Adaptive Route Optimization for Operations—System Requirements Specification

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FOREWORD

The *Adaptive Route Optimization for Operations—System Requirements Specification* supports systems engineering for creating a system or tool that incorporates real-time and historic data to develop an adaptive snowplow routing optimization solution for maintenance and operations personnel to use during adverse winter weather. This document is the final version of the first publication of this information.

This technical specification will be useful to transportation agency and academic researchers, operations and maintenance personnel, and systems and software developers working with transportation winter maintenance operations. The document is available on the research website (https://www.fhwa.dot.gov/research).

Mark Kehrli, Director,
Office of Transportation Operations

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract

The information contained in this document supports systems engineering for creating a system or tool that incorporates real-time and historic data to develop an adaptive snowplow routing optimization solution for maintenance and operations personnel to use during adverse winter weather.

State departments of transportation currently spend over $2 billion per year on snow and ice control, and over $5 billion per year on repairs due to snow and ice operations, chemical use, and wear. Given these significant costs, even minor improvements to snowplow routing can produce considerable agency savings through reduced staff time and material use and less waste.

This document describes the system requirements for adaptive route optimization.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1,000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

API	application programming interface
ARO	adaptive route optimization
AVL	automated vehicle location
DOT	department of transportation
FHWA	Federal Highway Administration
MDSS	maintenance decision support system
SyRS	system requirements specification

DEFINITIONS

adaptative	Able to change in response to objectives (for example, cycle times), events (for example, traffic incidents) and changing conditions (for example, precipitation).
atmospheric weather	Temperature, precipitation, visibility, and other conditions of the atmosphere above the earth's surface.
automated vehicle location system	A system for monitoring and sending information about a vehicle's location and operating conditions (for example, salt inventory) to an operations center or system.
cycle time	How long it takes to service all lanes of a road segment along a planned route one time.
maintenance facility	A place where equipment, supplies, and materials (for example, treatment materials) used for winter maintenance operations are stored.
optimization	Techniques or algorithms for finding the optimal solution to a set of objectives (for example, the fastest routes over a set of roadways), subject to a set of constraints (for example, with a limited set of vehicles).
patrol	A group of vehicles (for example, snowplow trucks) operating together to achieve an objective.
real-time	The actual time during which something takes place; without delay
road network conditions	Traffic and roadway surface conditions typical of roadways within a specific geographic area
road weather	Temperature, precipitation condition, slickness or friction, and other conditions on a roadway surface.
route	An ordered set of links.
link	A link between nodes (intersections) in a network; also, an ordered set of segments.
segment	A length of roadway with consistent geometry and operating conditions.

EXECUTIVE SUMMARY

Adverse weather has a measurable impact on roadway safety, mobility, and productivity. It increases driving risks and travel times, and creates operational challenges for transportation agencies. There were more than 241,000 injuries and 6,000 fatalities on U.S. roadways with adverse weather conditions as a contributing factor in 2019. State departments of transportation (DOT) spend over $2 billion per year on snow and ice control. They spend over $5 billion per year on repairs due to snow and ice operations, chemical use, and wear.

Operations to restore service on roads affected by winter weather conditions may include anti-icing to postpone frozen precipitation on the roadways, plowing to remove snow and ice from roadways, and using de-icing material to improve the pavement state. Each State DOT has its own goals and challenges in getting roadways back to pre-storm levels of service. Planning and routing for winter maintenance generally builds on past practice and results, conditioned by the profile of the storm.

Adaptive route optimization (ARO) is a method of dynamically and effectively routing winter maintenance vehicles across all segments of a road network to meet an agency's maintenance objectives, subject to weather conditions, traffic, and resource constraints. ARO can enable agencies to respond more quickly and efficiently than is possible with current routing systems to changing storm conditions, resource constraints, and service expectations. It has the potential to restore pavement conditions faster, reducing weather-related risk and improving mobility. Winter maintenance can be expensive and use up a big part of agency budgets, so any gains in efficiency can produce savings through more efficient material usage. Agencies using ARO can develop more efficient routing plans that makes the most use of staff time, materials, and equipment.

The ARO system will incorporate real-time and historic data in a snowplow routing solution for State DOT maintenance and operations to use during adverse winter weather. The solution will support a strategic view for maintenance planning and a tactical view for real-time operations. Dashboards will be provided for users, including managers, maintenance supervisors, and drivers.

The ARO system will consider level-of-service goals, route and segment priorities, cycle time expectations, and current and forecast roadway conditions in route optimization. Current (real-time) conditions to be addressed include atmospheric weather, road weather, incidents, work zones, and traffic volume (or demand). Forecast conditions to be considered will at minimum include weather and road weather conditions, and may include other traffic and operational predictions. Routes will further consider historical crash data, recurring problem areas, and weather-related experience for their routing risk implications. Routing will consider constraints specific to snowplowing operations such as access to maintenance facilities, turnarounds, U-turns, intersection snow clearance, and driver deadheading.

The ARO system will enable State DOTs to better respond to changing winter weather events and circumstances. Scenarios in which ARO can improve agency responses include, for example:

- Optimizing snowplow routes with reallocation of plowing resources among maintenance facilities and regions.
- Adaptively optimizing routes to changing weather conditions while treatment cycles are underway.
- Tactically reoptimizing snowplow patrols around active incident sites and the resulting congestion.

A successful ARO system implementation would lead to faster restoration of clear pavement, safer roadway conditions for the traveling public, and improved mobility under winter driving conditions. As a related benefit, an ARO implementation needs more complete and timely views of operations and winter maintenance activities across the road network. This process will improve awareness within and across the transportation agency, and will enable timelier and more effective communications with the public.

Within the agency's operations, ARO can improve human and equipment resource utilization in winter operations. The improved routing could reduce the total route miles and deadheading, which in turn would improve operator satisfaction and morale. Better knowledge of and planning for storm conditions and routing could potentially result in less treatment material usage (relative to nonoptimized routes in the absence of a maintenance decision support system (MDSS)) and reduced environmental load.

Requirements for the ARO system specify what the system is to do under what conditions and constraints. They may address functional, interface, performance, security, data, and reliability needs. The specifications do not address how the system is to be implemented.

CHAPTER 1. INTRODUCTION

IDENTIFICATION

This document is the system requirements specification (SyRS) for Adaptive Route Optimization (ARO) for Operations.

DOCUMENT OVERVIEW

The intent and structure of this document is consistent with the outline of an SyRS described in the Institute of Electrical and Electronics Engineers' (IEEE) *Systems and Software Engineering — Life Cycle Processes — Requirements Engineering* (Standard ISO/IEC/IEEE 29148) (IEEE 2011).[1] As stated therein, "[an SyRS] defines the high-level system requirements from the domain perspective, along with background information about the overall objectives for the system, its target environment and a statement of the constraints, assumptions and nonfunctional requirements." The standard describes what the system will do without prescribing how the system will be implemented.

Some sections have been amended to provide more details than are described in the standard, and titles of some sections have been edited to capture that enhancement.

The organization of the SyRS is as follows:

Chapter 1 introduces the purpose of the ARO project, describes the scope of this document, and provides an overview of the intended implementation.

Chapter 2 describes the specific technical requirements for the ARO concept.

Chapter 3 describes assumptions and dependencies behind the requirements specifications.

Chapter 4 identifies references relative to this SyRS.

SYSTEM PURPOSE

Road weather information such as pavement temperatures and condition can help reduce the operational impacts of adverse winter weather conditions. Timely and accurate traveler information can change driving patterns to reduce the risk of crashes, injuries, and fatalities. State departments of transportation (DOT) winter operations and maintenance staff use pavement condition, temperatures, and precipitation data to plan how to restore roads to levels of service commensurate with expected traffic volumes and speeds. These operations generally will include anti-icing to postpone frozen precipitation on the roadways, plowing to remove snow and ice from roadways, and using de-icing material to improve the pavement state.

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[1] This ISO/IEC/IEEE standard replaces the previous *IEEE Guide for Developing System Requirements Specifications*, standard IEEE 1233-1998.

Each State DOT has its own goals and challenges in getting roadways back to pre-storm levels of service. In general, maintenance planning and routing builds on past practice and results, conditioned by the profile of the storm. Results for the road network as a whole depend on setting the safety and mobility goals and routing the available vehicles in the maintenance fleet. Results for a specific segment of roadway depend on factors such as the type of storm and precipitation, timing of operations, and the type of treatment. The time to plow and treat all road lanes on a route can be affected by the truck's material capacity, location of maintenance facilities, events on the roadway, changing winter storm conditions, traffic, staff shift changes, and other factors.

Changes in weather patterns, the road network conditions, agency resources, and public expectations are challenging past practices for planning and routing. Intense weather events—whether winter snow and icing, hurricanes, or droughts and dust storms—are becoming more likely. Traffic in urban areas and along interstate corridors is more congested even while lane miles increase. Agencies continue to struggle with budgets and staffing to keep up with increased needs for maintenance resources. Public perceptions focus more on extreme events where expectations may not have been fully met than on regular consistent service.

This situation creates an opportunity to improve safety and mobility on roads subject to winter weather through better vehicle routing. Operators and maintenance supervisors understand the need to improve current practices. However, route optimization is a complex science. Routing for winter maintenance needs research into models and methods to improve the state of its practice.

The objective of this research in ARO for Operations is to create foundational systems engineering documentation to create a system or tool that incorporates real-time and historic data to develop an adaptive snowplow routing optimization solution for State DOT maintenance and operations personnel for use during adverse winter weather. This documentation will be based on current practices; State DOT experiences; and gaps found in a literature review, technology scan, and interviews of State DOT early deployers. End users for this system or tool will include snowplow operators, maintenance supervisors and management, transportation management center personnel, public information office staff, and emergency management responders.

SYSTEM SCOPE

The ARO system will incorporate real-time and historic data in a snowplow routing solution for State DOT maintenance and operations to use during adverse winter weather. The solution will support a strategic view for maintenance planning and a tactical view for real-time operations. Dashboards will be provided for users including managers, maintenance supervisors, and drivers.

The ARO system will consider level-of-service goals, route and segment priorities, cycle time expectations, and current and forecast roadway conditions in route optimization. Current (near real-time) conditions to be addressed include atmospheric weather, road weather, incidents, work zones, and traffic volume (or demand). The system will consider, at minimum, the weather and road weather conditions, and it may include other traffic and operational predictions. Routes will further consider historical crash data, recurring problem areas, and weather-related experience for their routing risk implications. Routing will consider constraints specific to snowplowing

operations, such as access to fuel and material facilities, turnarounds, U-turns, intersection snow clearance, and driver deadheading.

The ARO system will be agnostic with respect to its interfaces with other data systems and systems infrastructure. It will not be tied to a particular application suite or toolkit for implementation. It will use open data specifications drawn from technology standards to the extent that such standards exist and are applicable to its context. It will be able to integrate with existing Federal Highway Administration (FHWA) and State DOT maintenance and operations systems.

SYSTEM OVERVIEW

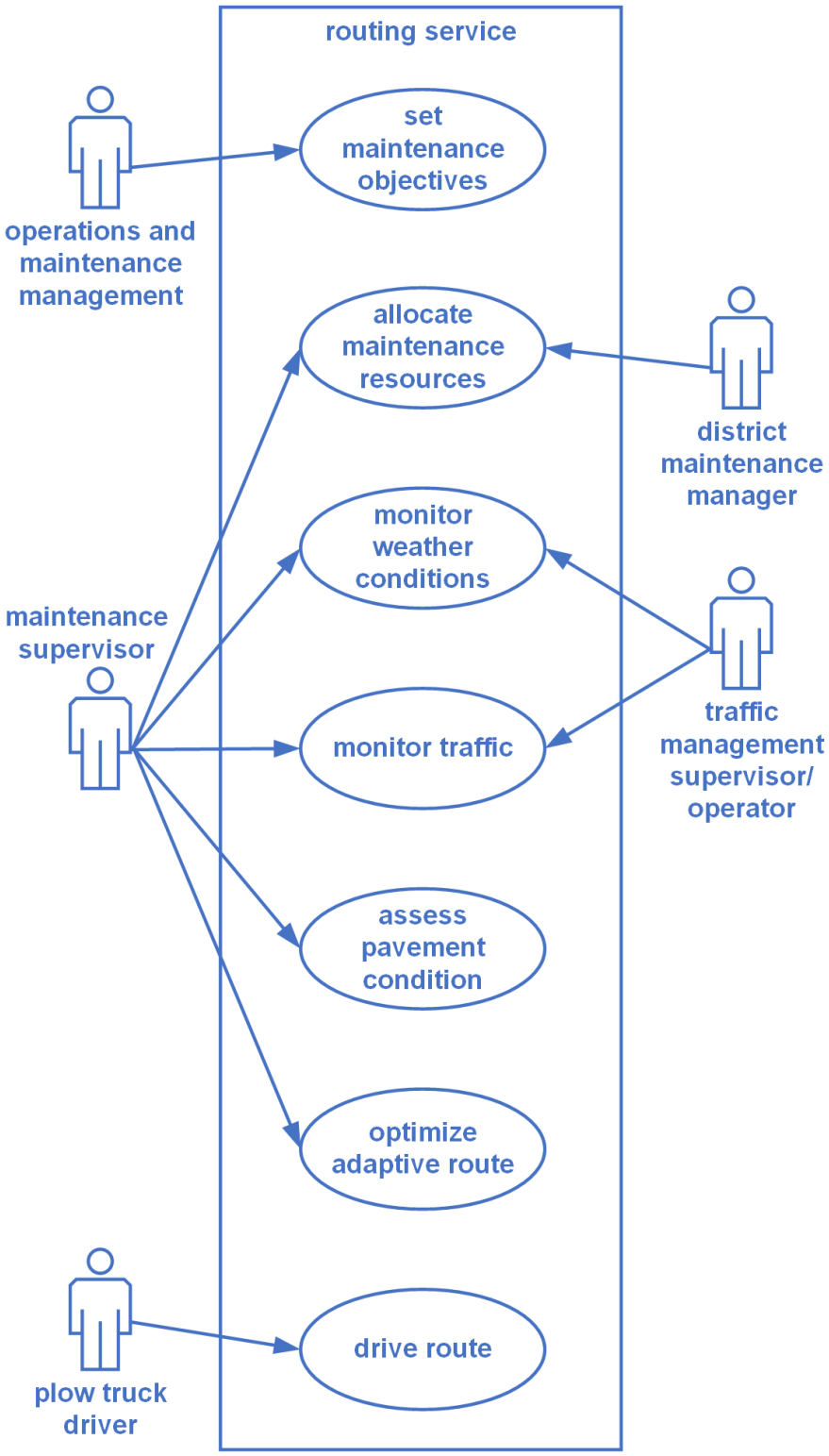
System Context

As described in the ARO Concept of Operations,[2] roadway winter maintenance involves complex coordination of activities and resources, from management levels to drivers on the road, over a long season of preparation and execution. Adaptively optimizing routes for road treatment and plowing is a new and specific function among winter weather operations, but it exchanges information with every other winter maintenance process.

Figure 1 illustrates routing use cases for winter maintenance routing with ARO. Current practices include each of the use cases, but in some respects, ARO changes the process and outcomes:

- Setting maintenance objectives becomes more dynamic with ARO than in current practice. ARO enables managers to adapt the extent and timing of treatment and plowing as operations and storms develop rather than work from static routing plans.
- Allocating maintenance resources becomes more dynamic with ARO. New information on material stores or shifts in plow truck assignments from one area to another can be implemented dynamically in route plans.
- Monitoring of weather conditions for adaptive routing becomes as important throughout the storm as it was forecasting before the event.
- Monitoring traffic becomes a proactive factor in adaptive routing rather than just a reactive notification of potential issues.
- Assessing pavement condition becomes available at a fleet and network level rather than just along routes as they are being driven.
- The routing activity has enough information to adapt to changing circumstances across the network so that maintenance can be optimized to meet or exceed objectives.
- Drivers are given explicit routing instructions in real time, adapted to conditions that optimize maintenance across the network, rather than just for their pre-assigned static route.

[2]Garrett, K., N. Hawkins, J. Dong, and R. Schaefer. 2022. *Adaptive Route Optimization for Operations – Concept of Operations*. FHWA-HOP-22-004. Washington, DC: Federal Highway Administration.

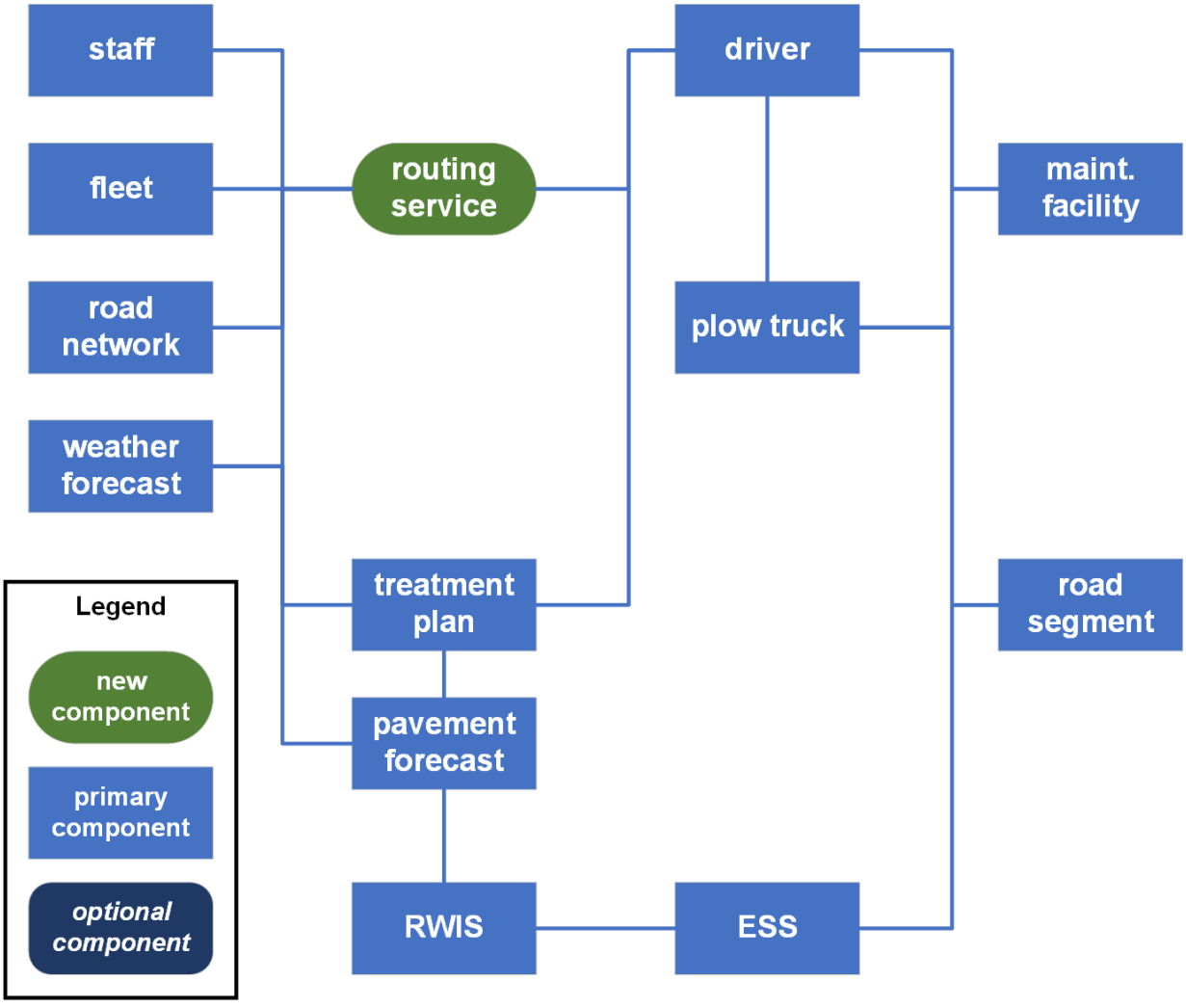


Source: FHWA.

Figure 1. Diagram. Winter maintenance routing use cases with adaptive route optimization.

Figure 2 illustrates components of a winter maintenance system of systems with ARO. Although practices and uses of technology vary among transportation agencies, the components are typical. Deployment of ARO changes the roles of only a couple of components relative to a pre-ARO context:

- Static routing plans are replaced with a routing service that dynamically provides optimized route plans adapted to current conditions.
- The pavement forecast, previously an optional component, becomes a primary component of an adaptive optimized solution.



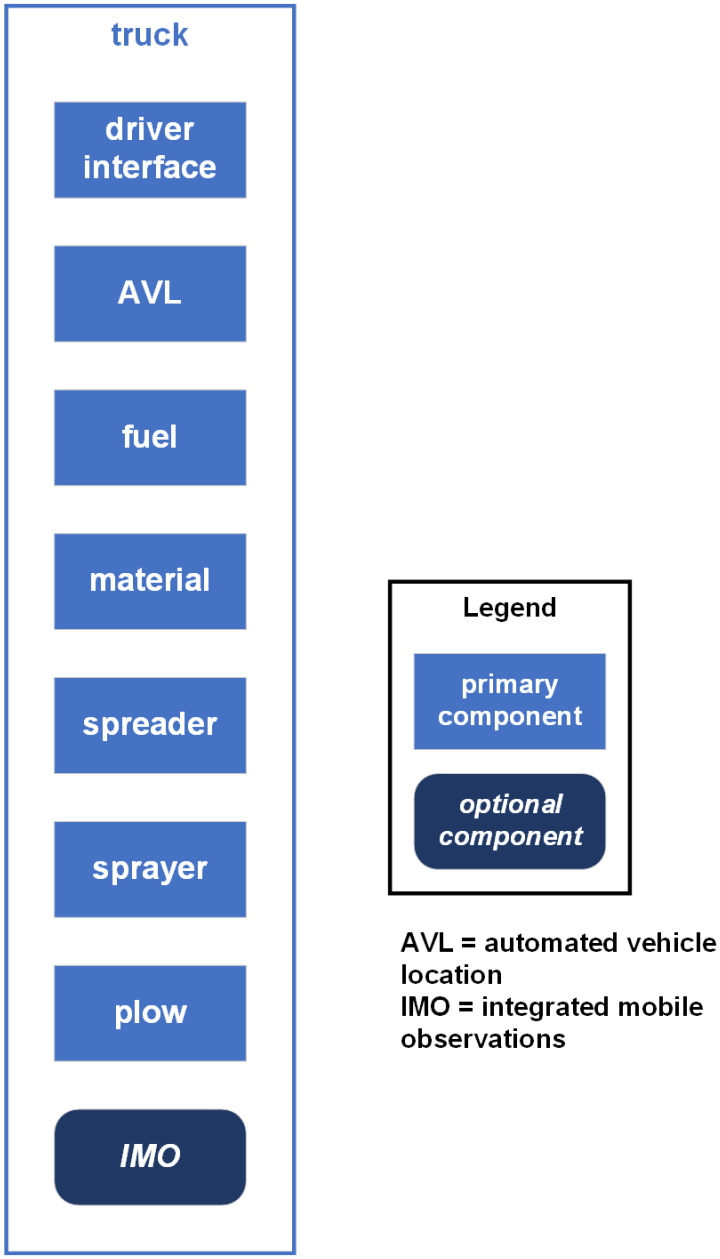
ESS = environmental sensor station. maint. = maintenance.
RWIS = road weather information system.

Source: FHWA.

Figure 2. Diagram. Winter maintenance system components with adaptive route optimization.

Figure 3 illustrates the winter maintenance components within a typical plow truck as they relate to an ARO deployment. Components in the plow truck may be affected by ARO beyond current practices, to the extent that:

- An automated vehicle location (AVL) system is needed for ARO to provide dynamic updates of vehicle location and route status.
- A driver interface is needed to provide the update routes and turn-by-turn recommendations to the drivers.



Source: FHWA.

Figure 3. Diagram. Winter maintenance system plow truck detail with adaptive route optimization.

Stakeholders

Figure 1 shows user interactions in winter maintenance with an ARO system. User roles are identical to those in current winter maintenance practices, except that their interactions with routing activities will be more dynamic throughout a winter maintenance event than they are with static routing.

System Functions

The desired characteristics of an ARO system can be enumerated as sets of needs and attributes to be addressed by the system. These can be categorized as functional, interface, performance, and nonfunctional needs; attributes; and constraints.

Functional Needs

Functional needs describe what the system needs to do, or enable users to do, to adaptively optimize snowplow routes:

1. The system needs to enable maintenance managers to set maintenance operations objectives (e.g., level of service and cycle time).
2. The system needs to enable maintenance managers to allocate maintenance resources (e.g., vehicles, drivers, facilities, materials) for State, county, and municipal agencies:
3. To and among agency service areas.
4. Within service areas to and among maintenance facilities.
5. The system needs to monitor atmospheric weather conditions (e.g., precipitation type and rates, and temperature).
6. The system needs to monitor traffic conditions (e.g., incidents, work zones, closures, and traffic speeds and volumes).
7. The system needs to assess road weather conditions (e.g., pavement status, pavement temperature, and friction).
8. The system needs to monitor maintenance vehicles in route (i.e., to receive telematics data [e.g., latitude and longitude] from those vehicles).
9. The system needs to optimize routes to changing road weather conditions.
10. The system needs to optimize routes to changing traffic conditions.
11. The system needs to provide optimized routes to maintenance vehicle drivers in near realtime.

Interface Needs

Interface needs describe the interfaces by which the system exchanges information with users and other systems. To adaptively optimize snowplow routes:

12. The system needs a means of specifying maintenance operations objectives.
13. The system needs a means of specifying the extent of the road network over which routing is to be performed.
14. The system needs a means of specifying maintenance resources.

15. The system needs sources of atmospheric weather condition information. The system needs sources of atmospheric weather condition forecasts(e.g., precipitation type and rates, and temperature).
16. The system needs sources of traffic condition information.
17. The system needs sources of historic operations data (e.g., crash data and recurring problem areas).
18. The system needs sources of road weather condition information.
19. The system needs sources of road weather condition forecasts(e.g., pavement status, pavement temperature, and friction).
20. The system needs sources of vehicle geo-position information.
21. The system needs a means of communicating between the traffic management (or operations) center and the maintenance vehicle.
22. The system needs a means of presenting route information to the maintenance vehicle driver (i.e., a driver interface) in realtime.

Performance Needs

Performance needs describe any limitations or constraints on the functions the system is to provide. To adaptively optimize snowplow routes:

23. The system needs to provide optimized routes fast enough to be implemented in route.

Nonfunctional Needs

Nonfunctional needs describe general attributes of the system. These needs may lead to more explicit requirements as the system is further specified. To adaptively optimize snowplow routes:

24. The system needs to be reliable.
25. The system needs to implement open data specifications drawn from technology standards to the extent that such standards exist and are applicable.
26. The system needs to be able to integrate with other State DOT maintenance and operations systems.
27. The system needs to be deployable without excessive customization to accommodate external interfaces.
28. The system needs to be flexible to provide deployment options consistent with, for example, agency institutional and contractual arrangements, policies, and resource management schemes.

System Attributes

System attributes describes the attributes of the system that may be needed to accommodate other needs. To adaptively optimize snowplow routes:

29. The system needs to have secure communications between operations center(s) and maintenance vehicles.
30. The system needs to have sufficient computing power to meet performance needs.

System Constraints

System constraints describe limitations placed on the system or its operations by users or other systems. To adaptively optimize snowplow routes:

31. The system needs its driver interface(s) (need 21) to comply with agency policies for in-vehicle use.

Table 1 summarizes expectations for the level of preroute and in-route adaptive optimization in response to changing conditions.

Table 1. Adaptive optimization response for changing conditions.

Changing Conditions	Strategic (Preroute) Optimization (From the Base-Optimized Routings)	Tactical (In-Route) Optimization
Objectives		
Level of service	Network	N/A
Cycle time	Network	N/A
Speed recovery	Network	N/A
Resources		
Vehicles	Network	Route
Plow implements	Network	Route
Drivers	Network	Route
Treatment material	Network	Route
Fuel	Network	Route
Weather and road conditions		
Weather conditions	Network	Network or route (e.g., microclimates and geometries)
Pavement state (precipitation accumulation)	Network	Network or route
Traffic congestion (speed)	Network	Route
Incident	Network or route (depending on severity, e.g., rockslide)	Route

CHAPTER 2. SPECIFIC REQUIREMENTS

This SyRS is the result of a survey of the current state of practices, a definition of needs, a concept of operations for the system, and an analysis of the requirements needed to fulfill the concept. The specific requirements laid out in this chapter are organized around high-level functional capabilities.

Requirements are assigned unique identifications to assure traceability. Requirements describe what the system shall do when implemented. Notes on the basis for the requirement may be provided if they offer additional information that clarifies the intent. Identifying related needs or requirements provides traceability to the high-level needs and parent requirements.

Requirement types are identified in a suffix to the identifier and may be:

- F: Functional
- I: Interface
- P: Performance
- S: Security
- D: Data
- R: Reliability

Requirements that may not be needed in all ARO system implementations are indicated in the text of the requirement as "(optional)."

The organization of requirements is as follows:

Table 2 identifies requirements for managing maintenance objectives.

Table 3 identifies requirements for managing maintenance resources.

Table 4 identifies requirements for monitoring atmospheric weather conditions.

Table 5 identifies requirements for monitoring road weather conditions.

Table 6 identifies requirements for managing road weather treatment plans.

Table 7 identifies requirements for monitoring traffic conditions.

Table 8 identifies requirements for monitoring maintenance vehicle operations.

Table 9 identifies requirements for managing road network configurations.

Table 10 identifies requirements for managing maintenance routes.

Table 11 identifies requirements for optimizing routes.

Table 12 identifies requirements for providing routes.

Table 13 identifies requirements for managing performance indicators.

Table 14 identifies requirements for map-based presentation.

Table 15 identifies requirements for reporting.

Table 16 identifies general system requirements.

Table 2. Requirements for managing maintenance objectives.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMO-01-F	The system shall track maintenance objectives.	-	Need-01
MMO-02-D	The system shall include a maintenance objective type for cycle time.	-	MMO-01-F
MMO-03-D	The system shall include a maintenance objective type for level of service (i.e., for the pavement surface conditions).	-	MMO-01-F
MMO-04-D	The system shall include a maintenance objective type for speed recovery.	-	MMO-01-F
MMO-05-D	The system shall include a maintenance objective type for weather hot spots.	-	MMO-01-F
MMO-06-D	The system shall include a maintenance objective type for crash hot spots.	-	MMO-01-F
MMO-07-D	The system shall include a maintenance objective type for driver time.	-	MMO-01-F
MMO-08-D	The system shall include a maintenance objective type for fuel cost.	-	MMO-01-F
MMO-09-D	The system shall include a maintenance objective type for material usage through a storm.	-	MMO-01-F
MMO-10-D	The system shall associate a maintenance objective type to a road network link.	-	MMO-01-F
MMO-11-D	The system shall associate a maintenance objective value for a type and road network link.	-	MMO-01-F
MMO-12-D	The system shall associate a maintenance objective priority with a type and road network link.	-	MMO-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMO-13-I	The system shall provide a user interface for setting maintenance objectives.	-	Need-10
MMO-14-S	The system shall enable only authorized users to set maintenance objectives.	-	MMO-13-F
MMO-15-F	The system shall enable authorized users to set a maintenance objective type, value, and priority for a set of road network links.	-	MMO-13-F
MMO-16-I	The system shall provide a map-based means of selecting a set of road network links to which a maintenance objective applies.	-	MMO-13-F
MMO-17-I	The system shall provide a map-based means of displaying which maintenance objective types apply to particular road network links.	-	MMO-13-F

- = no basis specified.

Table 3. Requirements for managing maintenance resources.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMR-01-F	The system shall monitor maintenance resources.	On dashboard; an application programming interface to an asset mgmt. system.	Need-02
MMR-02-F	The system shall monitor maintenance resources for a service area.	-	Need-02a
MMR-03-F	The system shall monitor maintenance resources available at maintenance facilities within a service area.	-	Need-02b
MMR-04-D	The system shall associate a location with each maintenance facility.	-	MMR-03-F
MMR-05-D	The system shall include a resource type for maintenance personnel.	-	MMR-03-F
MMR-06-D	The system shall include a resource type for maintenance vehicles.	-	MMR-03-F
MMR-07-D	The system shall include a resource type for snowplows.	-	MMR-03-F
MMR-08-D	The system shall include a front plow type.	-	MMR-07-F
MMR-09-D	The system shall include an underbelly plow type.	-	MMR-07-F
MMR-10-D	The system shall include a wing plow type.	-	MMR-07-F
MMR-11-D	The system shall include a rotary plow type.	-	MMR-07-F
MMR-12-D	The system shall include a tow plow type.	-	MMR-07-F
MMR-13-D	The system shall include an effective plow width for each type.	-	MMR-07-F
MMR-14-D	The system shall include a resource type for spreaders.	-	MMR-07-F
MMR-15-D	The system shall include a resource type for spreader materials.	-	MMR-03-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMR-16-D	The system shall include a resource type for sprayers.	-	MMR-03-F
MMR-17-D	The system shall include a resource type for sprayer materials.	-	MMR-03-F
MMR-18-D	The system shall include a resource type for fuel.	-	MMR-03-F
MMR-19-D	The system shall associate maintenance vehicles to maintenance facilities.	-	MMR-03-F
MMR-20-D	The system shall associate maintenance personnel to maintenance facilities.	-	MMR-03-F
MMR-21-D	The system shall associate maintenance personnel to maintenance vehicles.	-	MMR-03-F
MMR-22-D	The system shall associate spreader material inventory with date and time to maintenance facilities.	-	MMR-03-F
MMR-23-D	The system shall associate sprayer material inventory with date and time to maintenance facilities.	-	MMR-03-F
MMR-24-D	The system shall associate fuel inventory with date and time to maintenance facilities.	-	MMR-03-F
MMR-25-D	The system shall associate snowplows of particular types to maintenance vehicles.	-	MMR-06-F
MMR-26-D	The system shall associate spreaders to maintenance vehicles.	-	MMR-06-F
MMR-27-D	The system shall associate sprayers to maintenance vehicles.	-	MMR-06-F
MMR-28-D	The system shall associate spreader material inventory with date and time to maintenance vehicles.	-	MMR-06-F
MMR-29-D	The system shall associate sprayer material inventory with date and time to maintenance vehicles.	-	MMR-06-F
MMR-30-D	The system shall associate fuel inventory with date and time to maintenance vehicles.	-	MMR-06-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMR-31-I	The system shall provide a user interface for allocating resources to maintenance facilities and maintenance vehicles with which the resources are associated.	-	Need-02b
MMR-32-S	The system shall enable only authorized supervisors to allocate resources.	-	MMR-02-F
MMR-33-I	The system shall enable an authorized supervisor to request additional resources for a service area.		MMR-02-F
MMR-34-I	The system shall enable an authorized supervisor to offer resources to another service area.	-	MMR-02-F
MMR-35-I	The system shall enable an authorized supervisor to accept resources from another service area.	-	MMR-02-F
MMR-36-F	The system shall adjust resource inventory levels in the offering and accepting service areas.	-	MMR-02-F
MMR-37-I	The system shall provide a map-based means of selecting maintenance facilities and maintenance vehicles to which resources are being allocated.	-	MMR-03-F
MMR-38-I	The system shall provide a means of displaying resource allocations to maintenance facilities and maintenance vehicles.	-	MMR-03-F
MMR-39-I	The system shall provide indications of total resource allocations across the network on a dashboard.	-	MMR-01-F

- = no basis specified.

Table 4. Requirements for monitoring atmospheric weather conditions.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MAW-01-F	The system shall monitor atmospheric weather conditions.	It cannot be assumed that all potential user agencies will have access to alternative weather monitoring and forecast services.	Need-03
MAW-02-I	The system shall acquire atmospheric weather condition information in its native source format.	-	Need-13
MAW-03-I	The system shall acquire atmospheric weather condition forecasts in their native source formats.	-	Need-14
MAW-04-F	The system shall monitor atmospheric weather conditions in near real time.	-	MAW-01-F
MAW-05-F	The system shall monitor current ground-level air temperature.	-	MAW-01-F
MAW-06-F	The system shall monitor current ground-level precipitation rate.	-	MAW-01-F
MAW-07-F	The system shall monitor current ground-level precipitation type.	-	MAW-01-F
MAW-08-F	The system shall monitor current ground-level wind speed.	-	MAW-01-F
MAW-09-F	The system shall monitor current ground-level wind direction.	-	MAW-01-F
MAW-10-F	The system shall monitor current ground-level wind gust speed.	-	MAW-01-F
MAW-11-F	The system shall monitor forecast ground-level air temperature.	-	MAW-03-F
MAW-12-F	The system shall monitor forecast ground-level precipitation rate.	-	MAW-03-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MAW-13-F	The system shall monitor forecast ground-level precipitation type.	-	AW-03-F
MAW-14-F	The system shall monitor forecast ground-level wind speed.	For blowovers and blowing snow potential.	AW-03-F
MAW-15-F	The system shall monitor forecast ground-level wind direction.	For blowovers and blowing snow potential.	AW-03-F
MAW-16-F	The system shall monitor forecast ground-level wind gust speed.	For blowovers and blowing snow potential.	AW-03-F
MAW-17-F	The system shall monitor National Weather System alerts.	-	AW-03-F
MAW-18-I	The system shall provide a user interface for viewing atmospheric weather conditions.	-	AW-01-F
MAW-19-I	The system shall provide a map-based means of viewing atmospheric weather conditions.	-	AW-18-I

- = no basis specified.

Table 5. Requirements for monitoring road weather conditions.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MRW-01-F	The system shall monitor road weather conditions.	-	Need-05
MRW-02-I	The system shall acquire road weather condition information in its native source format.	-	Need-17
MRW-03-I	The system shall acquire road weather condition forecasts in their native source formats.	-	Need-18
MRW-04-I	The system shall be able to acquire thermal maps of pavement temperatures.	-	MRW-02-I
MRW-05-F	The system shall monitor road weather conditions for the service areas in near real time.	-	MRW-01-F
MRW-06-F	The system shall monitor current pavement temperatures for the service areas.	-	MRW-01-F
MRW-07-D	The system shall implement the NTCIP 1204 road weather condition data definitions.	-	Need-24
MRW-08-F	The system shall monitor current precipitation accumulations for the service areas.	-	MRW-01-F
MRW-09-F	The system shall monitor forecast pavement temperatures for the service areas.	-	MRW-01-F
MRW-10-F	The system shall monitor forecast road weather conditions for the service areas.	-	MRW-01-F
MRW-11-F	The system shall monitor forecast precipitation accumulations for the service areas.	-	MRW-01-F
MRW-12-I	The system shall provide a user interface for viewing road weather conditions.	-	MRW-01-F
MRW-13-I	The system shall provide a map-based means of viewing road weather conditions.	-	MRW-01-F

- = no basis specified.

Table 6. Requirements for managing road weather treatment plans.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
RWT-01-F	The system shall acquire road weather treatment plans.	-	Need-07
RWT-02-F	The system shall be able to acquire road treatment plans from user input.	Could be a default set of standard treatments input by a maintenance supervisor.	RWT-01-F
RWT-03-F	The system shall be able to acquire road treatment plans from agency policies and procedures.	-	RWT-01-F
RWT-04-F	The system shall be able to acquire road treatment plans from a maintenance decision support system in its native source format.	-	RWT-01-F Need-25
RWT-05-D	The system shall associate one or more treatment plan elements to a road network link.	-	RWT-01-F
RWT-06-D	The system shall include a treatment type for plowing.	-	RWT-01-F
RWT-07-D	The system shall include a treatment type for spreading.	-	RWT-01-F
RWT-08-D	The system shall include a spreading material.	-	RWT-01-F
RWT-09-D	The system shall include a spreader rate for the material.	-	RWT-01-F
RWT-10-D	The system shall include a treatment type for spraying.	-	RWT-01-F
RWT-11-D	The system shall include a spraying material.	-	RWT-01-F
RWT-12-D	The system shall include a spraying rate for the material.	-	RWT-01-F
RWT-13-D	The system shall include an estimated treatment travel speed.	-	RWT-01-F
RWT-14-D	The system shall include an earliest time for treatment for each plan element.	-	RWT-01-F
RWT-15-D	The system shall include a latest time for treatment for each plan element.	-	RWT-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
RWT-16-I	The system shall provide a user interface for specifying a treatment plan.	-	RWT-01-F
RWT-17-S	The system shall enable only authorized users to specify a treatment plan.	-	RWT-01-F
RWT-18-F	The system shall enable authorized users to specify a treatment plan for a set of road network links.	-	RWT-01-F
RWT-19-I	The system shall provide a map-based means of selecting a set of road network links to which a treatment plan applies.	-	RWT-01-F
RWT-20-I	The system shall provide a map-based means of displaying treatment plans specified for particular road network links.	-	RWT-01-F

- = no basis specified.

Table 7. Requirements for monitoring traffic conditions.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MTC-01-F	The system shall monitor traffic conditions.	-	Need-04
MTC-02-I	The system shall acquire traffic condition information in its native source format.	-	Need-15
MTC-03-I	The system shall acquire historic traffic condition information in its native source format.	-	Need-16
MTC-04-I	The system shall be able to acquire incident information in its native format from an incident alerting system.	-	MTC-02-I
MTC-05-F	The system shall monitor traffic conditions across all segments in the road network to be maintained.	-	MTC-01-F
MTC-06-F	The system shall monitor traffic conditions in realtime.	-	MTC-01-F
MTC-07-F	The system shall monitor traffic conditions including average traffic speed.	-	MTC-01-F
MTC-08-F	The system shall monitor traffic conditions including incident location.	-	MTC-01-F
MTC-09-F	The system shall monitor traffic conditions including lanes blocked.	-	MTC-01-F
MTC-10-F	The system shall monitor traffic conditions including incident clearance times.	-	MTC-01-F
MTC-11-I	The system shall be able to acquire work zone information in its native format from a work zone information system.	-	MTC-02-I
MTC-12-F	The system shall monitor traffic conditions including work zone location.	-	MTC-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MTC-13-F	The system shall monitor work zone conditions including lanes blocked.	-	MTC-01-F
MTC-14-F	The system shall monitor work zone conditions including work zone start and end times.	-	MTC-01-F

- = no basis specified.

Table 8. Requirements for monitoring maintenance vehicle operations.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MMV-01-F	The system shall monitor maintenance vehicle operations.	-	Need-06
MMV-02-F	The system shall monitor maintenance vehicle operations in real time.	-	Need-06
MMV-03-I	The system shall acquire maintenance vehicle operations information in its native source format.	-	Need-06 Need-19
MMV-04-F	The system shall monitor vehicle location.	-	MMV-01-F
MMV-05-F	The system shall monitor vehicle speed.	-	MMV-01-F
MMV-06-F	The system shall monitor vehicle heading.	-	MMV-01-F
MMV-07-F	The system shall monitor plow status.	i.e., up or down.	MMV-01-F
MMV-08-F	The system shall monitor spreader status.	i.e., off or on.	MMV-01-F
MMV-09-F	The system shall monitor sprayer status.	i.e., off or on.	MMV-01-F
MMV-10-F	The system shall monitor spreader material inventory.	-	MMV-01-F
MMV-11-F	The system shall monitor sprayer material inventory.	-	MMV-01-F

- = no basis specified.

Table 9. Requirements for managing road network configurations.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MRN-01-F	The system shall manage road network configurations.	-	Need-11
MRN-02-D	The system shall include terminations at maintenance facilities.	-	MRN-01-F
MRN-03-D	The system shall include links.	-	MRN-01-F
MRN-04-D	The system shall associate a roadway class with each link.	-	MRN-01-F
MRN-05-D	The system shall include segments.	-	MRN-01-F
MRN-06-D	The system shall associate a length with each segment.	-	MRN-01-F
MRN-07-D	The system shall associate a number of lanes with each segment.	-	MRN-01-F
MRN-08-D	The system shall associate an average speed with each segment.	-	MRN-01-F
MRN-09-D	The system shall associate segments with links.	-	MRN-01-F
MRN-10-D	The system shall include connections between terminations and links.	Terminations are route beginning and end points.	MRN-01-F
MRN-11-D	The system shall include connections between links.	-	MRN-01-F
MRN-12-D	The system shall associate a connection with a link from which it connects.	-	MRN-01-F
MRN-13-D	The system shall associate a connection with a link to which it connects.	-	MRN-01-F
MRN-14-D	The system shall associate a connection with a radius through which the connection turns.	-	MRN-01-F
MRN-15-D	The system shall associate a connection with a typical delay in moving through the connection.	-	MRN-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MRN-16-D	The system shall associate a connection or termination with both ends of every link.	-	MRN-01-F
MRN-17-I	The system shall provide a user interface for specifying a road network configuration.	-	Need-11
MRN-18-I	The system shall provide a map-based means of viewing a road network configuration.	-	MRN-17-I

- = no basis specified.

Table 10. Requirements for managing maintenance routes.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MRM-01-D	The system shall manage routes.	-	Need-07
MRM-02-D	The system shall associate a route with a starting maintenance facility.	-	MRM-01-D
MRM-03-D	The system shall associate a route with an ending maintenance facility.	The system will consider a return to any maintenance facility as the end of their route when, for example, the vehicle is refueling or loading materials.	MRM-01-D
MRM-04-D	The system shall associate links with routes.	-	MRM-01-D
MRM-05-D	The system shall associate connections with routes.	-	MRM-01-D
MRM-06-D	The system shall associate a sequence of links and connections with a route.	-	MRM-01-D
MRM-07-D	The system shall associate maintenance vehicles with a route.	-	MRM-01-D
MRM-08-D	The system shall associate a route with a patrol.	-	MRM-01-D
MRM-09-D	The system shall associate maintenance vehicles with a patrol.	-	MRM-01-D
MRM-10-I	The system shall provide a user interface for viewing routes.	-	MRM-01-D
MRM-11-I	The system shall provide a map-based means of viewing routes.	-	MRM-10-I
MRM-12-I	The system shall provide a text-based means of viewing routes.	-	MRM-10-I

- = no basis specified.

Table 11. Requirements for optimizing routes.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
ORR-01-F	The system shall optimize routes.	-	Need-07 Need-08
ORR-02-F	The system shall optimize routes within a service area when initiated by an authorized supervisor for that service area.	This provides the base case routing. There has to be a base case of drivers, vehicles, road network, treatments, and start/end points to generate the base case routes. Subsequent requirements define the triggers (changes in those bases) that initiate new route optimization.	ORR-01-F
ORR-03-F	The system shall optimize routes for the affected portion of the network when a level of service objective is changed.	-	ORR-01-F
ORR-04-F	The system shall optimize routes for the affected portion of the network when a cycle time objective is changed by more than a configurable time increment.	-	ORR-01-F
ORR-05-F	The system shall optimize routes once every cycle after maintenance operations have begun for the affected portion of the network when observed link speeds averaged over a configurable time interval are more than a configurable speed increment below the speed recovery objective value.	The intent of this requirement is to initiate a reoptimization for the next maintenance cycle when the speeds observed in the previous cycle are still lower than speed recovery objective.	Need-08
ORR-06-F	The system shall optimize routes for the affected portion of the network when planned treatment material application rates are changed by more than a configurable amount.	-	Need-07

Identifier	Requirement	Basis	Related Need or Requirement Identifier
ORR-07-F	The system shall optimize routes for the affected portion of the network when the number of maintenance vehicles being deployed for treatment changes.	-	ORR-01-F
ORR-08-F	The system shall optimize routes after maintenance operations have begun for the affected portion of the network when incidents closing one lane or more occur on a segment.	-	Need-08
ORR-09-F	The system shall find the set of routes that covers all links in the network, while meeting the specified maintenance objective priorities, subject to current resource availabilities and operational constraints on all segments.	-	ORR-01-F
ORR-10-P	The system shall optimize routes after maintenance operations have begun within a configurable interval of the initiating optimization trigger.	-	Need-22
ORR-11-P	The system shall not begin a new optimization computation until any prior optimization computation over the same affected portion of the network has been completed.	-	Need-22
ORR-12-F	The system shall optimize routes after maintenance operations have begun for the affected portion of the network when a vehicle goes off its assigned route.	-	ORR-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
ORR-13-I	The system shall provide an interface to enable a supervisor to initiate a route optimization.	-	ORR-02-F
ORR-14-I	The system shall provide an interface to enable a supervisor to provide a rationale for initiating a route optimization.	-	ORR-02-F

- = no basis specified.

Table 12. Requirements for providing routes.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
PRR-01-F	The system shall provide optimized routes to drivers in realtime.	-	Need-09
PRR-02-F	The system shall include a means of communicating between the adaptive route optimization service and the maintenance vehicle.	The particular means of communication is left to the system implementation. It might, for example, use a cellular data connection.	Need-20
PRR-03-I	The system shall provide an interface for drivers to accept or decline a routing plan.	-	PRR-01-F
PRR-04-F	The system shall require a driver to accept or decline a routing plan when it is received.	-	PRR-01-F
PRR-05-F	The system shall keep the prior active routing plan for a vehicle if the driver declines or does not accept a new routing plan.	A driver may not be able to explicitly accept or decline a new routing, in which case it is presumed that the prior active routing plan is still active.	PRR-01-F
PRR-06-F	The system shall replace the prior routing plan with the new active plan if the driver accepts a new routing plan.	-	PRR-01-F
PRR-07-I	The system shall provide an interface for an authorized driver to submit a request for assistance.	-	PRR-01-F
PRR-08-D	The assistance request shall include an assistance request type.	-	PRR-07-I
PRR-09-D	The system shall include an assistance request type for vehicle out-of-service.	-	PRR-07-I
PRR-10-D	The system shall include an assistance request type for a blocked route.	The assigned route might be blocked by, for example, a landslide, avalanche, or downed tree.	PRR-07-I
PRR-11-D	The system shall include an assistance request type for weather conditions worse than expected.	-	PRR-07-I

Identifier	Requirement	Basis	Related Need or Requirement Identifier
PRR-12-D	The system shall include an assistance request type for pavement conditions worse than expected.	-	PRR-07-I
PRR-13-D	The assistance request shall include a number of vehicles being requested, from 0 to N.	-	PRR-07-I
PRR-14-D	The assistance request shall include a type of material being requested.	-	PRR-07-I
PRR-15-D	The assistance request shall include an amount of material being requested.	-	PRR-07-I
PRR-16-D	The assistance request interface shall include a means of clearing the request.	-	PRR-07-I
PRR-17-D	The assistance request interface shall include a means of submitting the request.	-	PRR-07-I
PRR-18-F	The system shall send the assistance request to the adaptive routing service when submitted by the driver.	-	PRR-07-I
PRR-19-F	The system shall send an assistance request for additional vehicles to vehicles within a configurable vicinity of the requesting vehicle.	-	PRR-07-I
PRR-20-I	The system shall enable authorized drivers to accept assistance requests for additional vehicles.	“Assistance” in this context is a request for a vehicle to be added to a service area’s inventory of vehicles, as specified in table 3.	PRR-07-F
PRR-22-F	The system shall enable authorized drivers to decline requests for assistance.	-	PRR-07-F
PRR-23-F	The system shall inactivate an assistance request for additional vehicles if no response from authorized drivers is received within a configurable time interval.	-	PRR-07-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
PRR-24-F	The system shall optimize routes for the affected portion of the network when the allocation of maintenance vehicles being deployed for treatment changes in response to a request for assistance.	-	PRR-07-F
PRR-25-F	The system shall request authorized supervisors to approve assignment of drivers and vehicles from one service area to another.	-	PRR-07-F
PRR-26-I	The system shall provide optimized routes to drivers through an in-vehicle navigation map.	-	Need-21
PRR-27-I	The system shall provide optimized routes through turn-by-turn audio instructions.	-	Need-21
PRR-28-I	The system shall enable the driver to turn off the turn-by-turn audio instructions.	-	PRR-26-I
PRR-29-I	The system shall provide locations of incidents on the in-vehicle navigation map.	-	PRR-26-I
PRR-30-I	The system shall provide locations of work zones on the in-vehicle navigation map.	-	PRR-26-I

- = no basis specified.

Table 13. Requirements for managing performance indicators.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MPI-01-F	The system shall compute maintenance performance indicators corresponding to maintenance objectives.	-	Need-01
MPI-02-F	The system shall compute cycle time for each maintenance vehicle at the end of each cycle.	-	MPI-01-F
MPI-03-F	The system shall compute average cycle time for all maintenance vehicles in a service area after the last route in the service area has been completed for the cycles executed for a storm.	-	MPI-01-F
MPI-04-F	The system shall compute a percentage of links within a service area meeting their level of service objective after the last route in the service area has been completed for the cycles executed for a storm.	-	MPI-01-F
MPI-05-F	The system shall compute a percentage of links within a service area meeting their speed recovery objective after the last route in the service area has been completed for the cycles executed for a storm.	-	MPI-01-F
MPI-06-F	The system shall compute a treatment completion status for each hot spot based on whether or not treatment has been completed for that location.	-	MPI-01-F
MPI-07-I	The system shall display performance indicators on a dashboard interface.	-	MPI-01-F

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MPI-08-I	The system shall enable an authorized user to set the start and end times of a storm for which performance indicators will be computed.	Authorized users might be supervisors or higher-level regional or statewide management.	MPI-01-F
MPI-09-I	The system shall enable an authorized user to associate a label with a storm for which performance indicators will be computed.	-	MPI-01-F

- = no basis specified.

Table 14. Requirements for map-based presentation.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MAP-01-I	The system shall provide a map-based means of viewing maintenance activities.	-	Needs-NEW
MAP-02-I	The system shall provide selectable layers for viewing on the map.	-	MAP-01-I
MAP-03-I	The system shall include routes as a layer on the map.	-	MRM-10-I
MAP-04-I	The system shall include maintenance vehicle locations as a layer on the map.	-	MAP-01-I
MAP-05-I	The system shall include maintenance vehicle locations with active assistance requests as a layer on the map.	-	MAP-01-I
MAP-06-I	The system shall include facility locations as a layer on the map.	-	MAP-01-I
MAP-07-I	The system shall include maintenance area boundaries as a layer on the map.	-	MAP-01-I
MAP-08-I	The system shall include maintenance region boundaries as a layer on the map.	-	MAP-01-I
MAP-09-I	The system shall include state boundaries as a layer on the map.	-	MAP-01-I
MAP-10-I	The system shall include incidents as a layer on the map.	-	MAP-01-I
MAP-11-I	The system shall include work zones as a layer on the map.	-	MAP-01-I
MAP-12-I	The system shall include atmospheric weather conditions as layers on the map.	-	AW-18-I
MAP-13-I	The system shall include ground-level air temperature as a layer on the map.	-	MAP-01-I
MAP-14-I	The system shall include ground-level precipitation rate as a layer on the map.	-	MAP-01-I

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MAP-15-I	The system shall include ground-layer precipitation type as a layer on the map.	-	MAP-01-I
MAP-16-I	The system shall include ground-level wind speed as a layer on the map.	-	MAP-01-I
MAP-17-I	The system shall include ground-level wind direction as a layer on the map.	-	MAP-01-I
MAP-18-I	The system shall include ground-level wind gust speed as a layer on the map.	-	MAP-01-I
MAP-19-I	The system shall include forecast ground-level air temperature as a layer on the map.	-	MAP-01-I
MAP-20-I	The system shall include forecast ground-level precipitation rate as a layer on the map.	-	MAP-01-I
MAP-21-I	The system shall include forecast ground-level precipitation type as a layer on the map.	-	MAP-01-I
MAP-22-I	The system shall include forecast ground-level wind speed as a layer on the map.	-	MAP-01-I
MAP-23-I	The system shall include forecast ground-level wind direction as a layer on the map.	-	MAP-01-I
MAP-24-I	The system shall include forecast ground-level wind gust speed as a layer on the map.	-	MAP-01-I
MAP-25-I	The system shall include National Weather System alerts as a layer on the route map.	-	MAP-01-I
MAP-26-I	The system shall include thermal maps as a layer on the map.	-	MRW-04-I
MAP-27-I	The system shall include road weather conditions as layers on the map.	-	MRW-13-I

Identifier	Requirement	Basis	Related Need or Requirement Identifier
MAP-28-I	The system shall include pavement temperature as a layer on the map.	-	MAP-01-I
MAP-29-I	The system shall include road weather conditions as a layer on the map.	-	MAP-01-I
MAP-30-I	The system shall include precipitation accumulation as a layer on the map.	-	MAP-01-I
MAP-31-I	The system shall include forecast pavement temperature as a layer on the map.	-	MAP-01-I
MAP-32-I	The system shall include forecast road weather conditions as a layer on the map.	-	MAP-01-I
MAP-33-I	The system shall include forecast precipitation accumulation as a layer on the map.	-	MAP-01-I
MAP-34-I	The system shall include material application as a layer on the map.		RWT-01-F
MAP-35-I	The system shall enable a user to zoom into and out of the map.	-	MAP-01-I
MAP-36-I	The system shall enable a user to pan across the map.	-	MAP-01-I
MAP-37-I	The system shall enable a user to select a reference time for viewing the map.	-	MAP-01-I
MAP-38-I	The system shall enable a user to select a reference time based on a storm label for viewing the map.	-	MAP-01-I
MAP-39-I	The system shall enable a user to play back conditions by a configurable auto-increment of the reference time of the map view.	-	MAP-01-I

- = no basis specified.

Table 15. Requirements for reporting.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
REC-01-F	The system shall maintain records of all information acquired by the system.	-	Need-07 Need-08
REC-02-F	The system shall maintain records of all routing optimization computations performed by the system.	-	REC-01-F
REC-03-F	The system shall maintain records of all inputs to routing optimization computations performed by the system.	-	REC-01-F
REC-04-F	The system shall maintain records of all routing plans generated by the system.	-	REC-01-F
REC-05-F	The system shall maintain records of driver requests for assistance.	-	REC-01-F
REC-06-F	The system shall maintain records of driver responses to requests for assistance.	-	REC-01-F
REC-07-F	The system shall maintain records of distributions of routing plans.	-	REC-01-F
REC-07-F	The system shall maintain records of resource reassignments.	-	REC-01-F
REC-08-I	The system shall enable users to view records of routing plans generated by the system.	-	REC-01-F
REC-09-I	The system shall provide an interface for users to generate a report of routing plans.	-	REC-08-I
REC-10-I	The system shall provide an interface for users to view maintenance objectives and performance measures.	-	REC-08-I

Identifier	Requirement	Basis	Related Need or Requirement Identifier
REC-11-I	The system shall provide an interface for users to generate a report of maintenance objectives and performance measures.	-	REC-08-I
REC-12-I	The system shall be able to render reports as PDF files.	-	REC-08-I
REC-13-I	The system shall be able to render reports as Microsoft Word files.	-	REC-08-I
REC-14-I	The system reports of routing plans shall include triggers for route generation.	-	REC-09-I
REC-15-I	The system reports of routing plans shall include routes.	-	REC-09-I
REC-16-I	The system reports of routes shall include cycle times associated with routes.	-	REC-09-I
REC-17-I	The system reports of routes shall include vehicles associated with routes.	-	REC-09-I
REC-18-I	The system reports of routes shall include material usage associated with routes.	-	REC-09-I
REC-19-I	The system reports of routes shall include incidents along routes.	-	REC-09-I
REC-20-I	The system reports of routes shall include work zones along routes.	-	REC-09-I
REC-21-I	The system reports of routes shall include assistance requests associated with routes.	-	REC-09-I
REC-22-I	The system reports of routes shall include types of assistance requests associated with routes.	-	REC-09-I

- = no basis specified.

Table 16. General system requirements.

Identifier	Requirement	Basis	Related Need or Requirement Identifier
GEN-01-S	The system shall secure communications between operations center(s) and maintenance vehicles.	-	Need-28
GEN-02-R	The system shall be available 99.9% of the time between configurable start and end dates corresponding to the winter operations season.	-	Need-23
GEN-03-R	The system shall have sufficient computing power to meet its performance requirements for a configurable fraction of optimization computations.	-	Need-29
GEN-04-I	The system shall comply with agency requirements and constraints on in-vehicle user interfaces.	-	Need-30
GEN-05-I	The system interfaces shall be accessible through a web browser.	-	Need-26 Need-27
GEN-06-S	The system web interfaces shall use hypertext transfer protocol secure for information exchange with the system web services.	-	GEN-01-S
GEN-07-D	The system design shall not preclude the addition of new data elements associated with existing data types.	-	Need-24 Need-25 Need-26
GEN-08-D	The system design shall not preclude the addition of new data collectors for existing data types.	-	Need-24 Need-25 Need-26

- = no basis specified.

CHAPTER 3. ASSUMPTIONS AND DEPENDENCIES

The ARO system will need detailed maps on which to base its optimized routes. Maintenance vehicles may use roadways and parking surfaces that are not otherwise included in navigation maps as turnarounds for maintenance routing. Multilane roads will require a vehicle to pass along each lane, and the number of lanes may vary from one segment to the next along the length of a network link.

The ARO system needs extensive data resources to optimize routes. A lack of data to feed the optimization methods may compromise the accuracy and quality of the routing or limit its application with particular management objectives. For example, setting and measuring against a maintenance objective based on material usage necessitates having material usage specifications from a treatment plan and on monitoring material usage by vehicles as they apply the treatments. Adaptively optimizing routes to changing weather conditions after vehicles are in route necessitates having information about route history and real-time positions of the vehicles for which routes are to be reoptimized.

The ARO system needs information on maintenance resources to optimize routes. Information on assets such as maintenance vehicles, plows, and drivers may limit the number of routes than can simultaneously be operating on the road network. Information on consumable resources such as salt, brine mixtures, or fuel may affect route length and intermediate service stops within a cycle. Agencies may have other maintenance management systems already monitoring these resources. The ARO system could in those cases use an application programming interface (API) to access the data in a maintenance management system. Other cases might need a maintenance manager or supervisor to provide those asset and consumables inventories directly to the ARO system.

The ARO needs information on plowing and treatment for all links in the road network. Some agencies will make treatment plans based on experience and procedures specific to the expected storm characteristics. Other agencies may have established treatment plans that address forecast weather conditions such as pavement temperature and precipitation rates at locations across the road network. Such locations may be associated with road weather information system sites that may be used to monitor pavement conditions through the course of the storm and maintenance activities. Some agencies may have an MDSS that uses weather forecasts and real-time measurements to recommend treatments across the road network and monitor the results of the treatment. The ARO system may then be able to use an API to access those treatment plans as part of its route optimization inputs.

The ARO needs information on maintenance vehicle operations to monitor treatment progress and vehicle locations for tactical adaptive reoptimization. An AVL system that provides real-time operations data from the vehicle to the back office ARO system would fulfill this need. An AVL API would then provide the information to the ARO system.

The ARO system needs reliable communications between the vehicle and back-office components to get AVL data and to provide tactical routing results for the vehicle operator. The

frequency and latency of the AVL data and the routing messages may affect the quality and usefulness of the routing results.

The ARO system needs an in-vehicle interface for providing navigation instructions to the operator. Agency practices on providing in-vehicle navigation and maintenance systems vary widely. An ARO system deployment may need an interface to an existing in-vehicle system or a dedicated in-vehicle device to provide navigation instructions.

CHAPTER 4. REFERENCES

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