



Systems Engineering Analysis for Weigh-In-Motion System
Concept of Operations

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Revision History

This document will be used for design of MnDOT’s new weigh-in-motion 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	8/8/2019	Initial version
1.1	5/21/2020	Revisions per MnDOT comments
1.2	5/28/2020	Final version

Contents

Introduction	1
Current Environment	3
WIM for CVO Screening.....	3
CAV Infrastructure Systems and CAVs.....	5
Other	5
Users	5
Challenges and Needs.....	6
Operational Concept.....	7
WIM for CVO Screening.....	7
CAV Infrastructure Systems and CAVs.....	8
Other	8
Roles and Responsibilities.....	8
Operational Scenarios.....	9
Scenario A: Mainline Sorting	9
Scenario B: Ramp Sorting	10
Scenario C: Virtual Weigh Station	10
Scenario D: Data Analysis	10
Scenario E: CAVs Interaction with WIM	10
Risks and Mitigation.....	11
WIM for CVO Screening.....	11
Other	11
Appendix A. ITS Development Objectives	12

List of Figures

Figure 1. Typical WIM Site Sensors	1
Figure 2. Typical WIM Site Lane Sensor Layout	2
Figure 3. WIM Installation at “Virtual Weigh Station”	3
Figure 4. MnDOT VWS – Web Page Display.....	4

List of Tables

Table 1. WIM Needs by Stakeholder.....	6
Table 2. WIM Needs/Services & ITS Development Objectives by WIM Feature	7
Table 3. Operation and Maintenance Roles and Responsibilities	9

Introduction

This document provides a **Concept of Operations (ConOps)** for standard Weigh-in-Motion (WIM) installations. A WIM uses in-pavement sensors to measure the weights and speed of any vehicle passing over them at highway speed, as well as the number and spacing of axles. A roadside processor then instantly classifies the vehicle and determines whether or not it is likely legal in gross vehicle weight, individual axle weight, and axle group weight, focusing on commercial vehicle trucks. The action at the site then depends on the type of WIM installation, as described in the Current Environment section.

Due to the dynamics of weight load and transfer at speed, the weights from a WIM are used as a screening tool of weight compliance only and cannot be used directly for enforcement. The WIM equipment, for example, is required to be accurate on gross vehicle weight to within 10%, 95% of the time. Legal weight can only be established by static scales that the truck needs to pull onto at a weigh station, or by portable static scales carried by weight enforcement personnel. Static scales must be periodically checked and recertified for accuracy.

Figure 1 illustrates typical piezo quartz sensors used in the pavement, which is the only type of sensor used by the Minnesota Department of Transportation (MnDOT). Figure 2 illustrates loop detectors installed as a “speed trap” to measure speed very accurately. Accurate speed is needed so that axle spacings can be measured to within one-half foot accuracy. This is needed to check compliance for axle groups based on the FHWA “bridge formula,” which is a function of weight by axle spacing. Installations may also include a video camera viewing trucks as they pass over the road section near the sensors, or a camera to take still images of the passing trucks and license plate to monitor compliance.



PIEZO QUARTZ SENSOR INSTALLATION



INSTALLED SENSOR

Figure 1. Typical WIM Site Sensors

(Source: MnDOT files)



Figure 2. Typical WIM Site Lane Sensor Layout
(Source: MnDOT files)

Since the WIM system records information on all vehicles passing over the sensors, the detailed data can be archived to compute pavement vehicle loads in, usually, equivalent single axle loads (ESALs). This information is very useful in analyzing expected pavement life and needed rehabilitation, and in evaluating how well particular pavement designs withstand wear-and-tear for general design purposes. If the site is standalone, the data are stored locally for later transfer to other MnDOT (or FHWA) offices. If the site connects to a control center, the data are typically transferred via the communications network in real time. Current MnDOT WIM sites are standalone and are not connected to a control center.

This *ConOps* focuses on the field element WIM that are fairly standard, but also mentions oversight and monitoring from a control center. WIM sites may be either standalone or connected to a control center. In the second case, communications are needed, but WIM communications are typically a small part of a larger network that is outside the scope of this *ConOps*. As operations of Connected and Automated Vehicles (CAVs) expand, several data exchanges between WIM and CAVs are anticipated, and these are presented in this document.

Please see the corresponding *Minnesota Statewide Regional ITS Architecture and Systems Engineering Checklist (Checklist)* for the project locations.

Current Environment

WIM for CVO Screening

WIM is a technology that allows Commercial Vehicle Inspectors (CVIs) to screen a larger volume of trucks throughout the state than would be possible with conventional fixed-site scales and portable wheel-weigh scales. The WIM sensors might be placed only in the outside lane from which trucks enter a CVO inspection station. State Patrol currently use some WIM sites in collaboration with MnDOT Office of Transportation System Management (OTSM). State Patrol also uses WIM technology for ramp sorting at the Red River and St. Croix facilities and has two portable, low speed WIM units available for use statewide.

An advanced concept for a “virtual weigh station” is presented in Figure 3 from the cited statewide plan for weight enforcement. In this concept, there are several WIM sensors and other detectors strategically placed on the road network so that trucks cannot easily avoid inspection. Virtual weigh stations may also use a dynamic feedback system that presents a weight compliance message to vehicles immediately after they have passed over a WIM scale. This is similar to speed signs with a message “YOUR SPEED IS xx “, instead saying, for example, “YOUR VEHICLE IS OVERWEIGHT.” In other words, the sign would apply peer pressure, as opposed to actual enforcement.

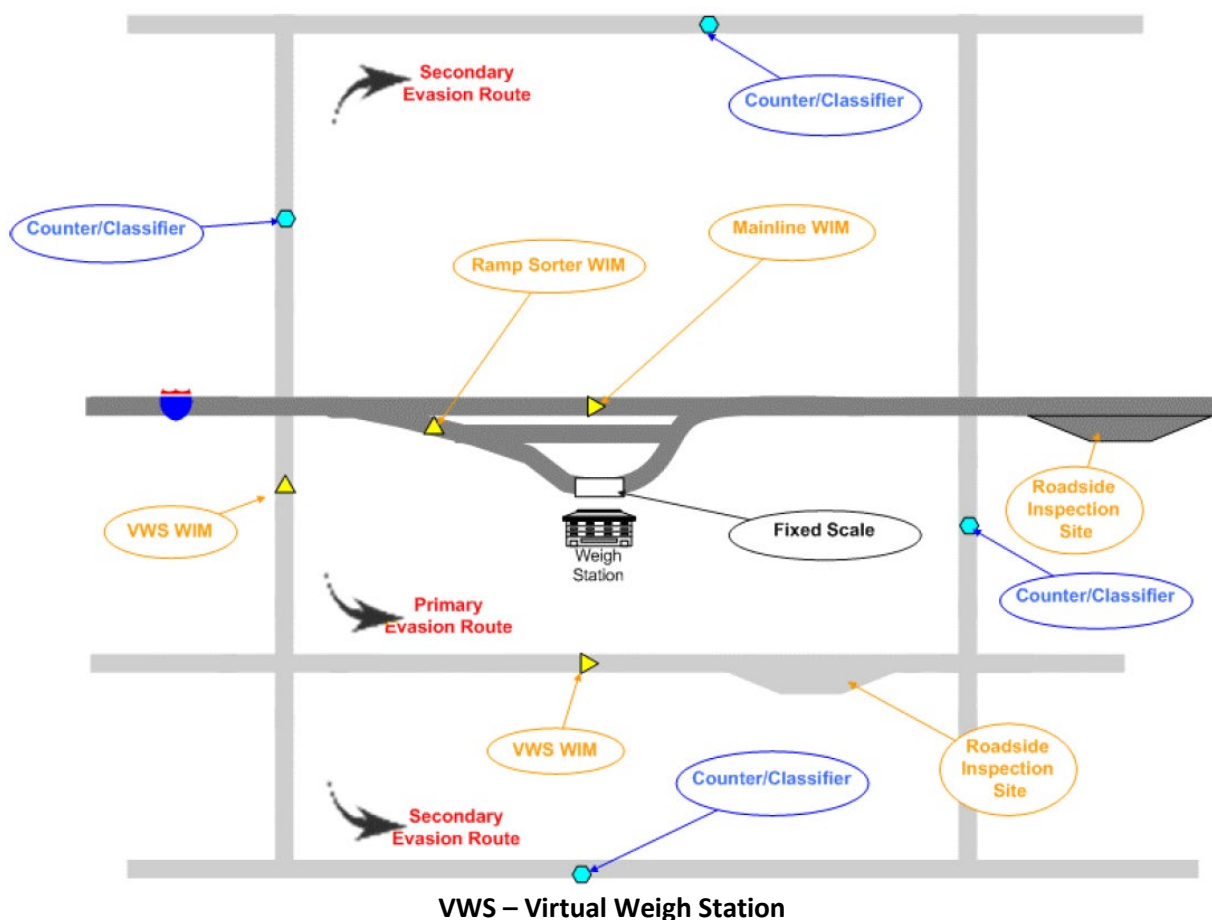


Figure 3. WIM Installation at “Virtual Weigh Station”

(Source: Minnesota Statewide Commercial Vehicle Weight Compliance Strategic Plan, 2005)

Video camera views or still images offer a tool for CVO inspection personnel to identify non-compliant trucks. It was noted in the 2018 Minnesota Weight Enforcement Investment Plan, State Patrol has found integrated cameras to be a critical tool for maximizing the utility of WIM sites for enforcement purposes. As of 2018, there were 16 WIM sites located throughout the state that have integrated cameras. The CVO station may include static scales to check vehicle weight. CVO inspection personnel thus are the primary initial users of the information from the WIM site.

In another version of WIM operation, a picture of the likely offending vehicle and weight information is posted on a real time web site to enforcement officers downstream of the site. Those officers would use a snap shot picture of the vehicle to identify it as it approaches, then they would stop the truck and again perform a static weigh-in using portable scales (“mobile weight enforcement”). Figure 4 illustrates the type of information displayed on a web page with a series of truck pictures, one of which is identified as potentially overweight (“Warning: Over GVW threshold”).

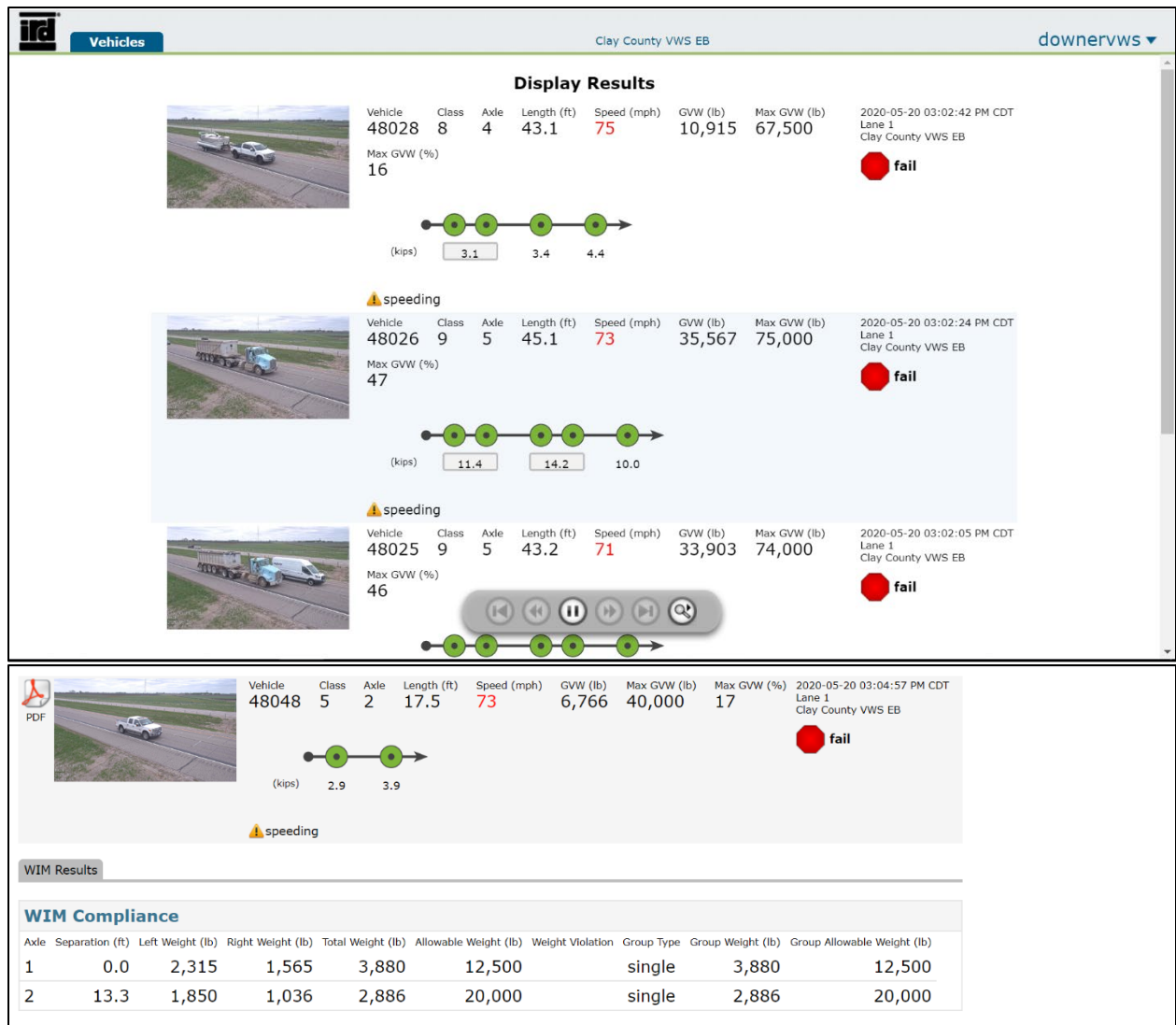


Figure 4. MnDOT VWS – Web Page Display

(Source: MnDOT)

For enforcement purposes, it is important that site data be archived for post-processing. With archived data, trends in violation behavior by location, day of week, and time of day can be investigated. Targeted enforcement can then aim to address the times and places most in need of enforcement.

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. WIM systems may communicate data with CAV Infrastructure Systems.

MnDOT may deploy CAV Infrastructure Systems that communicate WIM 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 WIM. CAV-enabled commercial vehicles may receive WIM screening results along with other safety messages such as pavement, traffic and weather conditions. For WIM scales that are installed in conjunction with electronic pre-clearance, electronic screening data may also be received from the commercial vehicles. CAV Infrastructure System can also send pass/fail notifications (or pull-in notifications if static scale sites are downstream) to the commercial vehicles and its driver based on the information received from the vehicle and the measurements taken.

Other

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

Users

MnDOT and the Minnesota State Patrol are responsible for planning, designing, operating, and maintaining weight enforcement systems, while the FHWA oversees the overall weight enforcement plan. The complete list of potential stakeholders, as per the Minnesota Statewide Regional ITS Architecture 2018 (*Statewide Architecture* for short), is 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 Southern Regional Communication Center (SRCC)
 - Office of Connected & Automated Vehicles (CAV-X)
 - Office of Transportation System Management (OTSM)
 - Office of Freight and Commercial Vehicle Operations (OFCVO)
- Minnesota Department of Public Safety (DPS)
- Minnesota State Patrol (MSP)

- Local Agencies: counties, cities, towns, villages, and townships
- Federal Highway Administration (FHWA)
- Commercial Vehicle Interagency Committee (CVIC)

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*.

Challenges and Needs

The needs of WIM installations for the various stakeholders are presented in Table 1.

Table 1. WIM Needs by Stakeholder

Stakeholder	WIM 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 DPS	WIM-1 Application of WIM data by appropriate authorities to enforce legal weight limits thus preserving the integrity and life of the key pavement asset and provide a safer operating environment.
	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 Needs and Functions follow:	
MnDOT, MnDOT District Offices, Local Agencies	WIM-2 Planning, design, and implementation of WIM sites that meet agency design and performance standards, are reliable and fairly easy to maintain. WIM-3 Access to WIM archived data for purposes of evaluating pavement performance and to help guide design.
MnDOT RTMC, SRCC, and CAV-X	WIM-4 Communications links to WIM management centers when indicated. WIM-5 Remote oversight of WIM sites when they are linked to a center.
MnDOT OTSM	WIM-6 Proactive maintenance of WIM equipment.
MSP	WIM-7 Accurate, reliable WIM equipment that can be used for CVO compliance and WIM enforcement. WIM-8 Access to WIM archived data so that violation patterns can be documented to help target enforcement.
MnDOT OFCVO and OTSM	WIM-9 Access to WIM archived data to help with CVO management, road safety, and facility planning.
FHWA	WIM-7 Accurate, reliable WIM performance that can be used to help manage the pavement asset.

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

Table 2. WIM Needs/Services & ITS Development Objectives by WIM Feature

ID	Feature	Needs/Services ¹	ITS Development Objectives
WIM-CVO	Weigh-in-Motion for CVO Screening	CVFO 01: Minimize delays at weigh stations through additional automation	E-2-03, E-2-04, E-2- 05, E-2-06, E-2-07, E3-01, E-3-11
		CVFO 12: Permit and route commercial vehicle operators of oversize and overweight loads to routes that accommodate size and weight requirements	A-1-01, A-1-02, A-1- 06, A-1-07, C-3-10, C3-11, C-3-12, C-3-13, C-3-15, F-1-02
		CVFO 18: Provide multi-state oversize/overweight permitting	E-2-04, E-2-05
		CVFO 02: Provide mobile weight enforcement	E-2-04, F-1-02
		CVFO 03: Target enforcement at locations with history of violations	F-1-01, F-1-02
		CVFO 04: Target enforcement on carriers, vehicles and drivers with history of violations and poor safety records	E-2-02, E-2-04, F-1- 01, F-1-02
WIM-Oth	Other		

Operational Concept

WIM for CVO Screening

WIM technology has progressed a long way in the last 20 years in step with advances in electronic processing and communications system development. CVO electronic clearance was a concept that evolved from the original Intelligent Vehicle Highway System program in the early 90s, though WIM technology was already under development at the time. The benefits of speeding up truck processing at state ports of entry and at inspection/weigh station are obvious in terms of more productive commerce, and WIM is one important part of expediting truck movements.

One of the best ways to preserve and protect the pavement infrastructure as well as improve overall safety is to make every effort to keep overweight trucks off road facilities. WIM screening is a very important tool that allows the state to monitor for compliance with load limits, assessing fines to drivers who do not comply with the law. Load limits on interstates across the US for the most part are the same or very similar, so that CVO screening in one state often has benefits for other states as well. The technology behind WIM is complex and sophisticated yet functions at a remarkably high level of accuracy as long as the equipment is well maintained.

¹ Needs/Services and ITS Development Objectives per *Minnesota Statewide Regional ITS Architecture* (December 2018).

The major operational aspects of WIM have been discussed in the Current Environment section. As more WIM installations are implemented in Minnesota, a potential advancement for future consideration could be networking all sites together to a control center so that data and trends can be actively monitored across the state.

The operational support environment will use operations and maintenance procedures completed either by agency personnel or contracted private services. WIM equipment is complex and specialized and must be maintained at a high level to achieve satisfactory performance. Initially, the equipment is subject to rigorous testing, and some fine tuning of settings and parameters can be expected. Ideally, the parameters and settings can be monitored and changed remotely from a control center based on field operations.

Specially trained technicians maintain WIM installations using supplier recommended procedures at regularly scheduled intervals. This would include periodic checking and recalibration of sensors. Further specialized procedures may be needed if the WIM equipment is linked to other CVO electronic clearance equipment. In general, trouble calls on WIM sites are not as critical as with, for example, traffic signals or active grade crossing protection. Nevertheless, CVO inspection personnel rely on a high-performance level so that they can fulfill their mission of assuring trucks operate within legal limits. Trouble calls will typically originate from alarms on standalone equipment that may be transmitted to the control center.

For WIM installations that connect to a control center, system architecture and communications system configuration will need to be developed during planning and design, ideally including redundant network design. Communications may be either wireline or wireless.

For enforcement purposes, WIM data needs to be archived for MSP personnel so that they can run reports that identify violation trends and patterns. These reports will then facilitate targeted enforcement.

CAV Infrastructure Systems and CAVs

The WIM operational concept from the perspective of CAV Infrastructure Systems and CAVs is described below. CAV equipped commercial vehicles may communicate directly with WIM to initiate CVO compliance check and receive compliance confirmation or other messages. CAV Infrastructure Systems may receive messages from WIM (either through vehicle to roadside communications or cloud-based communications) and provide in-vehicle display of the message to the driver.

Other

[Reserved for new features].

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 WIM system.

Table 3. Operation and Maintenance Roles and Responsibilities

User Group	Role / Responsibility
Commercial Vehicle Interagency Committee (CVIC)	<ul style="list-style-type: none"> • CVIC was created to make decisions on high level operations for commercial vehicle enforcement between MnDOT, MSP, FHWA, FMCSA and other regulatory partners.
MnDOT OFCVO	<ul style="list-style-type: none"> • Manage the maintenance of some of the WIM sites specifically used for enforcement • Planning, design and implementation of WIM sites • Access to WIM archived data to document and analyze violation patterns to help target enforcement • Access to WIM archived data to help with CVO management, road safety and facility planning
MnDOT District Offices	<ul style="list-style-type: none"> • Planning, design and implementation of WIM sites • Access to WIM archived data for evaluating pavement performance and to help guide design
Local Agencies	<ul style="list-style-type: none"> • Planning, design and implementation of WIM sites • Access to WIM archived data for evaluating pavement performance and to help guide design
MnDOT RTMC and SRCC	<ul style="list-style-type: none"> • Operate communications links to WIM management centers
MSP	<ul style="list-style-type: none"> • Access WIM sites and perform enforcement
MnDOT OTSM	<ul style="list-style-type: none"> • Manage the maintenance of WIM equipment • Planning, design and implementation of WIM sites • Access to WIM archived data to document and analyze violation patterns to help target enforcement • Access to WIM archived data to help with CVO management, road safety and facility planning

Operational Scenarios

Scenarios are intended to describe how users and systems will interact with WIM and related systems, specifically to provide a temporal description of the sequence of events. The following scenarios briefly describe how users will be impacted and how they are expected to respond.

- Scenario A: Mainline Sorting
- Scenario B: Ramp Sorting
- Scenario C: Virtual Weigh Station
- Scenario D: Data Analysis
- Scenario E: CAVs Interaction with WIM

Scenario A: Mainline Sorting

A mainline WIM scale has been installed on a roadway near a weight enforcement station. Based on the WIM information, the driver is alerted via a DMS to either enter the weigh station, or if compliant, to bypass the station. The scale records axle weights and gross vehicle weights on all vehicles passing over it at highway speeds. The scale also records other data such as vehicle speed, axle spacing, vehicle

classification and traffic counts. The data is stored locally for later transfer to MnDOT OTSM, OFCVO, Districts or other offices.

Scenario B: Ramp Sorting

A WIM scale has been installed on a ramp leading into a weigh station. This WIM site is also equipped with a video camera to enhance identification and enforcement of trucks violating weight restrictions. Vehicles passing through the WIM scale on the ramp without stopping, and the scale records axle weights, axle spacing and gross vehicle weights of all vehicles passing over it. The CVO enforcement personnel sits at a static scale site in the weigh station downstream nearby observing the activities recorded by the WIM scale. Drivers of vehicles in compliance with weight limits receive an indication through signals or signs to use the bypass ramp to bypass the static scale and continue traveling down the road. Drives of vehicles in question receive an indication to pull into the static scale for further screening and inspection.

Scenario C: Virtual Weigh Station

As a commercial truck approaches a virtual weigh station, it is weighed while in motion on a WIM scale. A State Trooper or sworn law enforcement officer positions downstream the virtual weigh station and accesses the WIM data via a screening software on the mobile computer in the enforcement officer's vehicle. Based on the screening data, the enforcement officer makes a decision to flag down the truck in question for weighing and inspection.

Scenario D: Data Analysis

A WIM system captures and records axle weights, gross vehicle weights, speeds and vehicle classification of all vehicles passing over the scale. The detailed data is useful not only for CVO weight enforcement but also for an array of applications, including pavement design, monitoring and research; bridge design, monitoring and research; weight violation trends; and others. Data recorded by the WIM system is archived in a database. MnDOT and local transportation agencies use the data to compute vehicle loads and analyze expected pavement life and needed rehabilitation. MnDOT and local transportation agencies also use the data to perform research and evaluation on pavement/bridge designs and make design decisions. CVO enforcement agencies analyze the data to identify trends in violation behavior by location, day of week and time of day; and use the information for targeted enforcement.

Scenario E: CAVs Interaction with WIM

At a time when a high number of CAVs are operational in Minnesota, connected and automated commercial vehicles passing over a WIM scale may receive communications from the WIM system indicating the status of weight compliance. Upon receiving the results of weight compliance check, commercial vehicle drivers may continue traveling down the road or take corrective actions when their vehicles are not in compliance. CVO screening and enforcement personnel may receive notifications of potential weight violations and identifications of vehicles in question in real time. CVO screening and enforcement personnel can intercept the vehicles in question to perform compliance check and inspection.

Risks and Mitigation

WIM for CVO Screening

A WIM system typically consists of roadway sensors that classify vehicles by type and measure the vehicle weight and the supporting electronic hardware and software needed to process, sort, analyze, and transmit the recorded data. WIM measures and records axle weights and gross vehicle weight without requiring the vehicle to come to a stop. WIM reduces congestion within the fixed weigh station facility; focuses enforcement on high-risk operators, thereby increasing enforcement personnel's effectiveness; and provides time savings for safe and legal carriers, supporting more efficient movement of freight. Accurate information is critical to WIM or any electronic measurement devices being effectively used. WIM is only about 90% accurate. This is due to the accuracy of the sensors, varying temperature and weather conditions (pavement frozen or thawed), the smoothness of the pavement, the suspension on the vehicles, when the system was last calibrated, etc. Enforcement personnel will not utilize the technology to its fullest extent if the data is perceived to be inaccurate. Therefore, maintenance and proper calibration of equipment at WIM sites is important.

Other

[Reserved for new WIM 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

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