DEPARTMENT OF TRANSPORTATION

Systems Engineering Analysis for Railroad-Highway Grade Crossing

Concept of Operations

May 2020
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Revision History

This document will be used for design of MnDOT's new railroad-highway grade crossing system. 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	8/23/2019	Initial version
1.1	11/19/2019	Minor revisions per FHWA comments
1.2	5/8/2020	Revisions per MnDOT comments
1.3	5/29/2020	Final version

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Introduction

This document provides a ***Concept of Operations*** (*ConOps*) for various types of active railroad-highway grade crossing warning systems that may apply to a particular project. Active warning means the use of some type of device that is activated to warn motorists of an approaching train, either flashing-light signals, or flashing-light signals and gates. Passive crossings with signing only is *not* included. Please see the corresponding *Minnesota Statewide Regional ITS Architecture and Systems Engineering Checklist* (*Checklist)* for the project to identify which type(s) apply.

Regardless of the type, all implementations of active grade crossing warning devices include the operational concepts for Flashing-Light Signals (FLS). Following are the name identifiers for the various warning device types:

- Flashing-Light Signals (FLS, common to all forms of active warning)
- Cantilever Flashing-Light Signals (CFL)
- Standard Railroad Gates (SRG)
- Four Quadrant Gates (FQG)
- Traffic Signal Preemption (TSPr)
- Other

For each section of this document where information is distinguished by an optional feature, the section follows the naming scheme per the above. For example, the Traffic Signal Preemption subsection in the Current Environment section covers the purpose and scope for Traffic Signal Preemption from the railroad system perspective. A separate document addresses Railroad Preemption *ConOps* from the traffic signal perspective. As operations of Connected and Automated Vehicles (CAVs) expand, several data exchanges between railroad-highway grade crossings and CAVs are anticipated, and these are presented in this document.

Current Environment

Railroad Flashing-Light Signals (FLS)

Basic FLS consist of (see Figure 1):

- A pole with “RAILROAD CROSSING” crossbuck sign at the top
- A pair of red flashing lights mounted in a horizontal line that flash in alternating sequence.

Figure 1. Typical Flashing-Light Signals
(Source: Public Utilities Commission of Ohio Grade Crossing Inventory)

FLS as shown are always included with both versions of gates (SRG and FQG) as well. Post-mounted flashing light signals are normally located on the right side of the highway on all highway approaches to the crossing. Flashing light signals are generally post-mounted, but where improved visibility to approaching traffic is required, cantilevered flashing light signals (CFL) are used.

The FLS are activated by the approach of a train that shunts a track circuit. Three basic operational modes are used that affect initiation of alternating light display. In the first mode, activation of active warning is programmed to occur a fixed time before the arrival of the railroad vehicle at the crossing. Typically, the lights flash for 20 seconds [minimum prescribed in *Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD)* and by the Federal Railroad Administration (FRA)] or more, but the constant warning should be of sufficient length to ensure clearance of a vehicle that might have stopped at the crossing and then proceeded to cross just before the flashing lights begin operation. To accomplish this, circuit controllers must be able to sense a train in the approach section, measure its speed and distance from the crossing, and activate the warning equipment to provide the selected minimum warning time. If a train stops prior to reaching the crossing or is moving away from the crossing, the warning devices are deactivated.

In the second mode, the approach of a train at the circuit termination point unconditionally activates flashing-light warning and speed of the train is not taken into account. Active crossing warning time thus is variable as a function of the speed of the approaching train and the location of the circuit terminus. With this mode, flashing operation continues until the train or trains fully clear the grade crossing area.

The third mode uses a motion sensitive track circuit and is designed to detect the presence as well as direction of motion of a railroad vehicle. This mode of operation is advantageous where trains stop or conduct switching operations within the normal approach limits of a particular crossing.

Ideally the crossing warning devices are monitored by both a rail operations center and a road maintenance and construction management (MCM) center for an alarm in case of a device failure so that a repair crew can be immediately dispatched.

Railroad Cantilever Flashing-Light Signals (CFL)

CFL are essentially the same functionally as FLS except that the flashing-light signals are suspended over the approach roadway to increase conspicuity and driver recognition (see Figure 2). As noted in the Railroad Flashing-Light Signals section above, post-mounted FLS are typically installed as well, as included in the Figure 2 example. CFL may be appropriate when any of the following conditions exist:

- Multilane highways (two or more lanes in one direction).
- Highways with paved shoulders or a parking lane that would require a post-mounted light to be more than 10 feet from the edge of the travel lane.
- Roadside foliage obstructing the view of post-mounted flashing light signals.
- A line of roadside obstacles such as utility poles (when minor lateral adjustment of the poles would not solve the problem).
- Distracting backgrounds such as an excessive number of neon signs (conversely, cantilevered flashing lights should not distract from nearby highway traffic signals).
- Horizontal or vertical curves at locations where the extension of flashing lights over the traffic lane will provide sufficient visibility for the required stopping sight distance.

Figure 2. Typical Cantilever Flashing-Light Signals

(Source: Public Utilities Commission of Ohio Grade Crossing Inventory)

Standard Railroad Gates (SRG)

SRG are the recommended active warning devices at grade crossings with multiple tracks, high speed train operations and other factors in urban and suburban areas across the US (see Figure 3 and Figure 4). Figure 3 shows SRG for vehicles only while Figure 4 adds pedestrian gates. The gates include red lights that are activated at the same time that the post-mounted flashing lights are activated. The lights serve as an initial warning to drivers that a train is approaching, and the gates cannot begin to descend until the lights have been activated for a minimum of three seconds. The gates must reach the horizontal position at least five seconds before the arrival of the train. The flashing lights remain active and the gates down until the train(s) leave or stop prior to reaching the grade crossing depending on what circuitry is installed. As can be seen in Figure 5, sometimes a median is constructed to discourage drivers from driving around lowered gates.

Figure 3. Standard Railroad Gates
(Source: Public Utilities Commission of Ohio Grade Crossing Inventory)

Figure 4. Standard Railroad Gates with Pedestrian Gates
(Source: MnDOT photo files)

Figure 5. Standard Railroad Gates – With Median
(Source: Public Utilities Commission of Ohio Grade Crossing Inventory)

Four Quadrant Railroad Gates (FQG)

FQG are the same in function as SRG but with an additional SRG so that both the approach and departure side of roadway lanes have SRG. FQG inhibits traffic movements over the crossing once the gates are lowered. (see Figure 6). Gate activation is more complex in that there is a need to delay the descent of the gates on the departing side, also known as the exit gate. The exit gate activation is based on vehicle presence detection or delay timing established for each site. This operation allows motorists on the tracks, when flashing light activation begins, to avoid becoming trapped behind the exit gate. Another aspect at sites where vehicles might queue from a downstream intersection, into the grade crossing area, is the use of dynamic exit gate operating mode. This mode has vehicle presence detection devices to control exit gate operation based on vehicle presence within the grade crossing area. In short, design of FQG timing must be carefully considered on an individual site basis to implement the best possible warning.

Figure 6. Four Quadrant Railroad Gates
(Source: MnDOT photo files)

Traffic Signal Preemption (TSPr)

When railroad-highway grade crossings are in near proximity to traffic signals, the two systems are directly connected so that the highest possible level of grade crossing warning is provided. The overall objective is to clear the crossing and maintain it that way while the train(s) passes to avoid a collision between the train(s) and vehicles or people (see Figure 7). The application scope here 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-highway grade crossings may have different operational characteristics. No single standard system of traffic control devices is universally applicable for all light rail transit-highway grade crossings. Part 8 of the *MN MUTCD* provides guidance and standards for traffic control devices and signal preemption for light rail transit-highway grade crossings. The approach of a train near a TSPr signal always preempts normal signal operation to clear the crossing and avoid a collision. In all cases, the train system sends a preempt message to the traffic signal controller, which then takes appropriate action to clear the crossing and hold the "crossing closed" preemption state. The railroad hardware side includes the track circuitry and the interconnection to the traffic signal up to the point where the preempt message is handed off to the traffic signal.

Figure 7. Grade Crossing with Traffic Signal Preemption
(Source: AECOM)

The basic operational mode as described in the FLS subsection critically affects traffic signal clearance timing. With constant warning time, traffic signal clearance timing must be related to the specific warning time for activating crossing warning devices. In the mode with non-constant warning time, the variable detection time of the train relative to when it reaches the crossing must be factored into site design and subsequent signal timing. In either case, the pre- emption response of the traffic signal controller is site specific and depends on the physical configuration of the railroad-highway grade crossing and the location of adjacent traffic signals. The control logic must clear vehicles, bicyclists, and pedestrians off the railroad tracks by special pre-emption phasing and timing. Figure 8 is an example of phase sequencing for railroad preemption of a traffic signal.

Signal operation with preemption may also include turning signals further downstream of a crossing to green to allow queued vehicles to leave the crossing area. Under all circumstances, preemption treatment of traffic signals is complex and must be carefully considered and designed to provide the greatest possible warning for the individual site conditions.

The railroad side must provide clear and precise information to the involved traffic signals. Related materials for the traffic signal(s) are presented in *Systems Engineering for Standard Traffic Signal: Concept of Operations.*

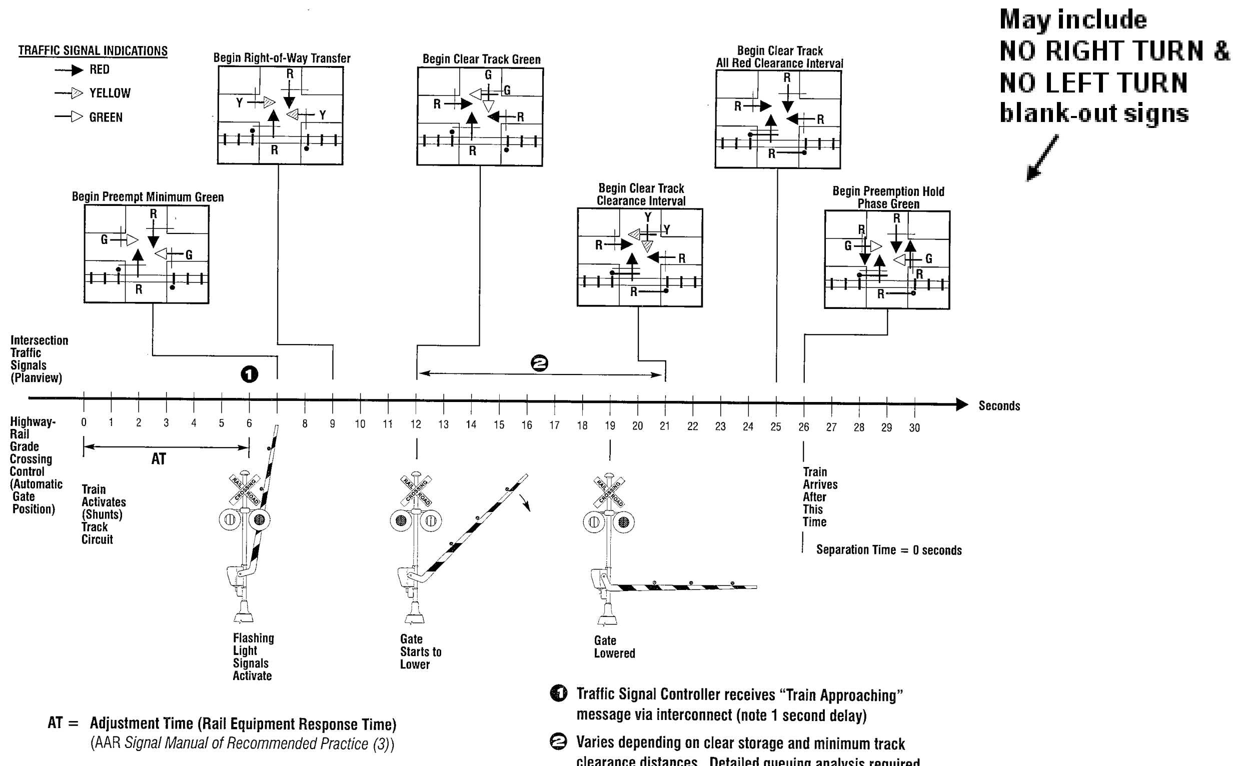

FIGURE 14 Sample simultaneous preemption time line (from (2)).

Figure 8. Traffic Signal Sequencing for Railroad Preemption

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

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. Railroad-highway grade crossing systems may communicate data with CAV Infrastructure Systems.

MnDOT may deploy CAV Infrastructure Systems that communicate Basic Safety Messages (BSMs) messages and railroad-highway grade crossing status messages to and from CAVs, either through roadside units (RSUs) or cloud-based communications. In some situations, CAVs may benefit from direct data exchanges with railroad-highway grade crossings.

Other

[Reserved for new grade crossing features and their characteristics. Please consult with appropriate MnDOT, FHWA, or local staff to develop needed scope description.]

With all of these standard grade crossing warning types, there is no absolute way to prevent an errant motorist from either running the gates or crashing through gates into the grade crossing area. Limited experimentation has taken place in the US with positive barriers based on the nets used on aircraft carriers to catch aircraft overrunning the landing area. If high- speed rail is deployed in Minnesota, this type of advanced warning devices could be considered for implementation. This is an example of another type of grade crossing warning that would require further research, design, and testing.

Users

The stakeholders, as per the *Minnesota Statewide Regional ITS Architecture 2018* (*Statewide Architecture* for short), for grade crossing warning will be all or nearly all of the following depending on the site:

- 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 SRCC (Southern Regional Communication Center)
    - Office of Freight and Commercial Vehicle Operations (OFCVO)
    - Office of Traffic Engineering
    - Electrical Services Section (ESS)
    - Office of Connected & Automated Vehicles (CAV-X)
    - Office of Maintenance (OM), and
    - Office of Transportation System Management
- Minnesota Department of Public Safety (DPS)
- Local Agencies: counties, cities, towns, villages, and townships
- (Local) Traffic Management Centers
- Local Maintenance and Construction Management (MCM) Agencies
- Local Transit Providers with light rail vehicle operations through grade crossings
- Railroad Companies
- Federal Highway Administration (FHWA)
- 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 DPS/Minnesota State Patrol (MSP) group.

An important overall aspect is that railroad-highway grade crossing warning planning, design, and operation must be a cooperative effort involving the railroad operating entity, the local municipality or unit of government, and where applicable the regulatory agency with statutory authority. Planning, design, and construction are the responsibility of MnDOT, railroad companies, and local government units, while maintenance of the warning devices is the responsibility of the railroad company. The local municipality or unit of government is responsible for maintenance of approach roadways and signing plus adjacent traffic signals and may share in maintenance of warning devices for Quiet Zones. In all cases, a high level of cooperation and coordination must be established and maintained between the involved public agencies and the railroad company.

Challenges and Needs

The needs of grade crossing warning for the various stakeholders are presented in Table 1.

Table 1. Grade Crossing Warning Needs by Stakeholder

Stakeholder	Grade Crossing Warning Needs
Travelers: private vehicle drivers and passengers, transit operators and passengers, commercial operators, school bus operators and passengers, pedestrians (including those with disabilities), and bicyclists	FLS-1 Deployment of active grade crossing warning at railroad-highway grade crossings that have historically high incident rates and have deficient sight distances.
	FLS-2 Highly conspicuous warning to travelers that they are approaching a grade crossing.
	FLS -3 Clear, unambiguous display of an active warning that a train is approaching and subsequently occupying the crossing.
	FLS -4 Safe and efficient clearance of the grade crossing of vehicles, pedestrians, and bicyclists.
	FLS-5 Safe and efficient termination of warning device once the train(s) has left the crossing area.
DPS	***Additional Needs and Functions by grade crossing warning feature:***
	CFL-1 Accentuated display of an active warning that a train is approaching and subsequently occupying the crossing.
	SRG-1 Fail-safe gate operation that minimizes the possibility of vehicles, objects or persons entering the grade crossing area from approach lanes. Separate pedestrian crossing gates from those for vehicles may be needed.
	FQG-1 Fail-safe gate operation that minimizes the possibility of vehicles, objects or persons entering the grade crossing area from approach lanes or by attempting to run the gates by using opposite direction exit lanes.
	FQG-1 Fail-safe gate operation that minimizes or eliminates the possibility of vehicles becoming trapped in the grade crossing area by exit gates.
	TSPr-1 Positive conveyance of track circuit message to adjacent traffic signal(s) in timely manner that train is approaching and subsequently occupying the crossing.
	Other – [Please consult with appropriate MnDOT, FHWA, or local staff to develop needed Needs and Functions]
All Stakeholders share in above to varying degree. Further specific Needs and Functions follow:	
MnDOT, MnDOT District Offices, Local Agencies, FHWA, and FRA	FLS-6 Planning, design, and implementation of grade crossing warning that meets agency and railroad performance standards or guidelines for operations and safety, and which is reliable and easily maintained. FLS-7 In coordination with railroad company, planning, design, and implementation of warning device monitoring of performance and device failures plus communications links, as required by site plans.

Stakeholder	Grade Crossing Warning Needs
MnDOT Office of Maintenance, RTMC, SRCC, CAV-X, Office of Traffic Engineering, ESS, Office of Transportation System Management, and OFCVO; Local MCM Agencies and Traffic Management Centers	FLS-8 Communications links and failure alarms as required by site plans. FLS-9 Archiving of equipment failure records for further analysis as required by site plans TSPr-2 Clear, unambiguous communications link with the traffic signal(s) that is preempted.
Railroad Companies, Local Transit Providers with light rail operations	FLS-10 Proactive operation and maintenance of warning equipment on a continuous basis.
	FLS-11 Proactive monitoring of grade crossing equipment, including current state, mode of operation, equipment condition, and fail-safe warning alarms on a continuous basis.
	FLS-7 See above, in coordination with responsible governmental unit.

The Needs and Services plus associated ITS Development Objectives, per the *Statewide Architecture*, are presented in Table 2.

Table 2. Grade Crossing Warning Needs/Services & ITS Development Objectives by Grade Crossing Warning Feature

ID	Feature	Needs/Services [1] [2]	ITS Development Objectives
GCP-FLS	Railroad Flashing-Light Signals	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
GCP-CFL	Railroad Cantilever Flashing-Light Signals	ATMS28: Provide railroad flashing light signals and gates	A-1-09, A-2-10, A-2- 31
GCP-SRG	Standard Railroad Gates	ATMS28: Provide railroad flashing light signals and gates	A-1-09, A-2-10, A-2- 31
GCP-FQG	Four Quadrant Railroad Gates	ATMS28: Provide railroad flashing light signals and gates	A-1-09, A-2-10, A-2- 31
TS-RRP	Traffic Signal Preemption	ATMS28: Provide railroad flashing light signals and gates	A-1-09, A-2-10, A-2- 31
TS-Oth	Other		

Operational Concept

Operational Description

Railroad Flashing-Light Signals (FLS)

Grade crossing warning is overseen and directed by the MnDOT Commissioner of Transportation, as indicated in *Minnesota Statutes 2009,* Chapter 219, "Railroad Safety and Employment." The Commissioner is charged with determining the most appropriate level of warning at grade crossings and with

[1] Needs/Services Key: ATMS - Traffic Management

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

investigating associated issues. This duty has evolved in response to the development of the rail system across the US over the past 150+ years. Railroads were originally given land grants in return for developing long distance rail service and generally granted absolute rights to operate on their right-of-way as they deemed necessary. Grade crossing warning has been an obvious basic issue from the start, with a major emphasis on safety at this critical interface between highway and rail systems. Laws, rules and regulations regarding railroads vary state to state. Communication between State, Federal and Railroads is critical to grade crossing safety.

Railroad Cantilever Flashing-Light Signals (CFL)

As discussed in the Current Environment section, CFL add to conspicuity of grade crossing warning.

Standard Railroad Gates (SRG)

Railroad gates were first patented in the 1860s. With the advent of the automobile and increasing mileage of roads and thus grade crossings in the 20th century, grade crossing gates became much more widespread. Standardization of design and application across the US has been the norm for several decades. Critical needs and guidance are provided in the *MN MUTCD*, particularly Part 8 and the guidance document prepared by the U.S DOT Technical Working Group (see Chapter V).

Four Quadrant Railroad Gates (FQG)

The Current Environment section discusses the expanded role and operation of FQG relative to SRG.

Traffic Signal Preemption (TSPr)

The major thrust of interconnecting railroad track circuits to nearby traffic signals and preempting their normal red-yellow-green operation is the need to clear the crossing area of conflicting objects and persons before the train arrives. This need leads to fairly complex communications and traffic signal sequencing to provide as much warning as possible.

CAV Infrastructure Systems and CAVs

The railroad-highway grade crossing operational concept from the perspective of CAV Infrastructure Systems and CAVs is described below. As operations of CAVs expand, several data exchanges between CAV management systems and CAVs are anticipated, some of which will utilize railroad-highway grade crossing equipment data. CAV Infrastructure Systems may communicate with CAVs to exchange Basic Safety Messages (BSMs) and provide in-vehicle display of the message to the driver. CAV Infrastructure Systems may exchange messages with railroad-highway grade crossings (either through vehicle to roadside communications or cloud-based communications). CAV equipped vehicles may communicate directly with railroad-highway grade crossings to receive crossing status and warning messages.

Other

Given the maturity of active grade crossing warning, other potential features, such as communication of train approach to individual vehicles, can be expected to evolve. These will require substantial documentation to justify and explain new technologies and applications.

Operational Environment

The major operational aspects of grade crossing warning have been discussed in the Current Environment and the Operational Description sections. The connection and interface between the rail system and the highway system are critical to assuring safe operation when such interconnection has been deemed appropriate. The railroad company and the public agency must work cooperatively in planning, designing, implementing, and managing grade crossing warning devices.

Railroad Flashing-Light Signals (FLS)

The operational support environment will use standard maintenance of railroad companies. Railroad technicians will operate and maintain the grade crossing warning using industry operational guidelines along with routine and emergency maintenance procedures that are well established. Grade crossing warning sequencing and timing is to be in conformance with the *MN MUTCD* and American Railway Engineering and Maintenance-of-Way Association (AREMA) standards.

With respect to operational scenarios, the most important maintenance aspect once warning sequences and timing have been prepared and implemented is to have defined quick response procedures for trouble calls. Trouble calls will typically originate from various sources: the general public, police, railroad company personnel, 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.

Preventive maintenance on the grade crossing warning devices will be scheduled to occur frequently as a part of routine maintenance. Review of operations can be expected to occur periodically or in response to changing conditions at the crossing, in terms of either rail activity or vehicle activity. Safety data (crash and “near miss” experience) plus vehicle delay data from each site should factor into site review, along with field observations and citizen complaints.

FLS sites may include central monitoring of grade crossing warning devices health by the railroad company, the local government entity, or both. In this case, system architecture and communications system configuration will need to be developed on an individual site basis, ideally including redundant network design.

Specialized training is required to handle operations and maintenance.

Railroad Cantilever Flashing-Light Signals (CFL)

CFL operational scenarios are essentially the same as for FLS, but with a greater focus on confirming that the desired level of conspicuity is achieved by the grade crossing warning equipment.

Standard Railroad Gates (SRG)

The basic SRG operational scenario is as described in the Current Environment section above to provide standard, readily understood messages and warning at each grade crossing. Uniform national standards are the basis for operations so that any non-local driver can immediately comprehend the layout and appropriate response action when flashing lights and gates are activated.

Four Quadrant Railroad Gates (FQG)

The Current Environment section describes the basic operational scenario that provides additional warning to inhibit virtually all traffic movements over the crossing. The most important aspect is the programmed or controlled delay in lowering the exit gates, to avoid trapping vehicles on the grade crossing. The dynamic exit gate operating mode with appropriate vehicle presence detection in the grade crossing area help to address this issue.

Traffic Signal Preemption (TSPr)

The Current Environment section describes the basic operations. The interface between the track circuit and the traffic signal plus the associated signal preemption timing are critical aspects that must be carefully developed and fine-tuned as necessary. TSPr also requires regular routine maintenance and quick response in case of performance failure or trouble call. Although the operations of each site are standalone, remote monitoring of the preemption circuitry that sends alarm messages to both the railroad and the local highway agency 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. Periodic operational and safety reviews need to be conducted, potentially leading to adjustment in TSPr activation sequencing and timing.

Other

[Reserved for new features and their scenarios].

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 the railroad-highway grade crossing system.

Table 3. Operation and Maintenance Roles and Responsibilities

User Group	Role / Responsibility
MnDOT District Offices	• Planning, design and implementation of grade crossing warning • In coordination with railroad company, planning, design, and implementation of warning device monitoring of performance and device failures plus communications links, as required by site plans
Local Agencies	• Planning, design and implementation of grade crossing warning • In coordination with railroad company, planning, design, and implementation of warning device monitoring of performance and device failures plus communications links, as required by site plans
MnDOT OFCVO and Transportation System Management	• Communications links and failure alarms as required by site plans • Clear, unambiguous communications link with the traffic signal(s) that is preempted

User Group	Role / Responsibility
MnDOT Office of Maintenance and ESS	• Communications links and failure alarms as required by site plans • Archiving of traffic signal preemption failure records for further analysis as required by site plans • Clear, unambiguous communications link with the traffic signal(s) that is preempted
MnDOT RTMC and SRCC	• Communications links and failure alarms as required by site plans • Archiving of equipment failure records for further analysis as required by site plans • Clear, unambiguous communications link with the traffic signal(s) that is preempted
Local Agency Traffic Management Centers and Local MCM Agencies	• Communications links and failure alarms as required by site plans • Archiving of equipment failure records for further analysis as required by site plans • Clear, unambiguous communications link with the traffic signal(s) that is preempted
Railroad Companies	• Proactive operation and maintenance of warning device equipment on a continuous basis • See above, in coordination with responsible governmental unit
Local Transit Providers w/ light rail operations	• Proactive operation and maintenance of warning device equipment on a continuous basis • See above, in coordination with responsible governmental unit

Operational Scenarios

Scenarios are intended to help users understand how they may interact with the railroad-highway grade crossing system and one another within the context of those situations that will most commonly require the use of railroad-highway grade crossings. The following scenarios briefly describe how users will be impacted and how they are expected to respond.

- Scenario A: Normal Operations at FLS / CFL / SRG
- Scenario B: Malfunction of FLS at Crossing
- Scenario C: Malfunction of SRG at Crossing
- Scenario D: Traffic Signal Preemption (TSPr)
- Scenario E: Connected Automated Vehicle Application

Scenario A: Normal Operations at FLS / CFL / SRG

This scenario describes the normal operations that are to occur at a railroad-highway grade crossing that have FLS, CFL, and SRG equipment installed for vehicle and train warning. The FLS and CFL are first activated by the approach of a train at the circuit terminal point that "shunt" the circuit. The FLS and CFL serve as an initial warning to vehicle drivers that a train is approaching and flash for at least three seconds.

Approaching vehicles see the flashing lights and stop prior to the at grade crossing.

The SRG equipment then comes down and reaches the horizontal position at least five seconds before the arrival of the train at the crossing. The FLS and CFL remain active and the SRG remain down in the horizontal position until the train has left the grade crossing.

After the train has left the crossing and passed over the circuit terminal point beyond the crossing, the SRG will ascend into the vertical position, after which the FLS and CFL will stop flashing. Vehicles that were stopped at the crossing begin to travel through the at grade crossing.

Scenario B: Malfunction of FLS at Crossing

This scenario describes a malfunction that is observed with FLS equipment at a railroad-highway grade crossing that also has SRG equipment installed for vehicle and train warning.

As the train approaches and passes over the circuit terminal point prior to the crossing, the FLS are not activated and do not provide an initial warning to vehicle drivers that a train is approaching. The SRG equipment comes down and reaches the horizontal position before the arrival of the train at the crossing. An approaching vehicle is able to see the SRG in the horizontal position and notices the FLS are not functioning properly. A call is made to the local public works department or the railroad company about the malfunction.

The call about the need for maintenance is forwarded to railroad technicians who operate and maintain the grade crossing warning equipment. There is a defined quick response procedure for repairs and maintenance to determine why the FLS was not functioning. The technicians determine the source of the problem and perform the needed repairs to the FLS at the crossing.

Scenario C: Malfunction of SRG / FQG at Crossing

This scenario describes a malfunction that is observed with SRG/FQG equipment at a railroad-highway grade crossing that also has FLS equipment installed for warning vehicles and pedestrians of an approaching train.

The FLS are activated as the train passes over the circuit terminal point as it approaches the crossing, providing an initial warning to vehicles and pedestrians that a train is approaching. The SRG/FQG flashing red lights, which flash simultaneously with the FLS, fail to activate properly. The gate arms also fail to begin lowering after the FLS have been activated for the minimum requirement of three seconds. An approaching driver notices that the railroad lights are flashing despite the gate arms not being lowered. The driver stops short of the crossing and places a call to the railroad company or the local public works department to provide notification of the malfunction.

The call about the need for maintenance is forwarded to railroad technicians who operate and maintain the grade crossing warning equipment. There is a defined quick response procedure for repairs and maintenance to determine why the SRG/FQG was not functioning. The technicians determine the source of the problem and perform the needed repairs to the SRG/FQG at the crossing.

Scenario D: Traffic Signal Preemption (TSPr)

This scenario describes the system operations that are to occur at a railroad-highway grade crossing in near proximity to traffic signal(s) equipped with Traffic Signal Preemption (TSPr). The two systems are directly connected. The FLS/CFL are first activated as the train approaches and passes over the circuit terminal point and “shunts" the circuit. The crossing equipment sends a preempt message to the traffic signal controller. Once the preemption request is received, traffic signal preemption is then activated to clear the crossing and hold the “crossing closed” preemption state. A blank-out or changeable message sign may be used to display messages and prohibit turning movements toward the crossing during preemption. The FLS/CFL remain active and the SRG/FQG remain down in the horizontal position 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 the railroad-highway grade crossing and that normal signal operations can safely be resumed. The SRG/FQG will then ascend into vertical position and the FLS/CFL will stop flashing. Vehicles stopped at the crossing begin to travel through the crossing.

Scenario E: Connected Automated Vehicle Application

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 railroad-highway grade crossing status. Railroad-highway grade crossing equipment may communicate data with CAV Infrastructure Systems. CAV Infrastructure Systems may broadcast crossing status, warnings and Basic Safety Messages (BSMs) to CAVs. The CAVs receive these messages via roadside units (RSUs) or cloud-based communications. In some situations, CAVs may benefit from direct data exchanges with the crossing equipment.

Risks and Mitigation

All Grade Crossing Warning

For all forms of grade crossing warning, the goal is elimination of all grade crossing crashes. The warning device should alert and warn all drivers, including those who are impaired and distracted, of the dangers associated with grade crossings. The consequences of failing to abide by the warning and messages are almost always severe; hence the safety benefit is of the highest importance. Grade crossing site characteristics and risk factors as established by MnDOT OFCVO should be the basis for determining the most appropriate form of warning.

Secondarily, occupied grade crossings cause stops and delays to motorists. Sequencing and timing should aim to limit flashing-light and gate down times to just those durations that are required to warn travelers of a train crossing a roadway. The time that a crossing is blocked by a crossing train depends on the operational characteristics of the railroad company. Railroad companies in general strive to be good corporate citizens and aim to limit individual gate down times.

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

<u>B-2 Increase average vehicle passenger occupancy and facility throughput *(TM, PT & ST)*</u>
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

<u>B-3 Reduce delays due to work zones *(TI, TM, PS, MC & VS)*</u>
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

<u>B-4 Reduce traffic delays during evacuation from homeland security and Hazmat incidents *(TI, TM, PT, CVO, PS & VS)*</u>
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
<u>C-1 Reduce congestion and incident-related delay for travelers *(TI, TM, PT, PS & VS)*</u>

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

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

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