (peak, off-peak) caused by work zones
B-3-02 Reduce the percentage of vehicles traveling through work zones that are queued
B-3-03 Reduce the average and maximum length of queues, when present,
B-3-04 Reduce the average time duration (in minutes) of queue length greater than some threshold (e.g., 0.5 mile)
B-3-05 Reduce the variability of travel time in work zones during peak and off-peak periods

B-4 Reduce traffic delays during evacuation from homeland security and Hazmat incidents *(TI, TM, PT, CVO, PS & VS)*
B-4-01 Reduce vehicle hours of delay per capita during evacuation from homeland security and Hazmat incidents

C. Enhance Mobility, Convenience, and Comfort for Transportation System Users
C-1 Reduce congestion and incident-related delay for travelers *(TI, TM, PT, PS & VS)*

B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F
B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods
B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
B-1-15 Reduce mean incident notification time
B-1-16 Reduce mean time for needed responders to arrive on-scene after notification
B-1-17 Reduce mean incident clearance time per incident
B-1-18 Reduce mean incident clearance time for Twin Cities urban freeway incidents
C-1-01 Reduce the vehicle hours of total delay associated with traffic incidents during peak and off-peak periods
C-1-02 Increase percentage of incident management agencies in the region that participate in a multi-modal information exchange network
C-1-03 Increase percentage of incident management agencies in the region that use interoperable voice communications
C-1-04 Increase percentage of incident management agencies in the region that participate in a regional coordinated incident response team
C-1-05 Increase the number of corridors in the region covered by regional coordinated incident response teams
C-1-06 Maintain a percentage of transportation operating agencies have a plan in place for a representative to be at the local or State Emergency Operations Center (EOC) to coordinate strategic activities and response planning for transportation during emergencies
C-1-07 Conduct joint training exercises among operators and emergency responders in the region
C-1-08 Maintain a percentage of staff in region with incident management responsibilities who have completed the National Incident Management System (NIMS) Training and a percentage of transportation responders in the region are familiar with the incident command structure (ICS)
C-1-09 Increase number of regional road miles covered by ITS-related assets (e.g., roadside cameras, dynamic message signs, vehicle speed detectors) in use for incident detection / response
C-1-10 Increase number of traffic signals equipped with emergency vehicle preemption

C-2 Improve travel time reliability *(TI, TM, PT & VS)*

B-1-07 Reduce the regional average travel time index
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods

B-2-15 Improve average on-time performance for specified transit routes/facilities
B-2-16 Increase use of automated fare collection system per year
B-2-17 Increase the percent of transfers performed with automated fare cards
C-2-01 Decrease the average buffer index for multiple routes or trips
C-2-02 Reduce the average planning time index for specific routes in region
C-2-03 Increase the miles of bus-only shoulder lanes in the metro area

C-3 Increase choice of travel modes *(TI, TM, PT & ST)*

B-2-01 Increase annual transit ridership
B-2-11 Reduce per capita single occupancy vehicle commute trip rate
B-2-12 Increase the percentage of major employers actively participating in transportation demand management programs
B-2-13 Reduce commuter vehicle miles traveled (VMT) per regional job
B-2-14 Create a transportation access guide, which provides concise directions to reach destinations by alternative modes (transit, walking, bike, etc.)
C-3-01 Increase active (bicycle/pedestrian) mode share
C-3-02 Reduce single occupancy vehicle trips through travel demand management strategies (e.g., employer or residential rideshare)
C-3-03 Increase the percent of alternative (non-single occupancy vehicle) mode share in transit station communities (or other areas)
C-3-04 Increase transit mode share
C-3-05 Increase transit mode share during peak periods
C-3-06 Increase average transit load factor
C-3-07 Increase passenger miles traveled per capita on transit
C-3-08 Reduce the travel time differential between transit and auto during peak periods per year
C-3-09 Increase the percent of the transportation system in which travel conditions can be detected remotely via video monitoring cameras, speed detectors, etc.
C-3-10 Increase the percent of transportation facilities whose owners share their traveler information with other agencies in the region
C-3-11 Increase number of 511 calls per year
C-3-12 Increase number of visitors to traveler information website per year
C-3-13 Increase number of users of notifications for traveler information (e.g., e-mail, text message)
C-3-14 Increase the number of transit routes with information being provided by ATIS
C-3-15 Increase the number of specifically tailored traveler information messages provided
C-3-16 Increase annual transit ridership reported by urbanized area transit providers
C-3-17 Increase annual transit ridership reported by rural area transit providers

C-4 Reduce stress caused by transportation *(TI, TM, PT, PM, PS, MC & VS)*

A-2-43 Reduce number of speed violations
A-2-44 Reduce number of traffic law violations
B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F
B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods

B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
B-1-15 Reduce mean incident notification time
B-1-16 Reduce mean time for needed responders to arrive on-scene after notification
C-3-11 Increase number of 511 calls per year
C-3-12 Increase number of visitors to traveler information website per year
C-3-13 Increase number of users of notifications for traveler information (e.g., e-mail, text message)
C-3-14 Increase the number of transit routes with information being provided by ATIS
C-3-15 Increase the number of specifically tailored traveler information messages provided
C-4-01 Reduce the speed differential between lanes of traffic on multi-lane highways
C-4-02 Increase the number of users aware of park-and-ride lots in their region
C-4-03 Increase the number parking facilities with electronic fee collection
C-4-04 Increase the number of parking facilities with automated occupancy counting and space management
C-4-05 Increase the number of parking facilities with advanced parking information to customers
C-4-06 Increase the number of parking facilities with coordinated electronic payment systems
C-4-07 Increase the number of parking facilities with coordinated availability information

D. Improve the Security of the Transportation System

D-1 Enhance traveler security *(PT & PS)*

C-3-09 Increase the percent of the transportation system in which travel conditions can be detected remotely via video monitoring cameras, speed detectors, etc.
D-1-01 Reduce on an annual basis the number of complaints per 1,000 boarding passengers
D-1-02 Increase the number of video monitoring cameras installed on platforms, park-n-ride lots, vehicles, and other transit facilities
D-1-03 Increase customer service and personal safety ratings
D-1-04 Reduce the number of reported personal safety incidents
D-1-05 Decrease the number of security incidents on roadways
D-1-06 Increase the percent of major and minor arterials are equipped with and operating with video monitoring cameras
D-1-07 Increase the number of critical sites with security monitoring
D-1-08 Reduce the number of security incidents on transportation infrastructure
D-1-09 Increase the number of critical sites with hardened security enhancements

D-2 Safeguard the motoring public from homeland security and/or Hazmat incidents *(TI, TM, PT, CVO, PS, MC & VS)*

B-1-16 Reduce mean time for needed responders to arrive on-scene after notification
C-3-09 Increase the percent of the transportation system in which travel conditions can be detected remotely via video monitoring cameras, speed detectors, etc.
D-1-01 Reduce on an annual basis the number of complaints per 1,000 boarding passengers
D-1-02 Increase the number of video monitoring cameras installed on platforms, park-n-ride lots, vehicles, and other transit facilities
D-1-03 Increase customer service and personal safety ratings
D-1-04 Reduce the number of reported personal safety incidents
D-1-05 Decrease the number of security incidents on roadways
D-1-06 Increase the percent of major and minor arterials are equipped with and operating with video monitoring cameras
D-1-07 Increase the number of critical sites with security monitoring

D-1-08 Reduce the number of security incidents on transportation infrastructure
D-1-09 Increase the number of critical sites with hardened security enhancements
D-2-01 Reduce the number of Hazmat incidents
D-2-02 Reduce the number of homeland security incidents
D-2-03 Increase the number of travelers routed around Hazmat incidents
D-2-04 Increase the number of travelers routed around homeland security incidents
D-2-05 Reduce the Hazmat incident response time
D-2-06 Reduce the homeland security incident response time
D-2-07 Increase the number of Hazmat shipments tracked in real-time

E. Support Regional Economic Productivity and Development

E-1 Reduce travel time for freight, transit and businesses *(TI, TM, PT, CVO & VS)*

B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
B-2-15 Improve average on-time performance for specified transit routes/facilities
B-2-16 Increase use of automated fare collection system per year
B-2-17 Increase the percent of transfers performed with automated fare cards
C-2-09 Increase the miles of bus-only shoulder lanes in the metro area
C-3-08 Reduce the travel time differential between transit and auto during peak periods per year
E-1-01 Maintain a travel time differential between transit and auto during peak periods
E-1-02 Improve average transit travel time compared to auto in major corridors
E-1-03 Decrease the annual average travel time index for selected freight-significant highways
E-1-04 Decrease point-to-point travel times on selected freight-significant highways
E-1-05 Decrease hours of delay per 1,000 vehicle miles traveled on selected freight-significant highways

E-2 Improve the efficiency of freight movement, permitting and credentials process *(TI & CVO)*

E-2-01 Increase the percent (or number) of commercial vehicles tracked by trucking companies
E-2-02 Increase the percent (or number) of freight shipment tracked
E-2-03 Increase the percent of agencies involved in CVO inspection, administration, enforcement, and emergency management in the region with interoperable communications
E-2-04 Increase the use of electronic credentialing at weigh stations and border crossings
E-2-05 Increase the number of automated permits/credentials issued
E-2-06 Reduce the frequency of delays per month at intermodal facilities
E-2-07 Reduce the average duration of delays per month at intermodal facilities

E-3 Improve travel time reliability for freight, transit and businesses *(TM, PT, CVO & VS)*

B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
B-2-15 Improve average on-time performance for specified transit routes/facilities
B-2-16 Increase use of automated fare collection system per year
B-2-17 Increase the percent of transfers performed with automated fare cards
C-1-06 Increase percentage of incident management agencies in the region that participate in a multi-modal information exchange network
C-2-09 Increase the miles of bus-only shoulder lanes in the metro area
C-3-09 Increase the percent of the transportation system in which travel conditions can be detected remotely via video monitoring cameras, speed detectors, etc.
C-3-10 Increase the percent of transportation facilities whose owners share their traveler information with other agencies in the region
C-3-13 Increase number of users of notifications for traveler information (e.g., e-mail, text message)

E-1-08 Decrease the annual average travel time index for selected freight-significant highways
E-2-04 Increase the use of electronic credentialing at weigh stations and border crossings
E-3-01 Reduce average crossing times at international borders

E-4 Increase agency efficiency *(DM, TM, PT, CVO, PS, MC & SU)*

B-2-15 Improve average on-time performance for specified transit routes/facilities
B-2-16 Increase use of automated fare collection system per year
B-2-17 Increase the percent of transfers performed with automated fare cards
C-2-09 Increase the miles of bus-only shoulder lanes in the metro area
E-2-01 Increase the percent (or number) of commercial vehicles tracked by trucking companies
E-2-03 Increase the percent of agencies involved in CVO inspection, administration, enforcement, and emergency management in the region with interoperable communications
E-4-01 Increase the number of ITS-related assets tracked
E-4-02 Reduce the number of pavement miles damaged by commercial vehicles
E-4-03 Increase the rate of on-time completion of construction projects
E-4-04 Increase the rate at which equipment is utilized
E-4-05 Increase the percentage of fleet / equipment within its lifecycle
E-4-06 Increase the number of fleet vehicles with maintenance diagnostic equipment
E-4-07 Increase the number of vehicles operating under CAD

E-5 Reduce vehicle operating costs *(TM, PT, CVO & VS)*

B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F
B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods
B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods

E-6 Enhance efficiency at borders *(TI & CVO)*

E-2-04 Increase the use of electronic credentialing at weigh stations and border crossings
E-3-11 Reduce average crossing times at international borders

F. Preserve the Transportation System

F-1 Safeguard existing infrastructure *(TM, CVO, PS & MC)*

C-3-09 Increase the percent of the transportation system in which travel conditions can be detected remotely via video monitoring cameras, speed detectors, etc.
D-1-06 Increase the percent of major and minor arterials are equipped with and operating with video monitoring cameras

D-1-07 Increase the number of critical sites with security monitoring
D-1-08 Reduce the number of security incidents on transportation infrastructure
D-1-09 Increase the number of critical sites with hardened security enhancements
E-2-03 Increase the percent of agencies involved in CVO inspection, administration, enforcement, and emergency management in the region with interoperable communications
E-4-03 Increase the rate of on-time completion of construction projects
F-1-01 Decrease the number of pavement miles damaged by commercial vehicles
F-1-02 Decrease the number of size and weight violations

G. Enhance the Integration and Connectivity of the Transportation System

G-1 Aid in transportation infrastructure and operations planning *(ALL)*

G-1-01 Increase the amount of data gathered from ITS enhancements used in infrastructure and operations planning
G-1-02 Increase the number of planning activities using data from ITS systems
G-1-03 Increase the number of years of data in database that is easily searchable and extractable
G-1-04 Reduce project schedule deviation
G-1-05 Reduce project cost deviation
G-1-06 Reduce operations cost deviation
G-1-07 Reduce administrative support rate (as part of overall project budget)

G-2 Reduce need for new facilities *(TM, CVO, MC & VS)*

B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F
B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods
B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
E-2-04 Increase the use of electronic credentialing at weigh stations and border crossings
E-2-05 Increase the number of automated permits/credentials issued
E-3-11 Reduce average crossing times at international borders

H. Reduce Environmental Impacts

H-1 Reduce emissions/energy impacts and use associated with congestion *(ST, TI, TM, CVO & VS)*

B-1-01 Reduce the percentage of facility miles (highway, arterial, rail, etc.) experiencing recurring congestion during peak periods
B-1-02 Reduce the percentage of Twin Cities freeway miles congested in weekday peak periods
B-1-03 Reduce the share of major intersections operating at LOS F

B-1-04 Maintain the rate of growth in facility miles experiencing recurring congestion as less than the population growth rate (or employment growth rate)
B-1-05 Reduce the daily hours of recurring congestion on major freeways
B-1-06 Reduce the number of hours per day that the top 20 most congested roadways experience recurring congestion
B-1-07 Reduce the regional average travel time index
B-1-08 Annual rate of change in regional average commute travel time will not exceed regional rate of population growth
B-1-09 Improve average travel time during peak periods
B-1-10 Reduce hours of delay per capita
B-1-11 Reduce hours of delay per driver
B-1-12 Reduce the average of the 90th (or 95th) percentile travel times for (a group of specific travel routes or trips in the region)
B-1-13 Reduce the 90th (or 95th) percentile travel times for each route selected
B-1-14 Reduce the variability of travel time on specified routes during peak and off-peak periods
H-1-01 Reduce excess fuel consumed due to congestion
H-1-02 Reduce total fuel consumed per capita for transportation
H-1-03 Reduce vehicle miles traveled per capita
H-1-04 Reduce MnDOT fleet gasoline use
H-1-05 Reduce MnDOT fleet diesel use
H-1-06 Reduce the amount of all emissions in the atmosphere
H-1-07 Reduce the amount of carbon dioxide emissions measured

H-2 Reduce negative impacts of the transportation system on communities *(TM, PT, PS, ST & MC)*

A-2-44 Reduce number of traffic law violations
B-2-01 Increase annual transit ridership
B-2-12 Increase the percentage of major employers actively participating in transportation demand management programs
B-2-13 Reduce commuter vehicle miles traveled (VMT) per regional job
B-2-14 Create a transportation access guide, which provides concise directions to reach destinations by alternative modes (transit, walking, bike, etc.)
B-2-19 Increase the number of carpools
B-2-20 Increase use of vanpools
B-2-21 Provide carpool/vanpool matching and ridesharing information services
B-2-22 Reduce trips per year in region through carpools/vanpools
H-2-01 Increase the average vehicle passenger occupancy rate in HOV lanes
H-2-02 Increase the amount of environmentally friendly de-icing material used