m DEPARTMENT OF TRANSPORTATION

Systems Engineering Analysis for Road Weather Information System

Concept of Operations

Revision History

This document will be used for design of MnDOT's new road weather information 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	8/19/2019	Initial version
1.1	11/19/2019	Minor revisions per FHWA comments
1.2	5/14/2020	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 Road Weather Information System (RWIS) installations. An RWIS uses Environmental Sensor Stations (ESSs) in the field with sensors and processors, a communication system for data transfer, and central systems to collect and disseminate field data from numerous ESSs. These stations measure atmospheric, pavement, or water level conditions, or combinations of these. Central RWIS hardware and software are used to process observations from ESSs to develop forecasts and display or disseminate road weather information in a format that can be easily interpreted by a manager to support decision making, or in a format for the general public to use, for instance, via a 511 information system. Often, ESSs provide basic input to Minnesota's Maintenance Decision Support System (MDSS), an interactive system that assists maintenance supervisors with best management practices or techniques given predicted weather.

Figure 1 illustrates the range of applications of information collected from an ESS, while Figure 2 shows typical connectivity. This *ConOps* focuses on the field elements of ESSs that are fairly standard. Although communications and processing at central locations are required, they tend to be part of a larger network or are a specialized application.
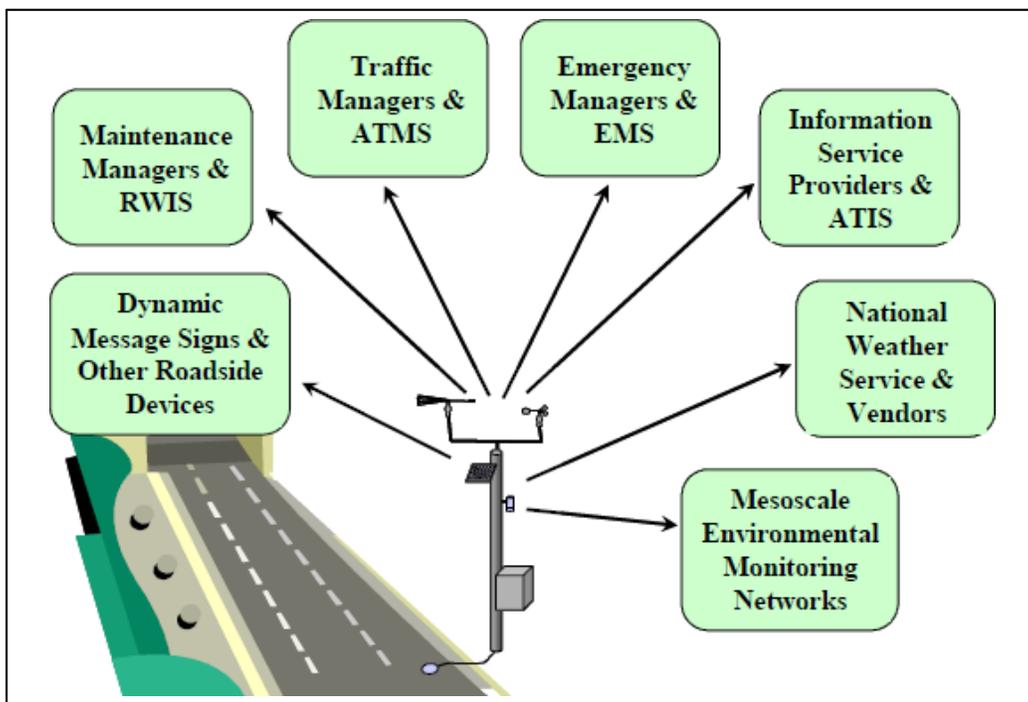
Figure 1. RWIS Uses and Customers
(Source: http://ops.fhwa.dot.gov/weather/mitigating_impacts/surveillance.htm#esrw)

Figure 2. Typical RWIS Connections
(Source: *Best Practices for Road Weather Management*, Report No. FHWA-OP-03-081, available at
http://ops.fhwa.dot.gov/weather/mitigating_impacts/best_practices.htm)

Mobile sensing may become an integral part of RWIS networks in the future. The Minnesota Department of Transportation (MnDOT) now has over 750 vehicles with air and pavement temperature sensors. MnDOT's entire snowplow fleet (830 vehicles) will soon be equipped with Mobile Data Computers capable of collecting and transmitting data from these and other sensors and/or operator input. This *ConOps*, however, does not address these mobile units. As operations of Connected and Automated Vehicles (CAVs) expand, several data exchanges between RWISs and CAVs are anticipated, and these are presented in this document.

Current Environment

Basic Road Weather Information Systems

Regarding the three information types, atmospheric data (Figure 3) include air temperature and humidity, visibility distance, wind speed and direction, precipitation type and rate, cloud cover, tornado or waterspout occurrence, lightning, storm cell location and track, as well as air quality. Pavement data (see Figure 4) cover surface temperature, freezing point, condition (e.g., wet, icy, flooded), chemical concentration (amount of deicing material), and subsurface conditions (e.g., soil temperature). Water level data include stream, river, and lake levels near roads, as well as tide levels where applicable. Some ESSs are also used to collect traffic data such as vehicle speed, length, and classification. Wider employment of such vehicle data collection can be expected as implementers move towards using speed as a measure of level of service.

In addition, Minnesota is generally including cameras at ESSs to take still images of the roadway for snow and ice control as well as for traveler information. RWIS installations may also be integrated with automated fixed anti-icing spray technology (FAST) installations to help proactively manage the pavement surface. This *ConOps* addresses only the RWIS.

The primary users of the information from RWIS installations are roadway maintenance, traffic operations, and weather service providers. The general public also may be a major user if the collected data are translated into useful traveler information, for example, by reporting on comparative conditions from several different sites.

Figure 3. ESS Above Ground Sensor
(Source: Road Weather Information System Environmental Sensor Station Siting Guidelines, Publication No. FHWA-HOP-05-026, April 2005)

Figure 4. ESS Pavement Sensor
(Source: *Best Practices for Road Weather Management*, Report No. FHWA-OP-03-081, available at http://ops.fhwa.dot.gov/weather/mitigating_impacts/best_practices.htm)

The FHWA Clarus Initiative is a multi-year effort to develop and demonstrate an integrated surface transportation weather observation data management system, and to establish a partnership to create a Nationwide Surface Transportation Weather Observing and Forecasting System. Minnesota RWIS installations can be an input to Clarus. MnDOT now provides data from its RWIS network to the FHWA Weather Data Environment project (https://wxde.fhwa.dot.gov/).

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

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. RWIS systems may communicate data with CAV Infrastructure Systems.

MnDOT may deploy CAV Infrastructure Systems that communicate Basic Safety Messages (BSMs) 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 the RWIS.

Other

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

Users

Stakeholders, as per the *Minnesota Statewide Regional ITS Architecture 2018* (*Statewide Architecture* for short), for RWIS installations include some or 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
- News media
- Minnesota Department of Transportation (MnDOT) and associated entities:
  - District Offices
  - RTMC (Regional Transportation Management Center), plus SRCC (Southern Regional Communication Center)
  - Office of Electronic Communications (OEC)
  - Office of Aeronautics (OA)
  - Office of Connected & Automated Vehicles (CAV-X)
  - Office of Maintenance (OM)
  - Office of Transportation System Management
- Local Agencies: counties, cities, towns, villages, and townships
- (Local) Traffic Management Centers
- Local Maintenance and Construction Management (MCM) Agencies
- Federal Highway Administration (FHWA)
- National Weather Service (NWS)
- Private Value Added Meteorological Services (VAMS)
- Minnesota State Patrol (MSP) and local law enforcement
- University of Minnesota Duluth Transportation Data Research Laboratory (UM-TDRL)

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 to the MSP group.

Challenges and Needs

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

Table 1. RWIS Needs by Stakeholder

Stakeholder	RWIS 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 News Media MSP and Local Law Enforcement	RWIS-1 Availability of wide-area weather information and forecasts based on ESSs as one of several inputs to other systems including the MDSS and Minnesota 511.
	RWIS-2 Access to ESS video camera views as feasible and applicable.
	Other – [Please consult with appropriate MnDOT, FHWA, or local staff to develop needed Needs and Functions]
All Stakeholders share in above to varying degree. Additional Needs and Functions follow:	
MnDOT, MnDOT District Offices, Local Agencies	RWIS-3 Planning, design, and implementation of ESSs that meet agency design and performance standards, are reliable and easily maintained. Where appropriate, share power and communications with adjacent device systems.
MnDOT OA, RTMC, SRCC, and CAV-X; Local Traffic Management Centers	RWIS-4 Communications links to RWIS management centers RWIS-5 Remote operation and control of ESSs per established hierarchy
MnDOT OM and OEC; Local MCM Agencies	RWIS-6 Oversight and maintenance of ESS devices
FHWA, NWS, Private VAMS	RWIS-7 Access to RWIS data for Clarus and for national/regional weather forecasting
UM-TDRL, MnDOT Transportation System Management	RWIS-8 Access to RWIS data for archiving and data analysis, including traffic data when available.
MnDOT	RWIS-9 Remotely aggregate RWIS data with data collected from mobile sensing on maintenance vehicles.

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

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

ID	Feature	Needs/Services [1] [2]	ITS Development Objectives
RWIS	Road Weather Information System	WTR01: Provide automated monitoring of road weather conditions	A-1-03, A-2-03, A-2-24, C-3-09
		ATMS04: Provide cameras at locations with high incidents and areas of high importance for incident identification and verification	B-1-15, B-1-17, B-1- 18, C-1-09, D-1-06
		ATMS12: Reduce clearance time for primary crashes	B-1-17, B-1-18
RWIS-Oth	Other		

Operational Concept

Basic RWIS

RWIS development has progressed a long way in the last 20-30 years along with advances in electronic processing and communications system development. Weather obviously has always been a major consideration in transportation, affecting travelers' choice of travel time, mode, and route, plus operator management of facilities to keep them open under adverse conditions. Any information that allows operators and maintenance organizations to not only keep apprised of weather conditions system-wide but also to help forecast future conditions is valuable and helps agencies be more effective and efficient in performing their duties. ESSs to support the entire RWIS are the key connection with the travel environment, and as more are installed, the resulting performance can only improve.

ESSs provide basic inputs to Clarus, the MnDOT MDSS, and the Minnesota 511 Traveler Information system. RWIS installations typically use the NTCIP 1204: Object Definitions for Environmental Sensor Stations (ESS).

The operational support environment will be completed either by agency personnel or contracted private services. Specially trained technicians will operate and maintain the ESSs using standard supplier operational guidelines along with routine and emergency maintenance procedures that are well established. In general, trouble calls on ESSs are not as critical as with, by comparison, traffic signals or active grade crossing protection, except in the case of RWIS equipment integrated with a fixed anti-icing spray technology (FAST) system. In that case, response time requirements should be established and strictly enforced. Trouble calls will typically originate from alarms on the equipment transmitted to the RWIS control center.

Preventive maintenance on the equipment will be scheduled to occur as a part of routine maintenance. This would include periodic checking and recalibration of sensors.

Since field ESSs will connect to an RWIS control center, system architecture and communications system

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[1] Needs/Services Key: WTR – Weather Service; ATMS – Traffic Management
[2] Needs/Services and ITS Development Objectives per *Minnesota Statewide Regional ITS Architecture* (December 2018).

configuration will need to be developed, ideally including redundant network design. Communications may be either wireline or wireless.

CAV Infrastructure Systems and CAVs

The RWIS 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 RWIS data, and some of which will be a source of road weather conditions data. Road weather information collection functions may be completed by field devices, collected from the communications of passing CAVs, or provided to MnDOT by third party weather services. CAVs will communicate with CAV Infrastructure Systems to exchange Basic Safety Messages (BSMs). CAV Infrastructure Systems may receive road weather condition messages from RWIS (either through vehicle to roadside communications or cloud-based communications). CAVs may communicate directly with RWIS to exchange road weather conditions data.

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 RWIS system.

Table 3. Operations and Maintenance Roles and Responsibilities

User Group	Role / Responsibility
MnDOT District Offices	• Planning, design and implementation of ESSs; where appropriate, share power and communications with adjacent device systems
Local Agencies	• Planning, design and implementation of ESSs; where appropriate, share power and communications with adjacent device systems
MnDOT RTMC and SRCC	• Operate communications links to RWIS management centers • Remote operation and control of ESSs per established hierarchy
Local Traffic Management Centers	• Operate communications links to RWIS management centers • Remote operation and control of ESSs per established hierarchy
MnDOT OA	• Operate communications links to RWIS management centers • Remote operation and control of ESSs per established hierarchy
MnDOT OM and OEC	• Oversight and maintenance of ESS devices
Local MCM Agencies	• Oversight and maintenance of ESS devices
MnDOT TDA	• Access to RWIS data for archiving and data analysis, including traffic data when available
UM-TDRL	• Access to RWIS data for archiving and data analysis, including traffic data when available
NWS	• Access to RWIS data for Clarus and for national/regional weather forecasting

User Group	Role / Responsibility
Private VAMS	• Access to RWIS data for Clarus and for national/regional weather forecasting

Operational Scenarios

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

- Scenario A: No Weather Event
- Scenario B: Snowstorm
- Scenario C: Freezing Rain and Heavy Snow
- Scenario D: Summertime Storm, Flooding and Washout
- Scenario E: CAVs Interaction with RWIS

Scenario A: No Weather Event

Air temperatures are between 20°F and 30°F and pavement temperatures are in the 40s. Roads and bridges are clear of snow and ice. MnDOT and NWS are sharing data and forecasts with all MnDOT and local agencies. MnDOT maintenance personnel and RTMC are monitoring current conditions and forecasts. Maintenance personnel are cleaning and repairing equipment to maintain readiness. Salt/sand stockpiles are checked, and salt may be loaded on some vehicles. Maintenance personnel are monitoring regional weather conditions and local weather forecasts. Maintenance personnel also monitor RWIS and other data sources to track the advance of inclement weather into their area. They also monitor the pavement temperature and dew point temperature relationship for potential frost formation.

Scenario B: Snowstorm

A snowstorm is predicted to hit at about 6:00 PM on Wednesday and is expected to be over by about 4:00 AM the next morning. The total of three inches of snow is predicted. Winter maintenance crews are notified in advance of the storm and a partial crew is standing by at the beginning of the snow event. Supervisors choose to go with a partial shift rather than a full shift, because it is felt that the partial shift could handle this limited event. Additional staff are available if conditions become more intense. Winter maintenance personnel actively monitor the storm movements using RWIS data and other sources.

Snow begins very near the projected 6:00 PM start time and crews are successful in getting a good layer of chemical down to prevent bonding. As the storm progresses, maintenance personnel continue monitoring the current and predicted conditions and tracking the storm from various sources, including the RWIS data. Maintenance personnel monitor the pavement temperatures closely to assure that the treatment plan does not need to be modified and that the treatment plan in use would permit the roads to return to bare pavement when the snow stopped. RWIS observations are a key part of the decision-making process. RWIS data along with other data sources are input into MnDOT's MDSS. Maintenance supervisors are able to use MDSS, RWIS data, and other data sources to determine an effective strategy.

Scenario C: Freezing Rain and Heavy Snow

The storm moving across the Twin Cities metropolitan area from the south is projected to begin with freezing rain and transition into heavy wet snow. Maintenance personnel are monitoring the storm's progress using information from RWIS and other sources, and have preparations well underway, including double checking equipment and chemicals and scheduling drivers and staff.

As the precipitation spreads into southern Minnesota from Iowa, maintenance personnel pay attention to observations from the RWIS stations south of the Twin Cities area in order to make more informed decisions about when to call in crews. They notice from NWS and RWIS reports that mist and light freezing drizzle are being reported ahead of the primary storm and that pavement temperatures across the Twin Cities area are remaining in the low to mid 20s. The extremely cold subsoil temperatures from the cold spell the previous week are keeping the pavement temperatures well below the air temperature. Possible ice is indicated in the areas south of the Twin Cities and radio communications confirms that slippery spots are developing ahead of the main storm.

As the storm moving in and transiting from freezing rain to snow, RWIS helps keep the maintenance personnel aware of current pavement and weather conditions. The information allows for making informed decisions on snow and ice control strategies.

Scenario D: Summertime Storm, Flooding and Washout

A summer rain started at 5:00 PM in Rochester from an area of thunderstorms that is slowly moving east. Between 5:00 and 7:00 PM, over an inch of rain fell in the Rochester area. The thunderstorm complex grows and stalls, becoming situated over the area. By mid-night, nearly four inches of rain falls at many locations within the area with no sign of stopping.

Maintenance staff prepare for the situation by readying flood warning signs for deployment at locations that frequently flood. As the rainfall persists, maintenance staff prepare and deploy signs and/or barricades where road closures became necessary. Law enforcement is contacted for road closures. SRCC coordinates the notification of other agencies when flooded roadways are reported. SRCC and maintenance staff monitor the wind conditions from RWIS and other sources to capture potential areas of high winds. RWIS shows rainfall amounts and helps track how fast it is raining. In this scenario, RWIS helps plan for and anticipate the flooding and allows for validation of alarms and conditions leading to more concise first responses.

Scenario E: CAVs Interaction with RWIS

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 pavement temperature, air temperature, presence of precipitation, pavement conditions, etc. CAV Infrastructure Systems may broadcast Basic Safety Messages (BSMs) to CAVs. MnDOT may have installed On-Board Units (OBUs) on maintenance vehicles. The maintenance vehicle OBUs may receive information from CAV Infrastructure Systems and generate data sets with information on position, speed, chemical application rates, and vehicle status. In some situations, CAVs may benefit from direct data exchanges with the RWIS.

Risks and Mitigation

Basic RWIS

Transportation managers can use roadway warning systems, interactive telephone systems (e.g., 511), and web sites to disseminate road weather information to travelers in order to influence their decisions. This information allows travelers to make choices about travel mode, departure time, route selection, vehicle type and equipment, and driving behavior based on current and forecast weather conditions to minimize exposure to severe weather conditions. The compiled information also can help to improve timeliness and efficiency of maintenance actions by way of the MDSS, such as when to snowplow or deposit anti-icing/de-icing chemicals on the highways. Such proactive facility management should result in safer roads with fewer weather-related accidents.

Other

[Reserved for new RWIS 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	