

Synthesis of Technical Requirements and Considerations for Automated Snowplow Route Optimization

Final Report



research for winter highway maintenance

University of Vermont

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CHAPTER 1: INTRODUCTION

Planning for snow and ice control (SIC) activities on the roadways before, during, and after winter storms involves complicated decisions about the staging and routing of winter maintenance vehicles (“snowplows”) that are responsible for plowing and spreading chemicals and abrasives. DOTs and other transportation agencies are increasingly exploring automated methods for snowplow route optimization as a means for increasing the efficiency of these staging, plowing, and spreading operations. Route optimization projects have been demonstrated to produce significant savings for transportation agencies when they result in the implementation of new routes.

However, many snowplow route optimization projects have fallen short of implementation. Interviews conducted with DOT staff in this project identified two types of challenges that prevent route optimization results from being implemented. These challenges are:

1. technical/operational issues with the final optimized routes make them unsafe or infeasible to implement, and
2. institutional barriers to change that prevent optimized routes that are safe and technically feasible from being implemented.

These challenges can be substantially mitigated with improvements to the process of soliciting, selecting, and managing the route optimization software or service provider. The purpose of this project is to provide DOTs with the tools required to make these improvements. These tools allow DOT staff to have a clear understanding of the technical requirements that must be met to conduct a route optimization project that produces safe, feasible routes as well as to understand the institutional barriers to changes that can prevent implementation so they can be proactive in addressing these concerns. The key lessons from this project are provided in two complementary documents: a Decision Support Guidance and a Contracting Language Template.

The Decision Support Guidance Document (Appendix A) provides DOT staff with an accessible and in-depth discussion of the technical requirements for route optimization and the key decisions DOTs should consider when developing the project scope. This document will also be instrumental in assisting DOT staff with the management of the route optimization service provider as the work progresses. The Contracting Document (Appendix B) provides DOTs with a flexible template to assist with the development of RFPs for automated snowplow route optimization. The language suggested in the Contracting document is intended to ensure that DOTs and service providers have a shared understanding of the scope of work that the DOT requires and to maximize the likelihood that the project will result in safe, feasible, implementation-ready routes.

The Guidance and Contracting documents cover the following key topics:

1. Optimization Purpose: What is the *primary* purpose of the project, to reduce costs or to reduce service time?
2. Optimization Scope: What components of winter maintenance operations (e.g. facility locations, service territory boundaries, fleet allocation) can realistically be changed to improve performance, and what components should be considered fixed? Should multiple routing scenarios be considered? Should route optimization be conducted for a pilot region or the entire state?
3. Data Needs and Sources: What information is required to conduct a route optimization and where can it be obtained?
4. SIC Operational Practices: What winter maintenance practices (vehicle operating speeds, material spreading rates, etc.) need to be included in the route optimization?
5. Route Review Process: How are the routes produced by the optimization software reviewed to ensure they are safe and feasible?
6. Other Key Considerations: What are the indications that a route optimization project will improve on existing routes and that the results will be successfully implemented? Should the optimization be conducted in-house or by a consultant?

The body of this report documents the creation of the stand-alone Decision Support Guidance and Contracting Language Template. In the initial phase of this project, the research team conducted a review of recent snowplow route optimization reports and publicly available route optimization RFPs and surveyed transportation agencies on their experiences with route optimization. These tasks resulted in an initial database of winter maintenance agencies familiar with automated route optimization processes, a catalog of route optimization technical requirements already identified by transportation agencies, and a set of vendors, contractors, and consultants who provide optimization software or services. Thereafter the research team conducted in-depth interviews with six transportation agencies and four route optimization service providers. The lessons learned from these interviews formed the foundation for the draft Guidance and Contracting documents which were then reviewed by the project's Technical Advisory Committee (TAC) and by a set of vendors active in this area. The finalized

versions of these documents are provided in the Appendices of this report. DOT staff interested in snowplow route optimization are encouraged to start by reading the Decision Support Guidance.

1.1 REPORT ORGANIZATION

Chapter 2 of this report summarizes the review of recent route optimization reports and RFPs. Chapter 3 summarizes the online survey of winter maintenance agencies and efforts to identify the service providers working with each of these agencies. Chapter 4 present the results of the agency and vendor interviews. Note that Chapters 2 through 4 of this report parallel the deliverables for project Tasks 1 through 3 but have been modified slightly to enhance the continuity of this report.

Appendices A and B are the final Decision Support Guidance and Contracting Language Template incorporating feedback from the TAC and representatives of the three route optimization providers (C2Logix, Enera, Vaisala). These documents can be used to inform the setup and solicitation of a snowplow route optimization project. Following the recommendations in the documents will enable DOTs to avoid known pitfalls with snowplow route optimization projects and increase the likelihood that their efforts will lead to improved winter maintenance operations.

CHAPTER 2: LITERATURE AND RFP REVIEW

This project began with a review of recent snowplow route optimization reports and publicly available route optimization RFPs. The review served three primary purposes: a) to develop an initial database of transportation agencies familiar with automated route optimization processes, b) to catalog route optimization technical requirements already identified by transportation agencies soliciting this work, and c) to identify vendors and consultants who provide optimization software or services.

The review builds on a previous Clear Roads research report that discussed in detail 10 snowplow route optimization projects that were completed in progress as of 2016 (Dowds et al., 2016). These earlier projects were conducted for the following agencies and jurisdictions:

- Indiana DOT
- MnDOT
- Ohio DOT
- VTrans
- Missouri DOT
- Centennial, Colorado
- PennDOT
- Edmonton, Alberta, Canada
- Dieppe, New Brunswick, Canada
- Colorado DOT

2.1 REVIEW OF RECENTLY COMPLETED ROUTE OPTIMIZATION EFFORTS

For this review, recent efforts at snowplow route optimization were identified that were targeted to or funded by the following agencies:

- Delaware Department of Transportation (Mingxin et. al., 2018)
- Wisconsin Department of Transportation (WisDOT, 2019; Nelson, 2018)
- The City of Chicago, Illinois (Xu et. al., 2017)
- Kentucky Transportation Cabinet (Blandford et. al., 2017)
- North Dakota Department of Transportation (NDDOT, 2018; Nelson, 2018)

The study undertaken for the Delaware Department of Transportation by the Delaware Center for Transportation at the University of Delaware was conducted as an academic research endeavor, so it is not clear if the results were implemented as new snowplow routes. The researchers used ArcGIS Network Analyst for Desktop to implement a statewide optimization of snowplow routes. Truck salt capacity was not considered, and it is not clear if realistic snowplow travel times were used, but a binary serviceability constraint was used to restrict certain vehicles from certain routes.

The Wisconsin Department of Transportation's Annual Winter Maintenance Report for 2017-2018 was also reviewed because it contained detailed information about the use of snowplow route optimization statewide. It was noted that C2Logix FleetRoute software is used in Wisconsin. Jim Hughes, the Chief

Maintenance Engineer for WisDOT, discussed the implementation of snowplow route optimization in Wisconsin in detail in a June 2018 episode of the SICOP podcast “SICOP Talks Winter Ops” (Nelson, 2018). He explained that each of Wisconsin’s 72 counties used to plow their own roads without crossing jurisdictional boundaries. The County Commissioner in Dane County (Madison) prompted WisDOT to start implementing snowplow route optimization. The goal of the effort was to reduce winter maintenance effort by allowing vehicles to provide services most efficiently. In Dane County, the number of routes was reduced from 76 to 55, mainly by combining state and county roads to be plowed by a single set of routes. He also pointed out that the efforts successfully balanced cycle times, and that WisDOT’s target is 2 to 2.5 hours for each cycle, which allows the salt or brine to dissolve and begin to work. The optimizations also allowed safer performance by reducing left turns in plow routes. The implementation used a maximum spreading rate of 300 lbs. per lane-mile of salt, and a plow speed of 32 mph. The efforts are reported to have resulted in savings of about \$185k per route per year. Approximately half of Wisconsin’s counties have had optimized snowplow routes developed.

The snowplow route optimization performed for Chicago, Illinois was conducted as an academic research endeavor using native scripting, so it contains less useful information for contracting these services (Xu et. al., 2017). The effort conducted for Kentucky was also targeted at reducing the number of routes with support by the Kentucky Transportation Center at the University of Kentucky. Researchers used ArcGIS Network Analyst for Desktop for the implementation of the vehicle-routing problem by assuming that salt is being delivered to road segments. Since the optimization was conducted by an academic research center, the lessons that can be learned from this contracting process may have limited generalizability.

North Dakota’s Department of Transportation performed a snow and ice control route optimization study which sought to reduce the number of routes, with more balanced cycle times amongst routes. C2Logix software was used for the study by a contracted consultant. The consultant analyzed current snowplow operations and determined the current cycle times being performed. Working with the consultant the department set up a team of Subject Matter Experts to establish the needed inputs for the optimization. The team consisted of representatives from the eight districts, the central office maintenance division, and the NDDOT executive office. North Dakota DOT’s Larry Gangl expanded on his state’s efforts in the SICOP podcast (Nelson, 2018). He explained that the study was prompted by the state legislature as a way to increase the efficiency of winter maintenance operations. He noted that it took several iterations to yield useful results, and one of the most important findings was to determine how many routes are needed for each garage’s service area. Their primary performance measure was FTE per lane-mile. He also noted that the assumed plowing speed is important, and will result in different routes. They initially used a 35 mph plowing speed but vehicle tracking showed that actual plow speeds were more like 27 mph, which changed the routes, cycle times, and levels of service.

2.2 REVIEW OF RFPS

A search of municipal and state contractor bid archives found eight RFPs for snowplow route optimization. The issuers of these RFPs were contacted by email to obtain the relevant scopes of work (SOW) for each. Six agencies responded and provided the SOWs used to contract these services:

1. Western Connecticut Council of Governments: 2017 Snow Storm Response and Routing Optimization
2. City of Pittsburgh, PA: 2018 Fleet Telematics and Route Optimization Services
3. City of Dayton, OH: 2012 Public Works Service Route Optimization Software and Services
4. Indiana: 2015 Telematics Program and Services
5. Dane County, WI: 2015 Snowplow Route Optimization Software & Consulting Services
6. Colorado: 2019 Adaptive Snow Plow Routing Platform (Phase I)

Other inquiries were made to the City of Glendale, California, and the City of Rochester Hills, Michigan but no responses were received. The City of Glendale offered an RFP for Route Optimization and Fleet Telematics in 2018 which was awarded through the Southern California Association of Governments' Future Communities Pilot Program in February 2019 for \$76k. The City of Rochester Hills, Michigan offered an RFP for a Snowplow Route Optimization Software System in 2014.

For the six RFPs reviewed, Table 1 summarizes the services that were being sought and Table 2 summarizes the items that were included in the SOW.

Table 1. Snowplow Route Optimization Services Sought in Each RFP

RFP	Telemetry/ Computing Equipment	Software & Training	Web Development (Dashboard)	Consulting Services	Software / Website Maintenance
Dane County, WI		X		X	X
Indiana DOT	X		X		X
City of Dayton, OH		X	X	X	X
City of Pittsburgh, PA	X	X			
WestCOG, CT				X	
Colorado DOT				X	

Table 2. Work Task Included in the SOW for Each RFP

Work Task	Dane County, WI	Indiana DOT	Dayton, OH	Pittsburgh, PA	West COG, CT	Colorado DOT
Review or geocode existing routes			X		X	X
Install telemetry systems in trucks		X				
Determine efficient new snowplow routes for every vehicle in the fleet	X					
Determine efficient new snowplow routes by leaving some vehicles idle			X		X	
Consider global and local minimization					X	
Specify the optimization problem						
Consider truck capacity and serviceability	X		X	X	X	
Consider wing plows and plow sides	X					
Consider plow speed	X		X			
Consider spread rate / storm intensity	X			X	X	
Consider SIC vehicle allocation	X					

Table 2 Continued. Work Task Included in the SOW for Each RFP

Work Task	Dane County, WI	Indiana DOT	Dayton, OH	Pittsburgh, PA	West COG, CT	Colorado DOT
Consider minimizing left and u-turns	X		X			
Consider minimizing crossing major routes at uncontrolled intersections	X					
Consider prioritized roadways	X		X	X	X	
Consider time windows	X		X		X	
Consider salt shed (resupply) locations	X			X	X	
Calculate performance measures			X		X	
Calculate efficient initial allocations of trucks to depots						
Determine the maximum feasible number of vehicles for the network						
Ability to change the network partitions/clusters/ service areas			X		X	
Ability to adjust parameters of the roadways			X			

Kyle Lester, Colorado DOT’s Director of Maintenance and Operations at that time of the project, expanded on the efforts of his agency in the SICOP podcast (Nelson, 2018). He explained that the original snowplow routes evolved through history and that the agency sought to reduce cycle times by optimizing routes. A review of the existing routes found that they became less efficient over time because crews would modify routes after being “scolded” by state police for not servicing a higher-risk segment more quickly. The target of the optimization was to reduce all cycle times to about an hour. In more rural applications where many routes are simply out and back, route optimizations may be most beneficial for vehicle allocation. It was also noted that different routes resulted from the optimization for different storm intensities and depending on whether a response to a traffic incident was needed. The ultimate goal is to allow dynamic resource allocation to be more responsive to more localized storms. Phase I of CoDOT’s effort included gathering info from districts to map existing routes, but the actual route optimization has not begun yet.

2.3 VENDOR AND CONSULTANT INFORMATION

There are a larger number of vendors providing route optimization services, primarily through the facilitation of web-based access to real-time and summary data. Some of these new vendors provide traditional software that needs to be installed and licensed, whereas others provide access to software tools and summary information through a web browser. All of the following vendors market “route optimization” capabilities:

- C2RouteApp by C2Logix - <https://www.c2routeapp.com/about.html>
- Route4Me Commercial Vehicle Route Planning - <https://www.route4me.com/>
- OptimoRoute - <https://optimoroute.com/>
- Locus Route Optimization - https://locus.sh/route-optimization-software/?utm_source=Capterra&utm_medium=Routeoptimization&utm_source=capterra
- Cigo - <https://cigoTracker.com/site/features/?type=operations>
- DispatchTrack - <https://www.dispatchtrack.com/products/routing-and-planning>
- WorkWave Route Manager - https://offer.workwave.com/route-manager-route-planning-software.html?utm_source=cap&utm_medium=dir&utm_campaign=rmrouteplanning
- PC Miler by Trimble, Inc. - <https://www.pcmiler.com/platforms/#desktop>
- eLogii - https://info.gartnerdigitalmarkets.com/elogii-gdm-lp?category=routeplanning&utm_source=capterra
- onfleet - <https://onfleet.com/features>
- Bringoz - <https://www.bringoz.com/platform/>
- Clear Destination - https://www.cleardestination.com/modules/route-planning-software/?utm_source=Capterra&utm_medium=cpc&campaign=Route&utm_campaign=Route
- Elite EXTRA - <http://eliteextra.com/external-delivery-services>
- Descartes Route Planner - <https://www.descartes.com/resources/knowledge-center/descartes-route-planner>
- PTV Route Optimizer - <https://www.ptvgroup.com/en-us/solutions/products/ptv-route-optimiser/>
- Geoconcept Opti-Time - <https://opti-time.com/>
- RouteSavvy - <https://www.routesavvy.com/routesavvy-info-route-planning-software/>
- Loginext - <https://www.loginextsolutions.com/products/mile>
- Track-POD - <https://www.track-pod.com/route-optimization-software-app/>
- RouteSmart for ArcGIS - <https://www.routesmart.com/>

Snowplow routing is among the more complex routing problems, however, and many of these vendors may not be able to provide a credible solution for this specific routing application. The following software packages and consultants were used for snowplow optimization in the project review here and in Clear Road Report 14-07:

Software:

- ArcGIS Network Analyst for Desktop by ESRI
- FleetRoute by CIVIX L.L.C.
- RouteSmart for ESRI ArcGIS

- TransCAD by Caliper
- WinterPlan by Cascade International (no longer operational)

Consultants:

- C2Logix
- Enera
- Geo-Decisions
- Route Optimization Consultants
- RouteSmart
- Spatial Matters, Inc.
- Vaisala

CHAPTER 3: SURVEY OF PRACTICE AND VENDOR OUTREACH

For Task 2 of this project, the research team designed and implemented an online survey of winter maintenance organizations to catalog contracted efforts for automated snowplow route optimization. In addition, the team identified and contacted vendors and consultants active in the field to participate in vendor interviews (summarized in Chapter 4 of this report) and to review the drafts of the Guidance and Contracting documents (summarized in Chapter 5 of this report).

3.1 SURVEY DESIGN AND IMPLEMENTATION

The project team developed a survey of winter maintenance organizations using the LimeSurvey survey platform. Survey questions were reviewed by the project technical advisory committee. Initial survey recruitment through the AASHTO Snow and Ice Listserv yielded 12 responses, nine from agencies that have conducted route optimization and three from agencies that have not.

3.1.1 Raw Survey Results

Survey questions and responses are documented in Tables 3 and 4 below. Table 3 documents the answers of the nine respondents from agencies that have used automated route optimization software or services. Table 4 documents the answers of the three respondents from agencies that have *not* used automated route optimization software or services. Top-level questions are shown in the left-most column while conditional questions are inset to the right. The number of responses to each possible answer is shown in bold after the response.

Table 3 Responses from agencies that have used automated route optimization software or services (10)

Are you currently using automated route optimization software or services?
Yes – 5
How long have you been using automated route optimization?
0-3 years – 1
3-10 years – 3
More than 10 - 1
No - 4
How long ago did you use automated route optimization?
Within the last 3 years – 3
3 to 10 years ago – 1
No response - 1
What optimization software or consultant did your agency use?
C2Logix – 4
WinterPlan – 1
FleetRoute – 1
RouteSmart – 1
UVM TRC – 1
No response – 2
Was the optimization program operated by your agency's staff or by an external vendor/consultant?
Our staff – 3
External vendor/consultant – 5
Other – 1
No response - 1
What was the approximate cost of the initial development of the optimization effort, including software costs and/or consultant costs?
Under \$10,000 – 1
\$10,000 - \$30,000 – 2
\$30,000 - \$50,000 – 2
Over \$100,000 – 2
Don't know – 2
No response - 1

Table 3 Continued. Responses from agencies that have used automated route optimization software or services

Has your agency changed its snowplow routing or garage locations in response to the findings of the optimization process?
Yes – 4
No – 2
What were the obstacles to implementing the optimized routes?
<i>Politics</i>
<i>The software did not allow for easy use within a municipal environment.</i>
Other – 3
No response - 1
How would you rate the success of the optimization (1 = Very Successful, 5 = Not Successful at All)? [Level of automation]
1 – 1
2 – 2
3 – 2
4 – 4
5 - 0
No response - 1
How would you rate the success of the optimization (1 = Very Successful, 5 = Not Successful at All)? [Ease of use]
1 – 0
2 – 2
3 – 2
4 – 2
5 - 1
No response - 3
How would you rate the success of the optimization (1 = Very Successful, 5 = Not Successful at All)? [Overall success]
1 – 1
2 – 1
3 – 2
4 – 3
5 - 2
No response - 1

Table 3 Continued. Responses from agencies that have used automated route optimization software or services

<p>Please provide any additional information about your experience with route optimization that would be helpful for agencies intending to implement these types of processes or services.</p>
<p><i>Optimization leads to a significant increase in efficiency, and savings in fuel, wear and tear, and also allows for reductions in number of routes. The application is easy to learn. Optimization leads to a conclusion that can be improved upon, but usually most of the benefit is from the initial effort.</i></p>
<p><i>It was pleasing to see that our routes were pretty well established and efficient. Now we are working on the more costly items of adding salt depots in areas where we don't have facilities.</i></p>
<p><i>The software was not able to handle the left turn strategy used in our agency. Often times the optimization had the driver going straight through an intersection or turning right at an intersection rather than using the left turn strategy. if an agency is considering the use of route optimization make sure the vendor is fully aware of the expectations, and do not accept what they give you if it doesn't meet expectations.</i></p>
<p><i>NDDOT's RFP asked for consultant services, software, and training for department staff. Based on our experiences, the software was difficult to learn. Staff would only use it occasionally and would need to be retrained. We would recommend only requesting consultant services unless the department has dedicated staff who would use the software often.</i></p>
<p><i>The consultant provided very valuable feedback to optimize snow plow routes in ND. The recommendations included removing several redundant garages in less populated areas of the state away from higher LOS highways. The recommendations also included reducing the number of plow operators needed in those areas as well. It was difficult to reduce operators and garages in our rural state because there was a lot of political pushback. NDDOT was forced to reevaluate LOS and public perception. In the end, the district operations took it upon themselves to adjust routes based on the optimization report, but could not implement the whole-scale changes recommended.</i></p>
<p>Can you provide a copy of any RFPs, Scopes of Work, or Contracts used to procure automated snowplow route optimization software or services?</p>
<p>Yes – 2</p>
<p>No – 6</p>

Table 4. Responses from agencies that have *not* used automated route optimization software or services (3)

Why hasn't your agency used automated route optimization?
Expected cost to be too high - 1
Agency doesn't have sufficient data available - 0
Insufficient agency staff time to manage the effort - 1
Insufficient agency technical expertise to manage the effort - 0
Uncertainty about the benefits of automated route optimization - 1
Insufficient agency knowledge of contracting process for automated route optimization - 0
Do you know of any transportation agencies that have used automated route optimization software or services?
<i>VT DOT</i>
<i>Unsure</i>
<i>Public transit uses AROS extensively. Salt payload distribution and access to salt is the primary limit to storm route planning.</i>

Nine (9) respondents left contact information and welcomed a follow-up phone call for more information.

3.2 VENDOR OUTREACH

Four vendors that offer highly automated software solutions were contacted and all agreed to participate in vendor interviews and to review the Guidance and Contracting documents produced for this project. These vendors were:

- C2Logix
- Enera
- RouteSmart
- Vaisala

CHAPTER 4: PRACTITIONER AND VENDOR INTERVIEWS

For Task 3 of this project, the project team interviewed staff involved in snowplow route optimization projects at five state DOTs (Colorado, Iowa, North Dakota, Wisconsin, and Utah), one regional planning agency (the Western Connecticut Council of Governments or WestCOG), and representatives of four vendors providing route optimization software and services (C2Logix, Enera, RouteSmart, and Vaisala). These interviews were designed to gain insight into the factors that supported or impeded the implementation of the optimized winter maintenance routes and are summarized below.

4.1 PRACTITIONER INTERVIEWS

The team used a semi-structured interview process to ensure interviewees were asked a standardized set of questions while also providing the opportunity for new issues and topics to arise. These interviews covered four key topic areas:

Project Contracting and Execution:

Project contracting questions covered whether the optimization project utilized a sole source or competitive bid process, the number of qualified bids received, the contract type (fixed-fee, cost-reimbursable, time and materials, etc.), and the project duration. *Project execution* questions covered what optimization software was used, whether the optimization was conducted in-house by agency staff or by a consultant, and the source of the input data for the project.

Optimization Purpose and Scope:

Optimization purpose questions covered the objectives of the routing project being contracted. Route optimization is generally structured either to 1) achieve cycle time targets with as few vehicles as possible or 2) complete routes as quickly as possible using all existing winter maintenance vehicles. Both purposes can produce more equalized route lengths as well as reduce deadheading and route overlap but produce different solutions. *Optimization scope* questions covered what aspects of winter maintenance operations were included in the optimization and what were considered fixed. Specifically, the questions addressed whether or not district boundaries, the allocation of vehicles between districts, and garage/depot locations could be adjusted in the optimization or if the current boundaries, vehicle allocations, and facility locations were to be held constant.

Optimization Scenarios and Operational Constraints

Optimization scenario questions covered the types of distinct routing scenarios (such as varying storm intensities and plowing versus spreading routes) to be considered as part of the project being contracted. Since vehicle travel speeds and material application rates are key inputs into the route optimization process, winter weather events that require different speeds/spread rates can produce different optimal routes. *Operational constraint* questions focused on the operational considerations to

be incorporated into the optimization (e.g. turn constraints, vehicle capacity constraints, use of tow plows).

Project Outputs, Implementation, and Lessons Learned

Finally, questions on the project outputs, implementation, and lessons learned were included to assess the success of the project and what, if anything, the staff would have changed about the solicitation and contracting of the optimization project. These questions are the most “open-ended” allowing for the interviewee to add new insights that might prove useful to other agencies.

4.1.1 Colorado Department of Transportation

Interviewee: David Johnson, FHWA Team Leader for Road Weather and Work Zone Management and formerly Manager of Winter Operation at CDOT

CDOT is unique among the agencies featured here in that its optimization project was intended to create a dynamic (rather than seasonal) optimization process that could be used in real-time to shift and reroute winter maintenance vehicles in response to weather and traffic conditions. In his current position with FHWA, David Johnson is working on a Federal effort, expected to launch in the spring of 2021, to examine the feasibility of a dynamic route-optimization system that would integrate with states’ Maintenance Decision Support Systems (MDSS). Phase I of this project would develop a concept of operation and document system requirements. This system might eventually align with FHWA’s Integrated Modeling for Road Condition Prediction (IMRCP) initiative. The balance of this section deals with the CDOT optimization initiative.

Project Contracting and Execution: Before launching its optimization project, CDOT issued a Request for Information (RFI) on the topic. Vaisala was the only respondent to the RFI and was ultimately selected to perform the project under a 12-month, sole-source contract. Vaisala and a subcontractor, WEOPTIT, developed a new software tool specifically for the project. Vaisala created the baseline routes and operated the software during the first test storm but thereafter it was operated by CDOT staff. CDOT provided the road priority and ADT data, facility locations, staffing, and existing winter operations plan including expected cycle times and known problem areas. Vaisala merged the DOT data with a base road layer from OpenStreet maps that included ramps and roads that were not in the CDOT data.

Optimization Purpose and Scope: The optimization project created a set of baseline routes and a tool for dynamically re-routing winter maintenance vehicles during winter events in response to weather and traffic conditions. The baseline routes were designed to create relatively equalized route lengths with a one-hour maximum cycle time for Category 1 roadways and a two-hour maximum cycle time for Category 2 roadways. The optimization project was piloted along a western section of the I-70 corridor serviced by three different CDOT Maintenance Sections. The vehicle fleet and facilities locations were considered to be fixed in the optimization but turn-around locations, which had previously been limited to Section boundaries, were adapted as part of the optimization.

Optimization Scenarios and Operational Constraints: The optimization tool allowed the user to adjust the relative weights given to 6-7 meteorological variables including blowing snow, icing, and freezing rain to reflect specific winter weather conditions. Material capacity, operating speed, and other relevant vehicle characteristics were included in the optimization. Turn constraints, which are often an important restriction, were not important in the road network used in the pilot.

Project Outputs, Implementation, and Lessons Learned: The baseline routes produced by the optimization were captured in GIS files. Given the relatively simple road network in the pilot region, the new routes were similar to the existing CDOT routes though there were adjustments to turn around locations resulting in more equal route lengths. Dynamic changes to the routes during winter storms were conveyed to the plow operators by radio.

Several lessons were learned during the optimization pilot. First, setting up the systems to link all of the weather and traffic data streams to the optimization tool (done via APIs) was time-consuming. Second, that training and demonstrating the benefits of the system to the operators was important. Finally, that relatively simple road network in the pilot region offered only limited opportunities to improve on existing route efficiency and test the effectiveness of the system. Piloting routing optimizations in areas that include more complex road networks is recommended.

4.1.2 Iowa Department of Transportation

DOT Interviewee: Craig Bargefrede

Project Contracting and Execution: Iowa DOT has a standing research agreement with InTrans, the Institute for Transportation at Iowa State University, and funded an 18-month route optimization project as a task order under this agreement. InTrans developed and operated an optimization program specifically for this project. Iowa DOT provided a road network derived from their Roadway Asset Management System which required revisions to show the number of lanes in each direction for some road types as well as the addition of some “non-service” connecting roads. winter maintenance vehicle travel speeds were derived from AVL data.

Optimization Purpose and Scope: The objective of the optimization was to minimize vehicle hours traveled while meeting cycle time targets. The optimization was tested in Iowa DOT District 3, which has 20 depots and is located in the northwest of the state. Depot locations were considered to be fixed and two optimizations were tested. The first used fixed vehicle allocations and jurisdictional boundaries, and three second incorporated vehicle allocation and jurisdictional boundaries within the optimization.

Optimization Scenarios and Operational Constraints: Routes were created using a 300 lbs/lane mile spread rate. Sensitivity analysis was used to assess the impact of lower spread rates, but for most routes cycle time, not vehicle capacity, was the limiting constraint. Vehicle operating speeds, material capacity, and turning constraints were all incorporated in the route though several issues with turning behavior and which vehicles could operate on which roads needed to be revisited throughout the project.

Project Outputs, Implementation, and Lessons Learned: Ultimately the routes produced for this project were not implemented. There were a number of operational issues that would have required additional adjustments for the routes to be feasible, and it was not easy to modify the routes. In addition, the baseline route data from the AVL had some quality issues that made it difficult to compare the new routes to existing practices.

4.1.3 North Dakota Department of Transportation

DOT Interviewee: Brandon Biese, Maintenance Operations Engineer

Project Contracting and Execution: The NDDOT optimization project was put out for a competitive bid in June of 2017. Multiple bids were received for the project though only one bidder, C2Logix, successfully addressed all aspects of the RFP. The project was set up as a fixed-price contract with a 9-month period of performance to develop the final routes and included technical support for an additional 14 months. This route development period was extended by 6 months to allow for additional optimization runs, an option that had been negotiated in the original contract.

The optimization used FleetRoute software and was conducted by C2Logix staff. NDDOT staff did receive training in the use of FleetRoute, but the software was challenging to use without devoting significant time to learning the nuances of its operation so NDDOT staff did not end up using FleetRoute in-house. NDDOT provided a routable GIS network as well as information on the winter maintenance fleet. Some additional refinement of the road network was completed by C2Logix.

Optimization Purpose and Scope: The goal of the NDDOT optimization project was to achieve the cycle times specified by the DOT's six-tiered winter maintenance LOS policy as efficiently as possible by consolidating routes and eliminating vehicles. The district boundaries, vehicle allocations, and the location of some (but not all) winter maintenance facilities were included in the scope of the optimization and could be changed to improve efficiency.

Optimization Scenarios and Operational Constraints: The NDDOT project considered a single weather scenario, requiring a chemical application rate of 100 lbs per lane mile. Several important operational constraints were included in the optimization including vehicle material capacity, historical vehicle operating speeds, the use of tow plows, and treatment of road shoulders. Vehicle turning constraints, including prioritizing right turns and limiting u-turns were included though they were not major issues in rural areas. The optimization assumed a 14-hour shift with 3.5 hours for non-plowing activities and required two cycles for all routes.

Project Outputs, Implementation, and Lessons Learned: Draft routes were provided in GIS and as turn-by-turn instructions. Drivers were given the opportunity to test the routes in their maintenance vehicles to make sure that the routes were safe and feasible. Some modifications were required to the initial routes to adjust turnaround points and to account for rest areas and turnouts that were not in the initial network. Compared to existing practice (input into FleetRoute by C2Logix for comparison purposes), the

optimization reduced the number of routes from 354 to 327, reduced the single-cycle plowing time by 23%, and total mileage by 8%.

NDDOT considered the route optimization to be successful from a technical perspective but ultimately institutional barriers to change prevented the optimized routes from being implemented. A survey of NDOT residents indicated that a majority of drivers expected similar cycle times on Interstate and non-Interstate 4-lane roads and wanted 2-lane roads plowed more often than 4-lane roads, which was not consistent with the existing LOS policy guidance. In addition, implementing the optimized routes would have required substantial changes to staffing and DOT section buildings. As a result, the optimized routes were not implemented.

One key lesson learned was that LOS requirements needed to be well defined and agreed upon in order to be the basis for route optimization. Additionally, allowing for changes in vehicle allocation and facility location created opportunities for monetary savings but required substantial changes in existing practice which requires widespread organizational support if these changes are to be implemented.

4.1.4 Utah Department of Transportation

DOT Interviewee: Kendall Draney, State Engineer for Maintenance

UDOT has engaged in multiple route optimization efforts dating back to spring 2016. These include projects with the consulting firms Spatial Matters and C2Logix and an ongoing project with the University of Utah. This interview focused on the most recent initiatives with C2Logix and the University of Utah.

Project Contracting and Execution: UDOT's project with C2Logix was performed under a fixed price contract set up through the state's procurement agreement with SHI International, a National Association of State Procurement Officials (NASPO) authorized contractor for the state of Utah. The project launched in May of 2019 and was scheduled to last for 5 months. It was ultimately extended through June of 2020 largely because it took longer than anticipated to collect all of the input data needed for the optimization. The optimization used the FleetRoute software, and the optimization was conducted by C2Logix staff.

The ongoing project with the University of Utah was developed as part of the UDOT Research Division's annual research program for the 2021 fiscal year. The project launched in July 2020 and has an anticipated end date of June 2021. The optimization is being conducted by the University of Utah within ESRI's GIS software. The ultimate goal is to have a route optimization tool that can be operated by UDOT's GIS group on an ongoing basis as new roads are added to the system.

For both projects, UDOT provided a GIS road layer that included lane widths, highway crossover locations, and facility locations. UDOT also provided a list of available equipment with the material capacity and maximum clearing capacity for each vehicle. AVL data was provided as a source of baseline

routes and speeds, but the AVL does not log when the plow is lowered, making it difficult to determine where routes begin and end.

Optimization Purpose and Scope: The goal for both of the optimization projects was to achieve target cycle/turn-around times. Since UDOT's existing performance standards are based on pavement conditions (rather than cycle times), this required UDOT to estimate the required cycle times. The C2Logix project incorporated adjustments to vehicle allocation and district boundaries into the optimization. For the University of Utah project, UDOT opted to focus on a single region with a fixed vehicle allocation.

Optimization Scenarios and Operational Constraints: Both optimization projects considered a single routing scenario, where all vehicles are operating at UDOT's maximum material spread rate. Vehicle capacity, turning behavior, and echelon plowing were all operational issues that were important to UDOT. The optimization was performed for a 24-hour storm to account for the impact of shift changes.

Project Outputs, Implementation, and Lessons Learned: Because UDOT does not have navigation systems in all of its winter maintenance vehicles, turn-by-turn directions were the key route deliverable. Once the initial routes were produced for the C2Logix project, several operational issues were identified during the review of these routes. Specifically, the u-turn locations used in the initial set of routes were problematic, therefore new turning constraints based on road width were implemented in subsequent optimization runs. The treatment of turn lanes and multi-lane exit ramps also required extensive review. Moreover, the challenges of Echelon plowing were never completely resolved. Ultimately, the number of alterations needed to the draft routes was considerable, and implementation was deemed infeasible.

Across several route optimization efforts, UDOT has learned several key lessons. First, reliable baseline data is essential to evaluate the effectiveness of the optimized routes. Without this comparison, it is difficult, if not impossible, to make the case to change existing practice. Second, optimization is more straightforward and performed better in rural areas than in more urban areas. Third, working directly with operations staff at the level of the garage foreman helps to get accurate inputs and to generate organizational buy-in.

4.1.5 Western Connecticut Council of Governments (WestCOG)

WestCOG interviewee: Kristin Floberg, Planner

Project Contracting and Execution: In June of 2017, WestCOG issued an RFP for route optimization services for the 18 towns and municipalities in its planning region and received three bids on the project. The project was conducted under a fixed price contract and lasted for approximately one year. The project was managed by Axiomatic, who subcontracted with C2Logix to run the optimization in the FleetRoute software. WestCOG provided a GIS road network, and Axiomatic worked directly with the member towns to get winter maintenance fleet information.

Optimization Purpose and Scope: The purpose of the optimization was to develop routes that used towns' current vehicle fleets to complete all routes as quickly as possible. Vehicle allocations and facility locations were fixed in all scenarios. Alternative scenarios were conducted with fixed and flexible jurisdictional boundaries.

Optimization Scenarios and Operational Constraints: Separate routes were created for plowing and salting service using "average" storm characteristics. The optimization incorporated the material capacity of the existing vehicles, historical operating speeds, and the consultant work with the individual municipalities to identify turn constraints, low bridges, and hilly road segments that required treatment in a specific travel direction.

Project Outputs, Implementation, and Lessons Learned: Optimized routes were proved to WestCOG in a GIS layer and as PDF maps. Each town had a test period during which they could review draft routes, resulting in several adjustments, mostly related to where winter maintenance vehicles could turn around. Finalized routes were compared to digitized versions of the existing routes in terms of deadheading distance, route lengths, and other variables. Five of the towns implemented the new routes. The biggest obstacles to wider implementation were a lack of buy-in from some of the towns and the time and effort required to collect the data needed to run the optimization, which could be a burden for public works directors who had many competing obligations.

4.1.6 Wisconsin Department of Transportation

DOT Interviewee: Peter Wisniewski, Highway Maintenance Engineer

WisDOT contracts with Wisconsin's 72 county highway departments to provide snow and ice control on the state and federal highway systems. Some routes are limited to only state or local roads and other routes service a combination of local, state, and federal highway systems.

Project Contracting and Execution: WisDOT opted to conduct its route optimization project in-house. An initial RFP for software and training produced five bids. After meeting with three vendors WisDOT opted to purchase the FleetRoute software license and training from C2Logix. The DOT has an ongoing software licensing and technical support agreement with C2Logix. Four staff members participated in an initial training lasting two weeks. Becoming proficient in the operation of the software took several months. During the initial project rollout, conducting the route optimizations was a full-time job, and completing routing for a large complex county can take well over a month of staff time.

Optimization Purpose and Scope: The goal of the optimization is to achieve target route lengths (typically 2.5 to 3 hours but closer to 2 hours for brine routes) and can include route consolidation. Depot locations and vehicle allocations are fixed but some flexibility is allowed at jurisdictional boundaries if there are opportunities to improve performance.

Optimization Scenarios and Operational Constraints: The route optimization is performed using a 300 lb per lane mile material spread rate to create mainline plow routes. The optimization considers

material type and capacity, and the vehicle speeds used in the optimization depend on the road and material type. Left turns and u-turns are avoided when possible. For multilane highways, each lane is covered by a separate vehicle. Manual adjustments are made to the routes to ensure that turning locations are safe and try to end routes at a traffic-controlled intersection to minimize the safety impact of a change in road conditions at route boundaries.

Project Outputs, Implementation, and Lessons Learned: Currently, WisDOT's optimized routes have been implemented in four Wisconsin counties though several others have opted not to use the routes. Where implemented, the routes resulted in four avoided vehicle purchases and a reduction in overtime. The biggest obstacle to implementation is change management with counties being reluctant to change their practices. In some cases, the optimized routes meet the DOT's cycle time targets but current cycle times are faster, creating an expectation that exceeds the level of service defined by the DOT. The software is reported to be time-consuming, including considerable manual post-processing but not to be excessively difficult to use. The optimization efforts are considered successful.

4.2 VENDOR OUTREACH

The research team interviewed representatives of four vendors that offer route optimization solutions: Tony Esposito at C2Logix, Doug Hill at RouteSmart, Paul Erling at Enera, and Mark DeVries at Vaisala. These vendor representatives were asked to provide feedback on their experience with route optimization and the factors that led to or inhibited the implementation of the optimized routes. A synopsis of their experience is provided below.

The vendors universally expressed that the key to a successful project is a shared understanding of the project objectives. For example, routes can be optimized to minimize costs while achieving cycle time targets or to reduce the time required to complete snow and ice control operations given the current vehicle fleet; these two objectives can produce very different results. Cost minimizing optimization often results in reductions in the size of the winter maintenance fleet and, if this outcome is not understood ahead of time, can be met with resistance by district managers who are potentially losing resources.

The issue of resistance to potential equipment reductions ties into a larger change management challenge that several vendors identified as a frequent obstacle to implementation. Prior to optimizing routes, DOT staff need to consider what changes are or are not acceptable to the agency at large. For example, targeting particular cycle times requires that DOTs consider whether there is a general acceptance of the cycle time targets in their winter maintenance plans. In some cases, optimized routes meet cycle time targets but receive pushback because the cycle time is longer than for the existing routes. Similarly, there are potentially significant benefits that can be achieved if facility locations are optimized along with the vehicle routes, but if the DOT lacks the funding to move facilities, routes that rely on different facility locations will not be implementable. Vendors viewed buy-in down to the operator level as being important to successful implementation and generally provide a review period during which drivers can test draft routes and identify issues that need to be corrected.

With regards to the execution of optimization projects, vendors preferred working with road network data provided by the DOT than street data from other commercial vendors. DOT networks are more likely to include non-public roads and facilities that need to be serviced and using commercial data sources often requires more time to modify the base GIS data. The most typical project arrangement is for the vendor to operate the software, at least for the initial optimization. Generally, these software packages require a substantial time commitment to learn, and if the agency does not plan on updating routes frequently, this may not be worth the investment. However, unlike the other vendors, RoadSmart, which has worked primarily with municipalities, typically emphasize staff operation of the software to allow in-house modifications throughout the year

The vendors recognized that there are particular challenges associated with winter maintenance optimization, but expressed confidence in the technical capacity of their staff and software. Consequently, they identified clear communication with agency staff about the optimization objectives and operational requirements as keys to success.

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APPENDIX A – DECISION SUPPORT GUIDANCE

CR 19-04: Technical Requirements and Considerations for an Automated Snowplow Route Optimization

Decision Support Guidance

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Introduction

Planning for snow and ice control (SIC) activities on the roadways before, during, and after winter weather events involves complicated decisions about staging and routing of the winter maintenance vehicles that are responsible for plowing and spreading chemicals and abrasives. DOTs and other transportation agencies are increasingly exploring automated methods for snowplow route optimization as a means for increasing the efficiency of these operations. Route optimization projects have been demonstrated to produce significant savings for transportation agencies when they result in the implementation of new routes.

However, many DOT snowplow route optimization projects have fallen short of implementation. Interviews with DOT staff identified two types of challenges that prevent winter maintenance optimization results from being implemented. These challenges are:

1. technical/operational issues with the final routes that make them unsafe or infeasible to implement, and
2. institutional barriers to change that prevent routes that are technically feasible from replacing existing routes.

These challenges can be substantially mitigated with improvements to the process of soliciting and selecting a contractor or platform to perform the optimization.

This Guidance Document is intended to provide DOT staff with a clear understanding of the technical requirements that must be met to conduct a route optimization project that produces feasible routes. In addition, it highlights several issues which can result in institutional resistance to route implementation so that DOTs undertaking route optimization projects can be proactive in addressing these concerns. The body of the Guidance Document includes six sections covering the following key topics:

1. Optimization Purpose: Is the *primary* purpose of the project to reduce costs or to reduce service time?
2. Optimization Scope: What components of winter maintenance operations (e.g. facility locations, service territory boundaries, fleet allocation) can realistically be changed to improve performance, and what components should be considered fixed? Should multiple routing scenarios be considered? Should route optimization be conducted for a pilot region or the entire state?
3. Data Needs and Sources: What information is required to conduct a route optimization and where can it be obtained?
4. SIC Operational Practices: What winter maintenance practices (vehicle operating speeds, material spreading rates, etc.) need to be included in the route optimization?
5. Route Review Process: How are the routes produced by the optimization software reviewed to ensure they are safe and feasible?
6. Other Key Considerations: What are the indications that a route optimization project will improve on existing routes and that the results will be successfully implemented? Should the optimization be conducted in-house or by a consultant?

Routes can be optimized in different ways to achieve different goals. Establishing the purpose of a route optimization project is essential to its success. Generally, optimizations are either structured to A) minimize operating costs while remaining within the maximum cycle time thresholds set by the DOT (“cost minimization”), or to B) minimize the time required to service all road segments using all existing winter maintenance vehicles (“service time minimization”). These two optimization purposes typically produce different route systems.

Figures 1 and 2 illustrate how the routing solutions produced by A) cost minimization and B) service time minimization differ for two hypothetical road networks. In each case, the road network is maintained by a single garage with two available winter maintenance vehicles (one blue and one red). In the cost minimization scenario for Figure 1, a single vehicle can provide winter maintenance within the maximum cycle time threshold. As a result, only one of the winter maintenance vehicles is utilized, eliminating all deadheading and route overlap, and resulting in the lowest possible vehicle operating time and miles of travel. The second vehicle can potentially be eliminated from the winter maintenance fleet. In the service time minimization scenario for Figure 1, both vehicles are routed. This creates some deadheading as the blue vehicle travels to and from the road segment that it is servicing but also results in the fastest possible winter maintenance for all road segments.

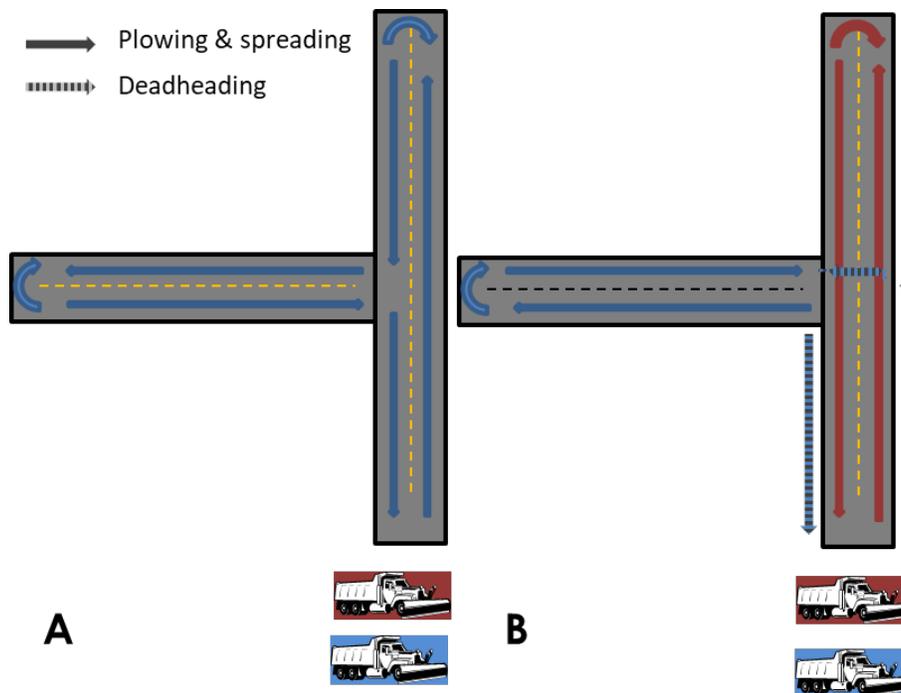


Figure 1. Routes optimized for A) cost minimization (all roads serviced by a single continuous route to minimize miles of travel), and B) service time minimization (all available vehicles are used to get all roads serviced as quickly as possible)

In Figure 2, the road network cannot be traversed by a single winter maintenance vehicle within the cycle time threshold so both vehicles are routed for the cost and service time minimizing optimizations. Once again, the cost-minimizing scenario eliminates all route overlap to minimize the total miles traveled by the winter maintenance vehicles. In contrast, the service time minimization scenario increases vehicle miles traveled in order to more quickly provide winter maintenance service to all road segments.

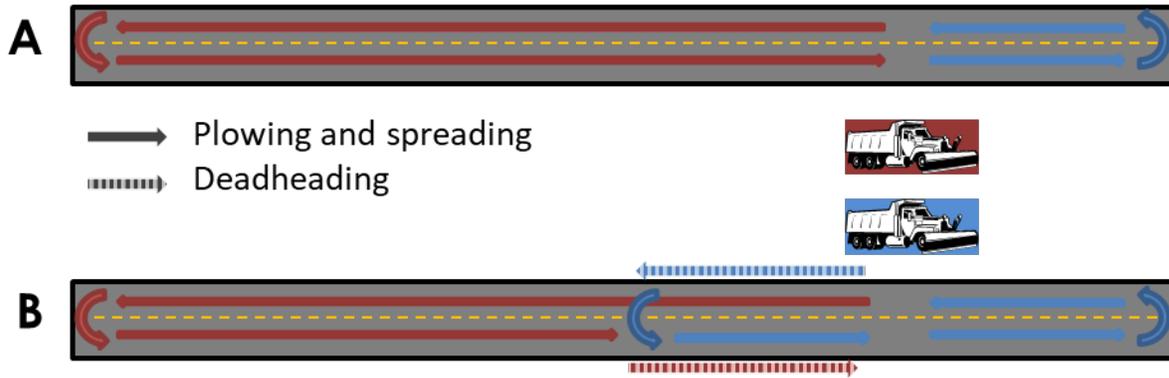


Figure 2. Routes optimized for A) cost minimization (non-overlapping vehicle routes minimize miles of travel), and B) service time minimization (roads serviced as quickly as possible with overlapping routes that are closer to equal in length)

Ultimately, each agency will need to determine which optimization purpose supports their overall route optimization goals, as these approaches make opposite trade-offs between cost and time savings. Cost minimization has the *potential for the largest cost savings*, but also the greatest potential to generate *internal or external pushback* against the proposed routes since they frequently result in a reduction in the number of routes/vehicles providing winter maintenance. Service time minimization has the greatest potential to *increase winter maintenance performance* but may not provide cost savings in comparison to existing routes.

In some cases, a DOT might be interested in a hybrid optimization approach utilizing different optimization purposes for different parts of the state. For example, a DOT might want to minimize service time in parts of the state with higher traffic volumes or elevated safety concerns and minimize costs in less-traveled areas.

When considering an optimization approach, the following questions should be answered:

- How will stakeholders react if the optimized routes increase the service time for some roadways?

Optimization can produce routes that meet a DOT's stated winter maintenance policies but that nonetheless result in slower winter maintenance service relative to existing routes on some roadways. Using the example in Figure 1, if a DOT transitioned from the two winter maintenance routes in scenario B to the single winter maintenance route in scenario A, the new route system would not cover all road segments as quickly as it had when servicing the road network with two winter maintenance vehicles. This has the potential to generate public pushback, even when the new routes are consistent with DOT policy. The DOT may want to consider how to communicate these types of changes to the public (potentially emphasizing cost savings) when undertaking these projects. This

occurrence is most common for cost minimization since route consolidation is a significant source of cost savings but can also occur for some road segments for service time minimization.

- To what extent does the operating speed of your Agency’s winter maintenance vehicles vary with storm severity?

The time that is required to complete a route is determined by the speed that winter maintenance vehicles travel while deadheading, plowing only, or plowing and spreading materials, each of which can vary with storm intensity. If optimized routes are produced using vehicle speeds from an average storm, it may not be possible to complete the routes within the cycle time thresholds during a more severe storm. To avoid routes that are too long to be completed on time in severe weather, DOTs may want to consider conducting multiple routing scenarios or using the lowest expected vehicle speeds for the optimization.

- If considering cost minimization, does your Agency have *agreed-upon* cycle time thresholds for winter maintenance?

DOTs interested in this cost minimization must have specific cycle time thresholds in their winter maintenance plans. The cycle time thresholds can vary by road classification or other prioritization schemes but must be available for all road segments. DOTs that use other criteria for winter maintenance performance, such as returning to bare pavement within a specific time period after the end of a storm, will need to determine what cycle time thresholds are suitable for achieving these criteria before using this optimization method. Generally speaking, route lengths created using this method will be relatively close to the maximum allowable cycle time, as routes that are significantly shorter than this threshold are candidates for route consolidation (which reduces miles of travel), so there should be broad agreement that hitting the cycle time thresholds is an appropriate standard for determining the suitability of winter maintenance routes. Lack of consensus/support for the cycle time thresholds used in the optimization can undermine support for implementing new routes once the optimization is complete.

- If considering cost minimization, how will your Agency manage pushback from internal stakeholders about potential reductions in the number of staff and vehicles available for winter maintenance resulting from route consolidation?

Winter maintenance is a demanding job and maintenance staff at the operational level may be reluctant to embrace optimized routes that reduce the resources that they have available to conduct winter maintenance activities within their district. Engaging with staff early in the project process may be important to set and manage expectations.

Optimization Scope

Importance: Essential

Route optimization projects can be narrow in scope, producing new routes for a single jurisdiction using existing facility locations and a fixed number of vehicles, or very wide-ranging, incorporating multiple

jurisdictions, considering new facility locations and changes to the winter maintenance vehicle fleet. Optimization projects with broader scopes have the potential to address a wider range of inefficiencies and, therefore, to produce larger cost savings and service time improvements. However, broader projects are likely to be costlier to conduct and to require more extensive changes to existing winter maintenance operations, potentially raising significant implementation barriers. Selecting the appropriate scope for an optimization project is a matter of balancing the potential for greater cost savings that can be achieved by a broader scope against the greater likelihood of implementation that comes from a narrower scope.

When determining the project scope, DOTs must consider which structural components of winter maintenance operations (facility locations, service territory boundaries, and fleet allocation) to include in the project. Facility locations, service territory boundaries, and fleet allocations can be revised as part of the route optimization project or excluded from the scope and held fixed, while only the routes themselves are optimized. Generally speaking, if it is not feasible to make changes to a particular component of winter maintenance operations in practice then that component should be excluded from the optimization process. Optimizing, for example, DOT garage locations without funding dedicated to relocating these facilities will result in routes that are incompatible with real-world conditions. Conducting alternative scenarios to explore the impact of optimizing winter maintenance components that cannot immediately be changed can be valuable for planning purposes but will not result in routes that are implementation-ready.

This section describes the potential benefits and drawbacks of including each of these structural components of winter maintenance operations in the optimization, as well as of using multiple routing scenarios to explore alternative configurations and varying weather conditions. Finally, it discusses whether the geographic extent of the route optimization project should be limited to a pilot region or extend statewide. These project elements help to set the breadth of the project scope.

Facility Locations

The locations of winter maintenance facilities (garages and salt sheds) are one determinant of optimal routes for winter maintenance activities. Facilities that are relatively evenly distributed across the road network tend to promote more equal route lengths and reduce deadheading. Garage locations and salt sheds can be revised as part of the optimization process potentially resulting in recommended new locations for these facilities that improve service territory partitioning and routing efficiency. Potential facility locations can be limited to pre-identified sites provided by the DOT as practical for construction or “blue sky” locations can be selected without pre-screening. The latter approach can identify locations that are superior with respect to routing efficiency but add complexity and cost to the project and may be less likely to be constructed than facilities at pre-identified locations. As a result, the “blue sky” approach is not recommended for projects designed to produce implementation-ready routes. It should be noted that changing garage locations can be costly and time-consuming. If moving a garage is not a realistic, near-term possibility, creating routes that are based on flexible garage locations will more than likely result in routes that cannot be implemented. DOTs interested in simultaneously optimizing garage locations and winter maintenance routes may want to consider conducting multiple optimization scenarios, one with facility locations included in the optimization and one using fixed facility locations. This approach would allow the DOT to assess the potential cost savings that could be achieved by changing garage locations while also ensuring that the project produced routes that could be

implemented with the current facilities. Since new salt sheds require less of an investment than new garages, it may be more feasible to optimize salt shed locations than garage locations although the benefit is likely to be smaller as well.

Service Territory Boundaries

Winter maintenance routes often terminate at service territory boundaries that may not have been created with the optimization purpose in mind. Often these service territory boundaries are administrative or political, like town or county boundaries. Adjusting service territory boundaries to further the route optimization provides additional flexibility to improve the efficiency of the routes and/or create more equal route lengths between jurisdictions. Because optimizing service territory boundaries does not require significant changes to infrastructure, including these boundaries in the optimization is generally desirable when there is buy-in among the jurisdictions. Minor adjustments to turnaround points on rural roads may be necessary to adjust service territory boundaries, and these new boundaries may require an initial period of adjustment for winter maintenance vehicle drivers. However, the benefits of optimized service-territory boundaries typically outweigh the costs of this adjustment period.

Fleet Allocation

In some cases, the allocation of winter maintenance vehicles between garages or districts is not compatible with the optimization purpose and the most efficient routing schemes require leaving some winter maintenance vehicles idle or reallocating vehicles between service territories.

Altering the allocation of vehicles between service territories can result in resistance from service territories that are losing vehicles and among drivers whose vehicles are being moved.

Number of Optimization Scenarios

DOTs undertaking route optimizations must also decide how many routing scenarios to model within the optimization project. Conducting multiple routing scenarios can be used to understand the impact of different weather conditions and winter maintenance strategies on the optimal routing as well as to explore the impact of optimizing facility locations, service territory boundaries, and fleet allocations. Since there is significant overlap in the setup required to optimize different scenarios, there are economies of scale associated with running multiple scenarios. While increasing the number of optimization scenarios should be expected to increase the total project cost it should also lower the cost per scenario.

Alternative routing scenarios can create routes that are optimized specifically for plowing, for varying weather conditions, for the application of different material types, or for differing equipment configurations, among other factors. Winter maintenance vehicles can generally travel longer distances before returning to a maintenance facility when plowing without applying materials since material capacity is often a limiting factor in route length. Material spreading rates and vehicle speeds can also vary with winter weather conditions, meaning that the routes produced by the optimization will vary depending on the assumed weather conditions. Conducting scenarios that explore the impact of shifting operational practices will result in routes that may not be implementation-ready but that can be valuable for strategic planning purposes and can help make the case for longer-term changes to the strategic winter maintenance plan. This might include optimizing winter maintenance facility locations or creating routes for the application of different material types since material capacity and spread rates

vary depending on the material that is being applied (e.g. with liquids versus solids). Conducting multiple routing scenarios may result in the DOT using different routes in response to different weather conditions or the DOT selecting a single set of routes for general use from among the different scenarios.

One potential drawback to conducting a large number of scenarios is that the process of reviewing routes produced by optimization software to ensure they are safe and do not require alterations (discussed later in this Guidance) can be time consuming. Having too many routing schemes may make it difficult for DOT staff to comprehensively review all of the options. Since winter maintenance vehicle capacities for material spreading are often a critical constraint on route optimization scenarios, we recommend conducting optimization scenarios for material spreading that capture both typical and high demand for material spreading. The assumption then can be made that these routes will also be well suited to storms that require little or no material spreading.

Geographic Extent

The choice between a statewide project and a more geographically limited pilot project poses a trade-off between project risk and project benefit.¹ Statewide projects have the potential to deliver greater savings than projects that cover a smaller geographic area. First, adjustments to service territory boundaries are a source of efficiency improvements that cannot be captured (or are only partially captured) when optimizing a pilot region that may only consist of one or two service territories. Second, potential efficiency improvements from route optimizations will vary from region to region depending on the efficiency of the existing routes. As a result, pilot optimization in regions that are already relatively efficient may underrepresent the potential savings in other parts of the state where existing routes are less efficient. Finally, a statewide project will include all of the state's routes, so the total efficiency savings will be greater than for a single pilot region and achieved more quickly than would be the case with a series of smaller projects.

Conversely, statewide projects are higher in cost and may face greater institutional implementation barriers than smaller pilot projects as they require buy-in from a larger number of supervisors, drivers, and administrators. Pilot projects are lower cost and can build confidence in the optimization process before a statewide application is attempted. Given the limited number of DOT route optimization projects that have resulted in the implementation of new routes to date, we recommend that state DOTs pilot route optimization in a smaller region before attempting to conduct or contract for a statewide optimization project. Pilot projects that include two adjacent regions would allow service territory boundary adjustments to be considered.

If a DOT opts to conduct a pilot route optimization, two factors should be considered when selecting the pilot region(s): the support of the operations staff in the pilot region(s) and the complexity of the road networks. Selecting a pilot region where there is strong support for optimization among winter maintenance supervisors will help to overcome the institutional barriers to change and is strongly advised. Generally speaking, the potential for cost savings is higher in areas where the road network is more complex. Existing routes in regions with a relatively simple road network are less likely to deviate

¹ Note that a "statewide project" or "statewide optimization" is used to refer to a project that covers all roads maintained by the DOT. Due to the computational intensity of route optimization, the optimization itself is likely to be conducted sequentially for smaller sub-state regions rather than for the entire state simultaneously.

significantly from the optimal routing since the optimal routes are easier to determine through a manual process. Therefore, DOTs should consider prioritizing pilot regions with greater road network complexity to achieve greater cost savings and/or performance improvements. For these reasons, the team recommends that a pilot project include a more urbanized region of the state’s road network and an adjacent region outside the urban core.

Data Needs and Sources

Importance: Essential

Three types of data are necessary for route optimization. The first is data about the roads that require winter maintenance, the second is data about the winter maintenance vehicle fleet available to service these roads, and the third is data about DOT garages and service territories. In addition to these required data, information about baseline winter maintenance practices (current vehicle allocations and current routes) is very helpful for making the case for implementation but is not essential for conducting the optimization itself. Providing sample data for the GIS road network, winter maintenance fleet table, facility locations, and services territory boundaries at the time an RFP is issued will allow consultants to better assess the extent of the data preparation required for the project and more narrowly tailor their project budgets.

GIS Road Network

Route optimization software typically requires a GIS representation of the road network, with coded topology (links directions, travel times, capacities, and turn penalties), which comprise a routable road network. A routable road network is a representation of the roads (or a subset of the roads) in a given area that embeds information about how vehicles can travel on the road network. Embedded information includes elements that are necessary to process how a winter maintenance vehicle can navigate the network, such as distinctions between overpasses and intersections, the direction of travel that is possible on a road segment (one-way or bi-directional), and the turning behaviors that are possible where road segments meet. Generally, DOT GIS staff will be able to supply a GIS representation of the road network for the state, but it won’t likely be fully coded and routable. In cases where the state does not maintain a routable network, they can often be acquired from commercial mapping companies, open-source providers, or developed as part of the contract.

Regardless of the source of the road network in GIS, some features may need to be corrected, added, or modified to ensure that it is routable for winter maintenance route optimization. Modifications to the GIS road network should be an expected step in the route optimization project. Modifications will likely be necessary to address many of the following road network topology attributes needed for the route optimization:

- Information about Individual lanes may need to be represented for multilane highways. Typical GIS road networks use single links to represent the traveled way, regardless of the number of lanes that are present, as shown in column B of Figure 3. The number of travel lanes in each direction is recorded as an attribute of the link. Thus, an undivided highway will generally be represented by a single, bidirectional link and a divided highway will be represented by two opposing links, one for each direction of travel. For winter maintenance routing, the representation of individual travel lanes is critical for developing lane-specific winter maintenance routes and to accurately represent limited-access features like emergency

turnarounds and on/off-ramps. This enables different vehicles to be dedicated to different lanes, as is necessary for a dedicated left-side plow vehicle for serving the left lane of travel on a divided freeway. Information about the width of pavement that needs to be cleared, including road shoulders if applicable, is also valuable.

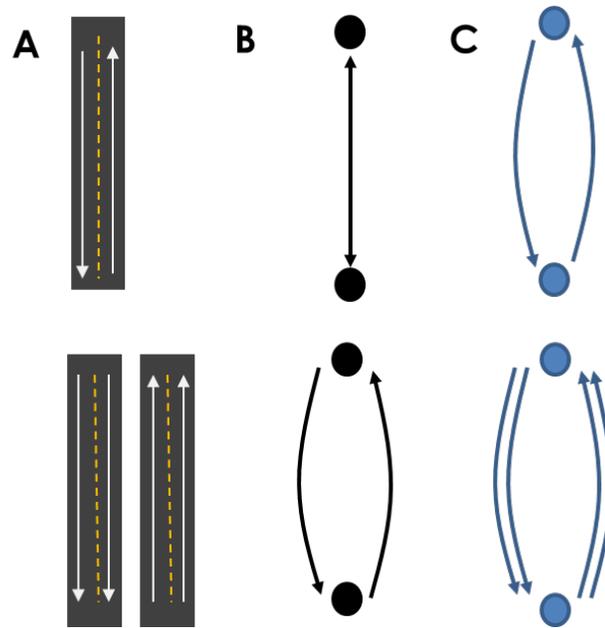


Figure 3. A) Actual road network, B) typical GIS representation, C) ideal representation for SIC routing for undivided (top) and divided multilane highways (bottom)

- Local roads that may be traversed by winter maintenance vehicles must be included in the network. State-maintained GIS road networks may exclude local roads and streets that are not maintained by the state. During the project setup phase, local roads that may be traversed by winter maintenance vehicles (for example, the roads between a state-owned garage and a state highway) should be identified and added to the road network if necessary. Even roads that are not provided with winter maintenance service may be critical linkages for efficient winter maintenance routes.
- Functional classification and winter maintenance priority levels must be included as link attributes of roads to be serviced. Many DOTs have different winter maintenance performance standards for different road segments depending on attributes like functional classification, or average daily traffic. These data must be included as link attributes for every state-maintained roadway or added to the GIS road network to be considered in the optimization. winter maintenance vehicle travel speeds may also be specific to the functional classification or other attributes of the roadway. In order to establish winter maintenance travel times for vehicles providing service, these speeds will need to be assigned to every serviceable link in the network, while safe travel speeds should be available for traversable local roads and streets where winter maintenance service is not to be provided.

- Road segments that require special treatment, such as known hazard areas that require more frequent service or different material application rates, should have this information included as a link attribute.
- Road-specific restrictions on material spreading must be included as link attributes – Restrictions on the chemicals or liquids that can be spread on any road segments should also be documented so that these restrictions can be added to the road network.
- Median crossovers that can be utilized by winter maintenance vehicles should be represented as links in the road network. These links can be added easily between parallel links for divided highways (bottom center of Figure 3). For median crossovers or u-turn opportunities on undivided highways, a bi-directional link may need to be converted to represent individual lanes (top right in Figure 3) so that the crossover link can be added. Failure to include these features in the road network is likely to result in inefficient routes, especially around on- and off-ramps.
- Off-network areas that need to be serviced – If the DOT is responsible for clearing rest areas, driveways for state facilities, or other non-road areas that are not represented on the GIS road network, these areas may also need to be added to the network. Alternatively, these areas can be left out of the route optimization project if there is a non-routable winter maintenance vehicle dedicated to servicing them.

While not required to conduct a route optimization, identification of existing (baseline) winter maintenance routes in GIS is *highly recommended* for DOTs interested in route optimization. Without the baseline routes and travel speeds coded into GIS or replicated in the optimization software, it will be more difficult to make the case for implementing new routes, since their benefit over the existing routes cannot be quantified. Data on existing routes in non-GIS formats can be converted to GIS as part of the optimization project. DOTs are advised to postpone route optimization projects if baseline data is not available.

Winter Maintenance Fleet and Equipment

The second piece of essential information that is required for route optimization is a tabulation of the winter maintenance vehicles available for routing and their attributes. For each vehicle in the winter maintenance fleet, the following information is required:

- The maximum distance the vehicle can travel before refueling
- The vehicle's capacity for solids, liquids, both, or neither
- The vehicle's compatibility with and access to tow plows or dedicated left-side plows that alter the number of lanes or the type of lane the vehicle can treat in a single pass (if used by the DOT) as well as how many
- The vehicle's home depot or garage

Generally, DOT's maintain all of the fleet information required for the routing process though it may be necessary to work with individual jurisdictions to gather, confirm, and tabulate this information. The winter maintenance vehicle's garage location may be altered by the optimization if the scope of the optimization project includes optimizing the vehicle allocation.

Facility Locations and Service Territory Boundaries

The locations of all DOT winter maintenance facilities (garages and salt sheds) as well as existing district service territory boundaries (if these boundaries are not being optimized) are also required for the

optimization. If garage and salt shed locations are available in a GIS format this information can be provided by address or latitude and longitude. If service territory boundaries are available, they can be used to assign links in the network to specific garages, by adding the “servicing garage” as a link attribute in the GIS.

Winter Maintenance Operational Practices

Importance: Essential

New routes must be consistent with the operational practices of the DOT in order to be considered for implementation. A wide range of operational constraints and practices can be built into the optimization process. Failure to include these constraints can lead to optimized routes that are infeasible to implement or that do not improve on existing practices. Optimization project teams should strongly consider engaging operations staff at the supervisor or operator level to ensure that the assumptions used in the optimization reflect on-the-ground practice. Operational practices that should be considered with the optimization team include:

Winter maintenance vehicle operating speeds

Importance: Essential

Vehicle travel speed is an essential optimization criterion. Variations in operating speed based on road classification, whether the vehicle is deadheading or performing winter maintenance activities, or other factors should be reflected in the optimization and should be as accurate as possible. Overstating operating speeds in the optimization risks producing routes that cannot be completed within DOT guidelines while understating operating speeds may eliminate opportunities for cost savings. Historical AVL data is one possible source of speed data.

Material spread rates

Importance: High

Material spreading rates determine how quickly winter maintenance vehicles need to return to a garage or salt shed to resupply with materials. Route optimizations for material spreading require reasonable estimates of the rates at which materials will be applied. Underestimating material spreading rates may result in infeasible routes. DOT guidelines and historical AVL data may be sources of material spreading rates.

Compatibility between roadways and vehicles/equipment

Importance: Variable

Different winter maintenance vehicles and equipment are appropriate for different road types. Trucks with tow plows that are suitable for use on multi-lane interstates are not suitable for narrow state highways and trucks with specific plow configurations may only be able to service left or right lanes. Restrictions on the equipment that is compatible with each road type or road segment should be documented at the start of the optimization process.

Turn restrictions and penalties

Importance: Variable

Many DOTs seek to avoid left-turns and/or U-turns to avoid dropping snow in the roadway as well as to avoid safety issues and reduce the length of time vehicles spend waiting to make a turn. Specific turning actions can be prohibited entirely or may be assigned a time penalty which reduces the frequency with

which the turning action occurs. Turn restrictions may be more relevant in high-traffic areas than in more rural regions and do not have to be uniform across the road network.

Cycle time thresholds and roadway prioritization

Importance: Variable

For cost minimization cycle time thresholds are essential. DOTs frequently have winter maintenance performance standards that vary by road functional class or other criteria. When this is the case, this prioritization scheme should be conveyed to the project team so that it can be incorporated into the optimization. DOTs should consider whether specific winter maintenance vehicles can treat roads with different priorities or if routes should be limited to a single prioritization level. Allowing winter maintenance routes with mixed prioritization can increase efficiency.

Treatment strategy for multilane highways

Importance: Variable

The treatment strategy for multilane highways should be documented for the project team. The use of tow plows, wing plows, and effective treatment width of all vehicles should be included in this documentation. If echelon plowing is used this should also be specifically noted as it can be difficult to incorporate into an optimization and the consultant/software provider should address their capacity to model echelon plowing specifically.

Treatment strategies for intersections, ramps, turn lanes, & roundabouts

Importance: Variable

Strategies for road features where lanes must be serviced in a specific order or where the equipment that is used deviates from that being used on adjacent road segments should be detailed at the start of the project. This might include roundabouts where the inner lane is cleared first and wing plows are generally retracted, specific intersection configurations, or exit ramps. These treatment options may differ based on storm intensity. Less critical turn lanes, for example, may be left uncleared during severe storms, but ramps must be kept clear at all times.

Route Review Process

Importance: Essential

The Data Needs and Operational Practices sections of this Guidance Document are intended to ensure that the initial optimization process does not omit or misrepresent major operational considerations. With these operational practices as inputs, optimization software will produce routes that are technically feasible on the road network and winter maintenance vehicle allocations for every garage included in the optimization. Nonetheless, idiosyncrasies in roadway geometry, grade, lines of sight, traffic conditions, equipment capabilities, or other factors may mean that rules that are generally true do not hold in a particular circumstance or location. Consequently, the project team should expect that the optimized routes will require review and at least minor revisions to be safe and feasible in practice, regardless of the rigor that goes into setting up the optimization inputs.

As a result, all route optimization projects should include a route review process to identify any safety concerns or incompatibilities between the initial optimized routes and the DOT's winter maintenance operational practices. Ideally, this review process would include supervisors and/or operations staff riding along on each of the optimized routes to confirm their viability and identify potential problem areas. Any problem areas that are identified in the review process should then be addressed by the

optimization team. To ensure that the finalized routes are fully compatible with DOT operational practices, the optimization project should be scoped to include multiple iterations of the review process.

Other Key Considerations

Importance: Variable

Beyond the technical considerations laid out in this guidance document, DOTs should consider certain key non-technical considerations, including:

- support of all winter maintenance operations stakeholders,
- indications that route efficiency can/should be improved,
- ability to demonstrate that the new routes improve upon the existing routes prior to undertaking a route optimization
- whether to conduct the optimization in-house or to have it performed by an external consultant or software vendor.

Strong support for the optimization process at all levels of the DOT, from executive leadership through district supervisors to winter maintenance drivers, and among all external winter maintenance stakeholders can help overcome the resistance that can prevent the implementation of new routes. Open communication between the optimization team and the supervisors and drivers that will be responsible for using the new routes is also helpful from a change management perspective.

The reductions in cost/service that can be achieved through route optimization depend on the efficiency of the existing routes. If the existing routes closely approximate the optimal routes, optimization will not produce large benefits. DOTs can explore several indicators that could suggest opportunities for optimization. Routes with cycle times that are substantially shorter than the DOTs maximum cycle time threshold indicate the potential for route consolidation in a cost-minimizing optimization. Significant variability in cycle times across different routes and garages can also indicate benefits from optimizing routes and vehicle allocations. Significant discrepancies across service territories in the ratio of winter maintenance vehicles to lane miles that must be plowed can be an indication that optimization of the fleet allocation could reduce costs and/or service times. Garages that are not relatively centrally located within their service territories suggest that facility locations and/or service territory boundaries adjustments could be beneficial. Another element to consider is the complexity of the road network. In areas with a relatively simple road network and a limited number of winter maintenance vehicles, careful manual review of winter maintenance routes may be a cheaper, faster, and comparably effective approach to designing winter maintenance routes. Routing in areas with higher numbers of winter maintenance vehicles and greater complexity in the road network is less easily done manually and therefore automated optimization can provide larger benefits.

Subjective indications that route efficiency can and should be improved are also helpful to motivate the route optimization project. For example, if the DOT is experiencing unusually high or inconsistent costs for winter maintenance from year to year as compared to peer states or fails to meet its stated performance targets, then the motivation for trying new routes and service territories may be high. It is also common for drivers and supervisors in a particular district to express concerns about the efficiency or effectiveness of existing routes. In some cases, highly variable route lengths could be causing

problems with staffing and overtime costs. Often these motivating factors can help pinpoint regions where a pilot project can be focused.

The ability to clearly demonstrate reductions in cost and/or service time is essential to carry a project through the implementation phase. As mentioned previously, documentation of existing winter maintenance routes is *highly recommended* for DOTs interested in route optimization. Without documentation of the baseline routes and cycle times, it is much more difficult to make the case for implementing new routes as it becomes more difficult to quantify cost savings and performance improvements. It also is worth verifying that actual winter maintenance practices align with stated winter maintenance routes as discrepancies between the theoretical and actual routing also make it more difficult to establish the magnitude of cost savings and performance improvements.

Finally, DOTs interested in route optimization must decide whether to purchase software and contract training services so that optimizations can be conducted in-house or to contract for route optimization services with a consultant. Both approaches offer benefits and drawbacks. Developing the capacity to conduct route optimization in-house enables the DOT's optimization team to bring local knowledge of winter maintenance operations into the optimization process. Staff analysts can work with winter maintenance operators over a longer timeframe to troubleshoot routes and build buy-in. This approach also gives the DOT the capacity to update optimizations as new roads and lanes are added to the network or as the winter maintenance fleet is improved. However, route optimization software packages are highly specialized, and developing and maintaining proficiency with them requires a significant investment of staff time (initially it may be a full-time commitment). Unless multiple staff members are trained and maintain proficiency with the software, there is a risk of losing optimization expertise if a relatively small number of staff positions turn over. For many DOTs, the road network that they maintain is relatively static and there is little benefit to frequently re-optimizing routes. In this case, it may make sense to work with an external consultant with experience conducting snowplow route optimizations.

APPENDIX B – CONTRACTING LANGUAGE TEMPLATE

CR 19-04: Technical Requirements and Considerations for an Automated Snowplow Route Optimization

Contracting Language Template

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Introduction

Planning for snow and ice control (SIC) activities on the roadways before, during, and after winter weather events involves complicated decisions about staging and routing of the winter maintenance vehicles that are responsible for plowing and spreading chemicals and abrasives. DOTs and other transportation agencies are increasingly exploring automated methods for snowplow route optimization as a means for increasing the efficiency of these operations. Route optimization projects have been demonstrated to produce significant savings for transportation agencies when they result in the implementation of new routes.

The purpose of this document is to provide DOTs with a flexible template to assist with the development of RFPs for automated snowplow route optimization. The language suggested here is intended to ensure that DOTs and consultants/software vendors have a shared understanding of the scope of work that the DOT requires and to maximize the likelihood that the project will result in safe, feasible, implementation-ready routes. The accompanying Guidance Document provides a more in-depth description of the technical requirements for route optimization and the key decisions DOTs should consider when developing an optimization scope.

This document is organized to reflect the scope section of a hypothetical RFP and contains the following sections:

1. Project Description
 - a. Optimization Purpose
 - b. Optimization Scope
 - i. Geographic Extent
 - ii. Optimization Scenarios
2. Data Needs and Sources
 - a. GIS Road Network
 - b. Winter Maintenance Fleet and Equipment
 - c. Winter Maintenance Facility Locations and Service Territory Boundaries
 - d. Existing Winter Maintenance Routes
 - e. Winter Maintenance Operational Practices
3. Project Tasks
 - a. Task 1. Project Launch Meeting
 - b. Task 2. Data Acquisition and Preparation
 - c. Task 3. Draft Route Optimization
 - d. Task 4. DOT Route Review
 - e. Task 5. Route Revisions
 - f. Task 6. Comparison of Baseline and Optimized Routes
 - g. Task 6. Final Report

Throughout this document, suggested contract language is shown in an inset text box:

This RFP is being issued by the {state DOT} for the purpose of developing optimized winter maintenance routes.

Curly brackets {} denote information that will vary by project and will need to be completed by the issuing DOT.

Project Description

The project description provides an overview of the optimization project, covering essential points including the purpose of the optimization, how many scenarios are to be conducted, what structural component of the DOT's winter maintenance plans should be included in the optimization, and the geographic area that the optimization will cover. The project description frequently includes an overview of the DOT's winter maintenance goals and responsibilities. Providing access to the DOT's winter maintenance plan or other policy documents that guide winter maintenance practice will give respondents to the RFP the opportunity to tailor their proposal to the DOT's practices.

1. This RFP is being issued by the {state DOT} for the purpose of contracting for winter maintenance route optimization services.

Optimization Purpose

The optimization purpose indicates whether cost-minimizing or service-time-minimizing routes will be sought. Software requirements are also provided regardless of the purpose chosen.

1.a. The purpose of this project is to develop new winter maintenance routes that minimize winter maintenance costs while successfully achieving the DOT's winter maintenance performance targets. The optimized routes must be consistent with the DOT's winter maintenance practices described below and in its Winter Maintenance Plan.

OR

1.a. The purpose of this project is to develop new winter maintenance routes that minimize winter maintenance service time using the currently available winter maintenance fleet. The optimized routes must be consistent with the DOT's winter maintenance practices described below and in its Winter Maintenance Plan.

OR

1.a. The purpose of this project is to develop new winter maintenance routes that are consistent with the DOT's winter maintenance practices described below and in its Winter Maintenance Plan. Optimized routes for {describe region} should minimize winter maintenance costs while successfully achieving the DOT's winter maintenance performance targets. Optimized routes for {describe region} should minimize winter maintenance service time using the currently available winter maintenance fleet.

AND

1.a. continued: Minimum expectations for the optimization software used for this project are that it is capable of addressing the following elements of winter maintenance operations {include applicable features}:

- capacitated routing for material spreading,
- mixed winter maintenance fleets consisting of vehicles with differing material capacities and plow configurations,
- constraints on the winter maintenance vehicles that are compatible with differing road types,
- lane-specific routing, and
- turning behavior prohibitions and penalties.

The DOT's Winter Maintenance Plan {and other relevant documents} can be accessed at {URL OR in Appendix X of this RFP}. Respondents are strongly encouraged to review these resources to identify any winter maintenance practices that may require modification to standard winter maintenance optimization approaches and highlight their capacity to address any identified issues in their proposal.

Optimization Scope

The optimization scope details the geographic extent of the project and the optimization scenarios to be conducted. As described in the Guidance Document, the optimization scenarios that should be conducted depends on which components of winter maintenance operations can realistically be altered to improve winter maintenance efficiency.

Geographic Extent

The optimization project can be conducted statewide or in a smaller pilot region.

1.b.i. This project shall cover all roadways maintained by the state. The state is responsible for winter maintenance on {##} lane miles. Existing routes utilize {##} winter maintenance vehicles routed from {##} winter maintenance garages.

OR

1.b.i. This project shall cover all roadways maintained by the state in {##} service territories located in {description of pilot territory locations}. In this region, the DOT is responsible for winter maintenance on {##} lane miles. Existing routes utilize {##} winter maintenance vehicles routed from {##} winter maintenance garages.

Optimization Scenarios

The optimization scenarios specified in the RFP should describe the winter maintenance treatment type (plowing vs spreading) and weather severity combinations for which routes should be developed as well as whether facility locations, service territory boundaries, and fleet allocations should be included in the optimization. The scenario elements are presented separately below but should be combined into a set of comprehensive scenario descriptions.

1.b.ii. The consultant shall produce optimized routes for {XX} separate winter maintenance scenarios. These scenarios should create routes for:

Treatment Type/Weather Severity:

- Plowing only, with vehicles speeds used during typical winter weather
- Plowing only, with vehicles speeds used during severe winter weather
- Material spreading replicating the current material(s) applied, with vehicle speeds and material spreading rates used during typical winter weather
- Material spreading replicating the current material(s) applied, with vehicle speeds and material spreading rates used during severe winter weather
- Material spreading using an alternative material type, with vehicle speeds and material spreading rates used during severe winter weather
- Material spreading using an alternative material type, with vehicle speeds and material spreading rates used during severe winter weather

Structural Components of winter maintenance - Facility Locations:

- All winter maintenance facility locations shall be considered fixed in their current locations.
- A total of {# of locations} preselected locations for {winter maintenance facilities OR winter maintenance garages OR salt sheds OR a subset of facility locations} should be tested for improved efficiency in conjunction with the winter maintenance route optimization.
- The locations of {all winter maintenance facilities OR all winter maintenance garages OR all salt sheds OR a subset of facility locations} should be optimized in conjunction with

the winter maintenance routes. All {described the locations that should be considered for new facilities, e.g.: all undeveloped land or all land in the state-owned right of way} should be considered for new facilities.

Structural Components of Winter Maintenance - Service Territory Boundaries:

- All service territory boundaries shall be considered fixed in their current locations.
- All service territory boundaries shall be optimized in conjunction with the winter maintenance routes.

Structural Components of Winter Maintenance - Fleet Allocation:

- The winter maintenance fleet allocation shall be considered fixed in its current configuration.
- The winter maintenance fleet allocation shall be optimized in conjunction with the winter maintenance routes.

Data Needs and Sources

This section of the RFP should describe the data that will be provided by the DOT, the quality control and modifications that the consultant will be expected to provide for this data, and data that the consultant must collect as part of the project. If feasible, providing a sample of the GIS road network, winter maintenance fleet table, facility locations, and services territory boundaries will allow consultants to better assess the extent of the data preparation required for the project and more narrowly tailor their project budgets. Ideally, this data would be made available through an open-access portal for the respondent to download and review.

2. The availability and format of the data that is anticipated to be used for this project are described here. If additional data beyond what is presented here is required, the consultant should describe what other data is needed as well as how they would obtain this information.

GIS Road Network

The RFP should provide a description of the existing road network if a sample or a link to the network GIS can not be provided. In either case, requirements for attributes of the improved road network should also be provided.

2.a. The DOT will provide a GIS road network for {all roads OR all state-maintained roads} in the {state OR pilot region} in {software file type, e.g., ESRI ArcGIS shapefile} format. The road

network includes the following features {select applicable features OR omit if sample road network data provided}:

- Representation of individual travel and turn lanes as separate links
- Local roads that may be traversed by winter maintenance vehicles
- Median crossovers that can be utilized by winter maintenance vehicles
- Off-network areas requiring service by the winter maintenance vehicles included in the optimization
- Link attributes for each road segment documenting:
 - o Functional classification and/or winter maintenance priority level
 - o Winter maintenance vehicle travel speeds
 - o Winter maintenance material spreading rates
 - o Any restrictions on the winter maintenance vehicles compatible with each road/lane
 - o Any restrictions on the material that can be applied
 - o Any deviations from standard cycle time thresholds to account for known hazard areas
 - o Pavement width

The consultant shall review the road network for completeness and accuracy and modify the GIS as necessary to include {select applicable features that are not included in the DOT's GIS files}:

- Representation of individual travel and turn lanes as separate links
- Local roads that may be traversed by winter maintenance vehicles
- Median crossovers that can be utilized by winter maintenance vehicles
- Off-network areas requiring service by the winter maintenance vehicles included in the optimization
- Link attributes for each road segment documenting:

- Functional classification and/or winter maintenance priority level
- Winter maintenance vehicle travel speeds
- Winter maintenance material spread rates
- Any restrictions on the winter maintenance vehicles compatible with each road/lane
- Any restrictions on the material that can be applied
- Any deviations from standard cycle time thresholds to account for known hazard areas
- Pavement width

OR

2.a. The consultant shall be responsible for acquiring a routable road network suitable for winter maintenance routing that includes all roadways that are the responsibility of {state DOT} for winter maintenance within the geographic extent of the project. The consultant shall review and modify the road network as necessary to include the following features:

- Representation of individual travel and turn lanes as separate links
- Local roads that may be traversed by winter maintenance vehicles
- Median crossovers that can be utilized by winter maintenance vehicles
- Off-network areas requiring service by the winter maintenance vehicles included in the optimization
- Link attributes for each road segment documenting:
 - Functional classification and/or winter maintenance priority level
 - Winter maintenance vehicle travel speeds
 - Winter maintenance material spread rates
 - Any restrictions on the winter maintenance vehicles compatible with each road/lane

- o Any restrictions on the material that can be applied
- o Any deviations from standard cycle time thresholds to account for known hazard areas
- o Pavement width

Winter Maintenance Fleet and Equipment

The RFP should provide a description of the winter maintenance fleet and equipment table that is required if a sample is not provided.

2.b. The DOT will provide a tabulation of the winter maintenance vehicles available for routing. For each vehicle in the winter maintenance fleet, the following information will be recorded {omit if providing sample fleet table}:

- The maximum distance the vehicle can travel before refueling
- The vehicle's material capacity for solids, liquids, or both
- The vehicle's compatibility with and access to tow plows or dedicated left-side plows that alter the number of lanes or the type of lane the vehicle can treat in a single pass (if used by the DOT) as well as how many of the plows are available
- The vehicle's home depot or garage

The fleet tabulation will be provided in {file format, e.g. .doc or .csv} format.

OR

2.b. The Consultant shall coordinate with DOT supervisors to develop a tabulation of winter maintenance vehicles available for routing. For each vehicle in the winter maintenance fleet, the following information will be recorded:

- The maximum distance the vehicle can travel before refueling
 - The vehicle's material capacity for solids, liquids, or both
 - The vehicle's compatibility with and access to tow plows or dedicated left-side plows that alter the number of lanes or the type of lane the vehicle can treat in a single pass (if used by the DOT) as well as how many of the plow are available
 - The vehicle's home depot or garage
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Winter Maintenance Facility Locations and Service Territory Boundaries

The RFP should provide a description of the winter maintenance facility locations where routes will begin/end and the service territory boundaries that are required if a sample is not provided. If the project includes vehicle reallocation, the maximum number of winter maintenance vehicles that can be based at each facility and the material storage capacity of the facilities may also be required.

2.c. The DOT will provide GIS files with the locations of all winter maintenance facilities {if vehicle reallocation is included in the optimization also add: the maximum number of vehicles that can be housed at each facility, each facility's material storage capacity,} and service territory boundaries in {software file type, e.g., ESRI ArcGIS shapefile} format.

OR

2.c. The DOT will provide {the address *OR* the latitude and longitude} of all winter maintenance facilities {if vehicle reallocation is included in the optimization also add: the maximum number of vehicles that can be housed at each facility, each facility's material storage capacity,} and service territory boundaries in {software file type, e.g., .doc} format.

OR

2.c. The consultant shall work with DOT staff to document the location of all winter maintenance facilities {if vehicle reallocation is included in the optimization also add: the maximum number of vehicles that can be housed at each facility, each facility's material storage capacity,} and service territory boundaries.

Existing Winter Maintenance Routes

The RFP should provide a description of how information about the existing winter maintenance routes is recorded. Existing routes can be in a GIS or as turn-by-turn directions that are converted into GIS or replicated as in the optimization software. GIS versions of existing routes are preferred and will generally lead to lower project costs.

2.d. The DOT will provide a GIS of existing winter maintenance routes, including the winter maintenance vehicle travel speeds and route completion times in {file format} to support comparisons between existing routes and the optimized routes created for this project.

OR

2.d. The DOT will provide a text file of turn-by-turn directions for each existing route with identification of the territory or facility associated with the route. Vehicle travel speeds and

route completion times will be included to support comparisons between existing routes and the optimized routes created for this project.

OR

2.d. The consultant shall work with DOT staff to document existing winter maintenance routes, including the winter maintenance vehicle travel speeds and route completion times, and shall create a GIS version of these routes to support comparisons between existing routes and the optimized routes created for this project.

Winter Maintenance Operational Practices

The RFP should provide a description of the existing winter maintenance operational practices as described below.

2.e. The consultant shall review the DOT's winter maintenance plan and work with DOT operations staff to document the following elements of winter maintenance operations so that they can be incorporated in the optimization {include all that apply}:

- Accurate winter maintenance vehicle operating speeds reflecting differences in operating speed by road class, mode of operation (deadheading, plowing, or spreading), and weather severity {if conducting multiple weather severity scenarios}
- Accurate material spread rates reflecting differences by road class and weather severity {if conducting multiple weather severity scenarios}
- Roadway prioritization and maximum allowable cycle time thresholds for all road classifications
- Restriction on the compatibility between roadways and vehicles/equipment to ensure that all roadways are treated by appropriately sized and equipped winter maintenance vehicles
- Turn restrictions and penalties so that safer/more efficient turning actions are used preferentially and unsafe turning actions are prohibited
- Treatment strategy for multilane highways, including the use of tow plows and wing plows which alter the number of winter maintenance vehicles needed to clear multiple lanes or limit the lanes that can be serviced by a specific vehicle. {If the DOT utilizes echelon plowing that should be explicitly noted here.}

- Treatment strategies for intersections, ramps, turn lanes, and roundabouts where lanes must be serviced in a specific order or where the equipment that is used deviates from that being used on adjacent road segments
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Project Tasks

Task 1. Project Launch Meeting

The project launch meeting should ensure that there is a common understanding of the project expectations and work plan. It should include a review of the DOT's winter maintenance plan to ensure that relevant operational considerations are captured in the optimization. The involvement of stakeholders at all levels of winter maintenance operations will help to ensure key operational considerations are not overlooked. Suggested participants include the project champion at the DOT, representatives of the DOT's GIS or data management division, district supervisor(s), and one or more drivers from service territory(ies) where the optimization is being conducted. The role of DOT staff sharing data for Task 2 should also be reviewed.

3.a. The consultant shall convene a Project Launch Meeting in the first month of the project to review the project work plan and the DOT's winter maintenance plan. The purpose of this meeting will be to ensure that all relevant operational considerations are captured in the optimization and to finalize the project work plan. The meeting shall include appropriate stakeholders responsible for the state's winter maintenance and data management efforts, as identified by the DOT.

Task 2. Data Acquisition and Preparation

During the data acquisition and preparation phase, the consultant should acquire and modify the data described in the "Data Needs and Sources" section of this template: the GIS road network, winter maintenance fleet tabulation, facility locations, service territory boundaries, and winter maintenance operational practices.

3.b. The consultant shall coordinate with the DOT to acquire data on the GIS road network, winter maintenance fleet, facility locations, service territory boundaries, existing winter maintenance routes, and winter maintenance operation practices to provide the starting point for data preparation. Once acquired, the consultant shall review these data for quality and completeness and make any necessary modifications described in the "Data Needs and Sources" section of this RFP or that are otherwise required for compatibility with the winter maintenance optimization software, the optimization scope, and the optimization scenarios.

Task 3. Draft Route Optimization

For the route optimization task, the consultant will conduct the actual optimization and provide initial routes in an accessible format for the DOT to review. If multiple route optimization scenarios are being conducted, the DOT should consider completing Tasks 3, 4, and 5 for the simplest routing scenario and conducting the route optimization and route review for the additional optimization scenario after one scenario has been completed.

3.c. The consultant shall produce optimized routes for each of the scenarios described in the "Optimization Scenarios" section of this RFP. Optimized routes {and facility locations, service territory boundaries, and fleet allocations, if included in the optimization} shall be provided to the DOT for staff review in the following formats {select all desired formats}:

- Printable turn-by-turn directions in {file format, e.g., .doc or .pdf}
- GIS layer(s) of the routes
- Route files compatible with {navigation device type, e.g. Garmin, TomTom, or Navigon}. If the finalized routes are not compatible with this navigation system, the vendor should propose an alternative format for delivery that supports in-vehicle navigation.

Task 4. DOT Route Review

During the DOT route review, supervisors and/or drivers should drive each of the routes produced for Task 3 to identify any safety issues or other technical problems that would prevent the implementation of the routes. The duration of this task should be long enough that all routes can be reviewed.

3.d. The DOT shall have {# of weeks} to test and review the initial routes. For each route, the DOT will identify any winter maintenance vehicle behaviors that are unsafe or incompatible with winter maintenance operational practices. The DOT will document where on the route these actions occur and provide a list of required revisions to the consultant.

Task 5. Route Revisions

After DOT staff have completed the route review, the consultant should revise the initial routes to address the problematic vehicle behaviors identified during the review process.

3.e. The consultant shall modify the optimized routes to address all winter maintenance vehicle behaviors that the DOT identifies as unsafe or incompatible with winter maintenance operational practices. Revised routes shall be provided to the DOT in the following formats {select desired formats}:

- Printable turn-by-turn directions in {file format, e.g., .doc or .pdf}
 - GIS layer
 - Route files compatible with {navigation device type, e.g. Garmin, TomTom, or Navigon}. If the finalized routes are not compatible with this navigation system, the vendor should propose an alternative format for delivery that supports in-vehicle navigation.
-

Task 6. Comparison of Existing and Optimized Routes

Once routes have been finalized, the consultant should compare the optimized routes to the existing routes in order to quantify the changes in cost and performance that would result from utilizing the new route system.

3.f. The consultant shall detail the overall cost and/or service time savings relative to existing winter maintenance routes and provide a breakdown of savings by garage included in the optimization project. Other indicators of improved performance, such as reductions in deadheading or left turns should also be noted.

Task 7. Final Report

The project's Final Report should document the development of the optimized routes and the cost/service time savings that these routes produce relative to the existing winter maintenance routes documented in Task 2. Demonstrated cost/service time savings can be a key factor for making the case for implementation.

3.g. The consultant shall produce a narrative final report describing the route optimization process and results. The report shall detail the overall cost and/or service time savings relative to existing winter maintenance routes and provide a breakdown of savings by garage included in the optimization project.

In addition to the final report, the consultant shall provide electronic copies of the final input files used in the optimization including the finished routable road network, the route system GIS, and the final vehicle table.
