Optimizing Winter Maintenance Operations with Stacked Technology Solutions
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ABSTRACT

Public agencies responsible for winter maintenance operations have improved performance by utilizing emerging technologies to optimize snowplow routes, to provide navigation to drivers, and to track location and operational parameters. Varying levels of sophistication exist across individual technologies. Route optimization has a wide range of applications, including desk-based investigations to determine if route optimization would reduce the number of routes. It also uses out-of-the-box, point-based Vehicle Routing Problem (VRP) solvers to optimize routes on a static basis or locations of material stockpiles. Route optimization has also been used to eliminate jurisdictional boundaries, in order to increase the size and density of the snowplow network and reduce the number of routes. Driver dispatch tools range from CB radio and paper route maps to in-cab tablets with turn-by-turn navigation. Fleet telematics are used to track material spread rates, plow usage, and other operational metrics.

This paper discusses a winter operations support framework that integrates route optimization, winter operations event management, fleet telematics, and performance measurement/management in a single solution stack. The integrated framework supports the end-to-end process for planning, operations, and continuous improvement.

Snowplow route optimization is based on a configurable model relying on client-driven operational constraints to design and optimize routes for various scenarios. For example, routes may be designed for a two-inch snowstorm with 2°-7°F temperatures or an eight-inch event with 27°-29°F temperatures scenario. Models usually incorporate road network data, winter operational constraints, material depot locations, material type, and Level of Service (LOS) requirements. A web-based winter event management application allows supervisors to plan for a snowstorm, assign routes, monitor work assignment status, and flexibly manage operational situations, including prioritizing routes or handling emergencies. A mobile dynamic routing application allows drivers to receive assignments in real-time and follow assigned routes with turn-by-turn navigation instructions. Integrated fleet telematic technologies, such as AVL mobile data collection systems and in-cab tablets, allow drivers to mark exceptions of a route due to obstructions and receive routing to points of interest, like a salt depot. The integrated solution tracks performance and provides data analytics and reporting capabilities.

In case studies, significant return on investment from this integrated solution stack is derived from improved operational efficiency and a reduction in operational costs by minimizing deadhead miles, eliminating redundant plowing and salting, reducing fuel, salt, labor and equipment usage, and improving service levels.

1 CHALLENGES IN MANAGING WINTER OPERATIONS

Managing winter operations during snowstorms presents a unique set of challenges in order to effectively maintain operating surfaces given resource constraints. Snow and ice on highways present a significant safety, productivity, and maintenance cost issue for state and provincial departments of transportation (DOT) and municipalities in the “snowbelt” across the northern tier of the United States and in Canada. A survey conducted by the American Association of State Highway and Transportation Officials (AASHTO) during the 2014-15 winter found that winter maintenance operations cost over $1.13 billion among 23 responding state DOTs.

Improving public safety and creating better processes are strategic objectives for transportation agencies to meet the needs and expectations of the traveling public. Agencies face significant challenges while working to improve winter operations, including evaluating and optimizing alternative routing strategies to simultaneously minimize deadhead miles, improve service levels, and maximize working miles. Additionally, challenges involve incorporating quantitative decisions related to identifying the most efficient locations for stockpiles and depots, optimal equipment types/quantities and staffing/skill levels to support routing and equipment decisions. Each of these aspects of winter operations are inherently symbiotic and successful planning requires combining a large number of data points, network attributes and a wide variety of assets into a technical optimization framework to develop feasible and economically advantageous strategies for winter operations.

Additional challenges that are typically encountered with winter operations are centered around experience gaps between driver groups. More experienced drivers will typically rely on historical methods of snow removal operations (i.e., completing routes from paper or memory). Furthermore, less experienced drivers that rely on more manual methods have a higher propensity to miss streets. Moreover, the existing paper routes that most agencies are currently using for winter operations were created several years (or decades) prior and may not have been updated with road network changes.

Many agencies currently maintain a 3-1-1 call center or similar service that residents can call to determine when the plow trucks will treat their street and/or to log complaints. In most cases, the calls and complaints are logged, but no database or means of analysis are available for agencies to effectively manage and/or resolve the logged issues. The primary challenge is that the 3-1-1 team does not have adequate data or information to utilize in preparing and responding to issues, emergencies, or complaints regarding winter operations.

Some agencies maintain a public website by which residents can obtain information online, such as the current locations of plow trucks. Challenges related to public websites of this nature include, but are not necessarily limited to, the following:

- The agency does not have a means to collect real-time data on the status of winter operations;
- Data does not exist within the system to show scheduled plow route(s);
- Real-time data is not available to show where the plows are relative to their scheduled routes;
- Data that is collected is inaccurate and/or causes confusion;
- The public website is not user-friendly; and/or
- The information provided is not useful due to lack of necessary data or detail.

Data challenges also exist in trying to recreate an accurate road network for route planning and execution. Conflation of multiple data sets may be needed, in order to capture the entire road network, since public agencies often only have data for those roads under their jurisdiction. Conflation is also required when the road data is inventoried within a Linear Referencing System (LRS). While an LRS is incredibly useful for storing the numerous data classes associated with roads, all data classes must be combined in order to create a network with consistently segmented roads for route planning and execution.

2 WINTER MAINTENANCE TECHNOLOGIES OVERVIEW

Public agencies responsible for winter maintenance operations have improved performance by utilizing emerging technologies to optimize snowplow routes, dispatch routes, provide navigation to drivers, and track location and operational parameters. Varying levels of sophistication exist across these individual technologies. Dispatch operations range from CB radio and paper route maps to in-cab tablets providing turn-by-turn navigation. Automatic Vehicle Locating (AVL) and telematics technology is used to communicate the location of snowplows to the general public via on-line maps, as well as to track where and when plows are done clearing snow and spreaders have dispensed materials.

A review of recent snowplow route optimization efforts by state DOT's shows various project objectives and constraints, as well as differences in project sophistication. Colorado DOT undertook a desk-based investigation to determine if route optimization would provide benefits by reducing the number of routes and improving route efficiency. Its analysis, which evaluated fleet capacity versus the required material capacity to treat the entire study area under any spread rate, determined it would [1]. Subsequent efforts have focused on working closely with regional staff to right-size employee levels to equipment levels [2].

Many DOT optimization studies have used ESRI's ArcGIS Network Analyst Tool which includes a point-based Vehicle Routing Problem (VRP) solver. Delaware used the tool to reduce the total snowplow travel distances and travel times state-wide [3]. The Kentucky Transportation Cabinet used the ESRI optimization tool to study the performance of its current routing procedures. It found that while the optimized results did reduce the number of trucks needed to treat all routes, the tool produced overly complex routes with unrealistic travel paths [4]. Kentucky also experienced common tool failure when too many variables were introduced. Minnesota used the ESRI tool to optimize the location of material depots [5].

Iowa used a memetic algorithm (MA) and a number of constraints (fixed speeds, spreading rates, fleet size, truck capacity, service cycle times, and plow direction) to solve a single-depot winter maintenance routing problem. Its results showed a 13.2 percent reduction in dead-head miles [6]. Ohio, Kentucky, and Wisconsin analyzed optimization improvements by removing boundaries. Ohio removed district boundaries, while Kentucky did so at the county level [7]. Wisconsin took an optimization approach which combined state and county highways to increase its network size and density, thereby reducing the number of routes [8].

The literature suggests the majority of existing winter maintenance optimization efforts have focused on static route optimization, i.e., where a single optimal solution is generated. However, dynamic route optimization to accommodate various snowstorms and resource availability scenarios may be more appropriate due to changing staff and equipment availability along with unique weather events. Operations during a 10-inch snowstorm with a 25 percent reduction in staff will look vastly different from a fully-staffed, 3-inch snowstorm. An adaptive approach to snowplow route optimization and management is proposed as an ultimate goal, providing optimized turn-by-turn instructions to the vehicles in real-time during snowstorms, and dynamically revising these plans as unexpected events (such as blocked roads, equipment problems and emergency requests) force changes [9].

A number of constraints were commonly found and discussed in the literature:

- Personnel - the number of available drivers
- Equipment - the types and number of trucks and plows available (trucks have varying material capacities and fuel range, while plows differ in the direction snow is pushed.)
- Operational - plowing, spreading, or both (impacts the traveling speed and the length of routes/treatable distance) as well as the spread rate (impacts treatable distance)
- Material Type
- Facility locations- home shops, material depots, refuelling stations
- Cycle times
- Levels of Service (LOS)

Winter operations span from pre-season strategic planning to execution, including route design, operation planning for each snowstorm to treat each road, emergency management, and continuous improvement. However, the technologies discussed above do not provide maximum benefits, until they are integrated with one another. For example, using AVL technology without first optimizing routes means agencies will be tracking unneeded deadhead and working miles. Dispatching plow operators to routes they are unfamiliar with using paper routes or CB radios could result in missed segments. Optimizing routes without the use of AVL technology may result in roads being treated with too little or too much material, thereby reducing the level of service or efficiency of the operations.

3 A STACKED TECHNOLOGY FRAMEWORK TO ASSIST WINTER OPERATIONS

Stacking technology solutions provides not only the stand-alone benefits associated with static route optimization and fleet telematics, but synergistic benefits as well. An integrated solution allows for winter maintenance planning, dynamic snowstorm management capabilities, and continuous improvements by measuring and tracking key performance indicators (KPIs). Figure 1 outlines a framework for an integrated solution. Information related to the roadway network, operational constraints, and parameters interface with the various solutions on cloud-based servers via standard web browsers, while cellular networks provide two-way communication capabilities between a fleet and the integrated solutions by relaying information about location and activity.

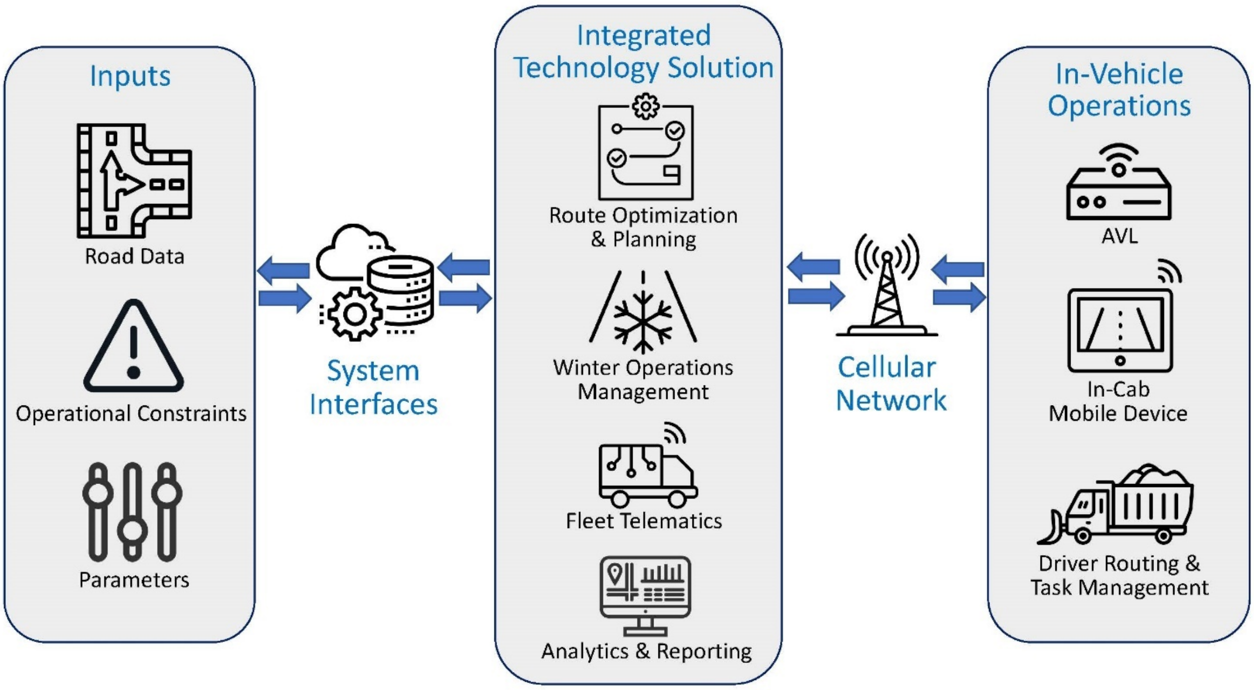

Figure 1 - Stacked Winter Maintenance Operations Technology Framework

Route optimization within the framework is especially suited for winter maintenance planning activities. Routes can be optimized to account for changes to the road network, such as the construction of new roads or the change in maintenance responsibility from one jurisdiction to another. Routes can be optimized to account for changes to operational constraints as well. For example, optimization can be used to plan for the upcoming winter season (based on the number of drivers and equipment expected to be available), to plan for typical snowstorms (based on plow speeds and treatment spread rates of various material types), or to meet cycle times and LOS goals.

Planning for the expansion or contraction of constraints, such as the location of material and fuel depots or division boundaries, can also be accomplished with optimization. It can be used to balance the workload across districts/regions and trucks. Optimization parameters can also be used to understand changes to routes and performance by giving priority to routes providing access to hospitals and schools or those with heavy commuter traffic flows.

Winter maintenance operations management also benefit from the integrated framework. Route optimization can be done dynamically in real-time to account for changes in operational constraints, such as driver and equipment availability or changing parameters in order to assign priority to routes due to special events (e.g., a concert or sporting event). Dynamic capabilities are enabled through cellular-based fleet telematics. AVL technology allows work assignments to be tracked, while in-cab mobile devices in combination with routing technology allows drivers to respond to normal operational situations (such as the need to mark network segments due to obstructions or the need to efficiently route to points of interest). Fleet telematics also allow dispatchers to reassign routes to different drivers when the need arises and provide turn-by-turn instructions to drivers who may not be familiar with an assigned route.

AVL technologies can be used to track the time spent traveling with the plow down or up, as well as the amount of material and spread rate of material applications. Used within an integrated framework, agencies are provided with the ability to analyze and report on the performance of its winter maintenance activities. The AVL integration is an important aspect of the framework, as it assists agencies in justifying past material usage and expenditures, as well as estimating future quantities needed.

Maintaining data records along with the implementation of KPIs allows agencies to continuously improve their performance over time. KPIs for winter maintenance operations can be tracked and analyzed on a per event basis, for the entire season, or for similar winter weather events based on snowfall accumulation (e.g., less than two inches, two to four inches, four to eight inches, and over eight inches) or using a storm severity index which also incorporates wind speeds.

A few examples of winter maintenance KPIs include:

- Time to complete all streets, pre-treatment routes, or plow routes;
- Time to complete each existing pre-treatment route or plow route;
- Deadhead miles incurred to complete all streets, pre-treatment routes, plow routes;
- Level of Service;
- Fuel consumed;
- Amount of material applied (e.g., salt, sand, magnesium chloride, brine, etc.);
- Labor costs; and
- Total costs

4 IMPLEMENTATION AND CASE STUDY

An Integrated Winter Operations Framework can be implemented using cloud and GIS technologies to assist state/provincial DOTs and municipal departments of public works in planning and managing their winter operations. An implementation approach is illustrated in this section, followed by results of recent case studies.

4.1 Integrated Winter Operations Framework Implementation

Implementation of the integrated framework consists of four major systems:

- A route optimization and planning system that takes in digital road data and winter operational constraints, and then designs optimized snowplow routes for each winter operation scenario;
- A web-based application for winter operations supervisors used to assign routes to drivers and keep track of the route completion status;
- A mobile application running on in-cab tablets that helps drivers navigate through each assigned route to plow and treat roads; and
- An AVL/telematics solution that tracks truck position and material application rates and posts information in real-time for stakeholder visibility and review.

This integrated framework implementation enables winter operations to utilize fact-based, quantifiable data to streamline winter operations including strategic planning before the season, operational planning for each snowstorm based on available resources at the time, treating each road in an optimized process, tracking the operation status in real-time, and collecting KPIs for continuous improvement.

4.1.1 *Route Optimization and Planning*

Route optimization and planning is implemented using a data-driven approach to designing routes based on optimization objectives, road network data, and operational constraints in order to improve winter operations service levels. The implementation goes far beyond the typical outcomes of “shortest route” and/or “quickest route” solutions. It provides planners a tool to restructure routes and divisions for the entire organization that minimize deadhead miles, decrease resource usage, reduce operational costs, and improve service levels across the network.

Two types of route optimization approaches are considered in the implementation process:

1. Point-based route optimization. This approach is designed for a routing problem given a set of points to visit. The optimization algorithms will design a set of routes to reach every given point with the least amount of traveling using a pre-defined set of resources and other constraints. Local delivery is a common example of using point-based route optimization.
2. Segment-based route optimization. This approach starts with a set of road segments that need to be serviced and designs routes to traverse all road segments with the least amount of deadhead miles, given the resource and other operational constraints.

Since winter operations are required to treat each road segment in an organization’s responsibility, segment-based route optimization is implemented in the integrated framework. Multiple optimization algorithms such as linear programming, Chinese Postman Problem (CPP), and heuristics are used to implement route optimization and planning. Route optimization and planning uses the entire winter operation road network and other relevant factors such as the ones outlined below to design the routes:

1. The amount of work defined in the road segments for which an organization is responsible. For example, if a work scope is for a district in a state DOT, the entire state highway system in the district is defined as the work scope. If a project is for a city, then all the streets the city is responsible for winter operations will be included in the work scope.
2. The available resources. Typically, these resources include equipment (e.g., trucks), drivers, and depots for salt and sand needed for winter operations.
3. Resource capacity constraints. These factors include equipment/truck capacity, driver capacity (i.e., number of hours available to work), depot capacity, and others that constrain the route design.
4. Service levels. Organizations typically have published service levels. For example, a service level can state that all primary roads must be plowed within three hours. The defined service levels are major factors when designing routes.
5. Other operational constraints. These are factors affecting winter maintenance operational execution. For example, agencies may use different materials (salt, sand, or mixed) on different road categories. Some city streets may be too narrow for the larger trucks. Some roads may need to be treated with priority because they are arterial roads or are on emergency vehicle routes.

The resulting routes from the optimization and planning process include all the details to manage winter operations. Each route includes the sequence of road segments to treat and turn-by-turn instructions to traverse the route from a depot to the first work segment, the remaining segments, and from the last work segment back to the depot. The final optimized routes are output in KML format and can be converted to shapefiles or other digital formats.

Technology-wise, the route optimization and planning system includes three software components: an optimization model that houses all optimization objectives, road data, operation constraints, and other optimization factors in a database; an optimization engine that includes all the optimization algorithms; and a user interface for users to visualize the routes and, if needed, make minor adjustments to the routes. Figure 2 shows an example to use Google Earth user interface to visualize routes for a city division.

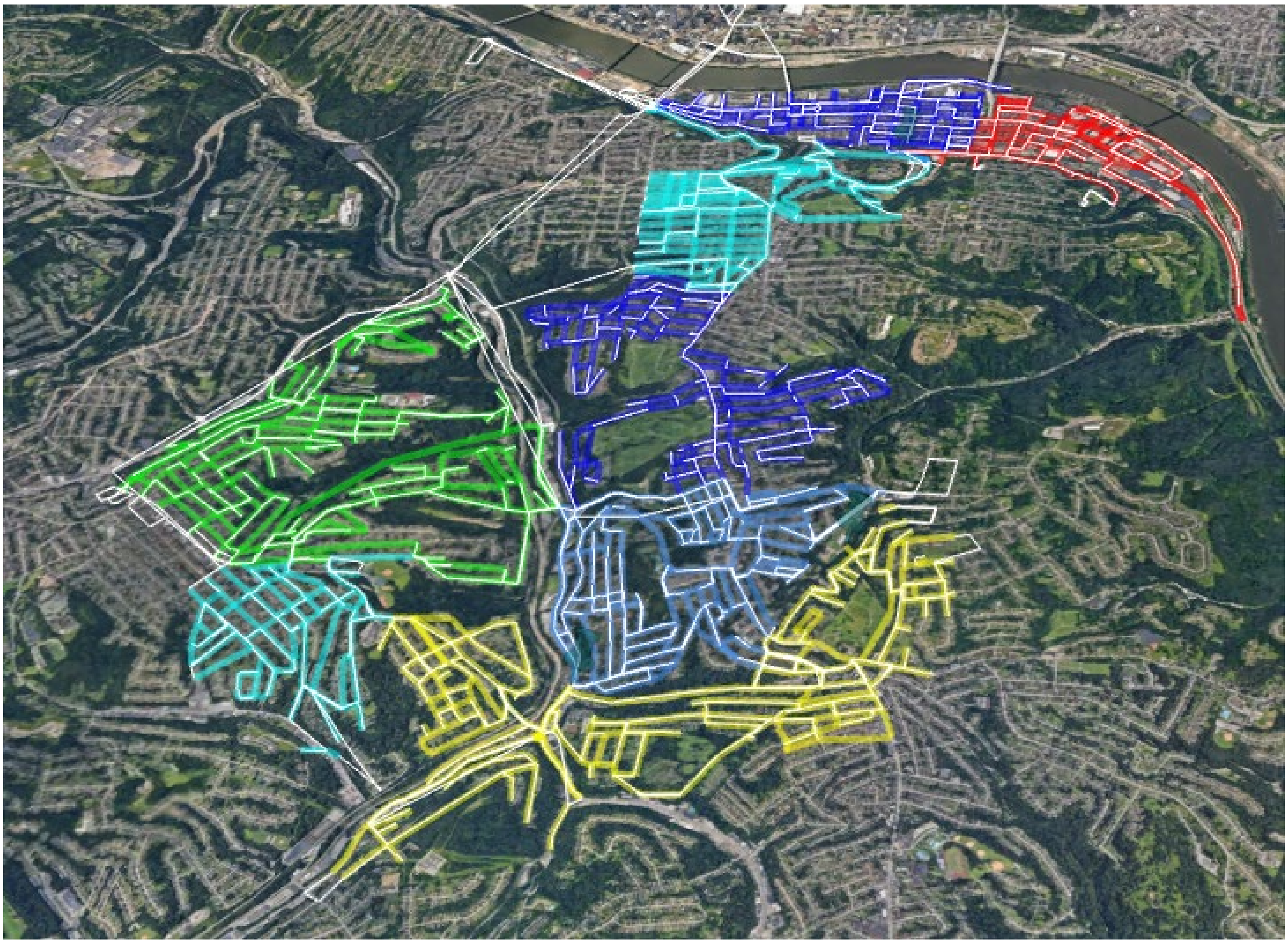

Figure 2 – Visualizing Optimized Routes for a Division using Google Earth

4.1.2 *Winter Operations Management*

A web-based application is deployed to implement winter operations management capabilities in the integrated framework. Once optimized routes are published, the routes are available in the winter operations management application for supervisors to use to manage routes and assignments during each snowstorm.

The application provides capabilities for a supervisor to create a winter operational event when a snowstorm is forecasted. An operational event consists of all the routes to be treated. In the event planning process, the supervisor reviews the routes, creates a task for each route, and assigns the tasks to available drivers and trucks. Figure 3 shows the typical steps a supervisor would follow to assign routes to drivers. Once the tasks/routes are assigned, the application tracks the status of each task/route in real-time and provides management an overall picture of the event status.

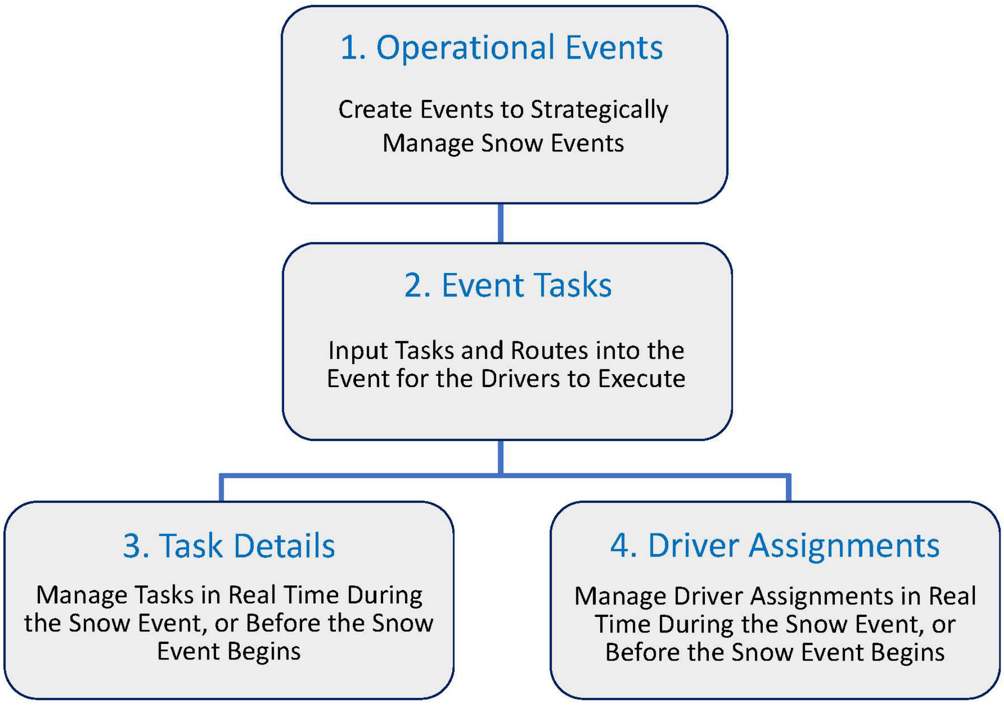

Figure 3 – Winter Operation Event Management Process

In order to support event management for a large organization, a system security structure is implemented to allow the organization to partition the entire state, province, city or region into a hierarchy of smaller management units. Figure 4 illustrates an example where an organization partitions the entire road network into two districts, and each district into three divisions to manage winter operations. An access control structure is implemented to allow supervisors in each division to manage the division's events and routes but disallow users in a different division from accessing the events and routes. For example, supervisors in Division 1-1 have full permission to create events and assign routes to drivers in Division 1-1. However, the same supervisors don't have access to events and routes in Divisions 1-2 and 1-3. On the other hand, senior managers in Headquarters or District 1 can review and manage the events and routes in Division 1-1 on behalf of the division. This system capability empowers the supervisors to manage winter operations in their own divisions. It also provides senior managers at the headquarters or district level with visibility to winter operations across the entire organization and the ability to step in to back up their supervisors, if needed.

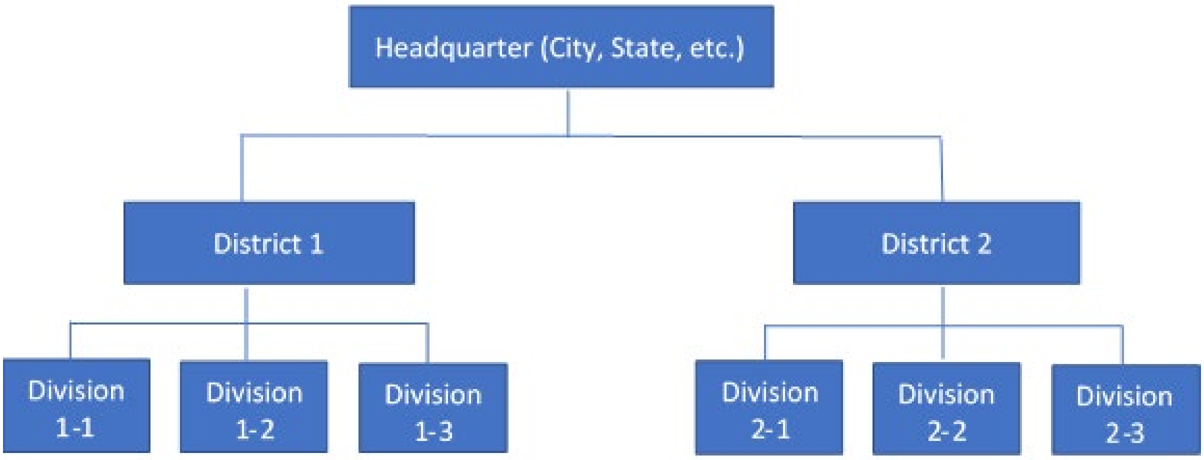

Figure 4 – A Sample Organization Hierarchy for Winter Operation Management

The implemented system provides additional capabilities to help supervisors manage exceptions in winter operations. These exception management capabilities are critical to deal with real-world operation situations. Some of these capabilities include:

- Event and task cancellation. Events and tasks/routes can be cancelled if a winter storm does not come as forecast, or a storm ends and did not leave snow on the roads in some of the neighborhoods or divisions. Supervisors can cancel the tasks or the entire event as appropriate and redeploy the resources.
- Prioritizing tasks. Some routes may have higher priority than the others because the routes cover hospitals or school bus routes that need to be treated first. If a supervisor wants a driver to follow a particular priority order for all the assigned tasks, the priority order would be specified in the assignment process or can be updated during the event using the implemented system.
- Transferring tasks. There are situations that routes must be transferred to another driver. For example, a driver may get called out to deal with an emergency, a driver could call in sick, or a driver's shift is done before the assigned routes are completed. Supervisors need the capabilities to transfer the unfinished routes to another driver. The snow treatment status of the transferred routes needs to be preserved, so the new driver will start with where the previous driver left off.

4.1.3 Driver Routing and Turn-by-Turn Navigation

A mobile app is implemented to run on in-cab tablets to assist drivers in managing their assigned tasks and navigating the routes. Once tasks are assigned, they will be pushed to drivers' in-cab tablets over the internet via cellular signals. Drivers can view the routes they need to work on and use the mobile app to start a route and follow it turn-by-turn using a mapping system for navigation. The navigation app is like a GPS (Global Positioning System) navigation device or Google Map app, with a few key capabilities added for winter operations:

- Treating vs. Traveling. The implemented mobile app provides navigation instructions to get to the starting point of a route and instructs drivers to start treating the roads. It tracks the road treatment progress and provides clear instructions to the driver to just travel on the road or start treating. The tracking capability is critical to assist drivers in treating all roads on the route and avoid double treating some road segments if they travel on the treated segments to get to the next road.
- Managing Incorrect Mapping Data. Incorrect mapping data is a common issue in navigation in that the physical roads deviate from the map on a tablet. Regardless of the mapping system used, there is always a potential lag in updating the mapping data with changes in the road network. The implemented system provides tools for drivers to skip road segments that physically do not exist and continue the process to complete the rest of the route.
- Static vs. Dynamic Routing. Static routing means sending trucks through pre-configured routes with no deviations allowed. This is typically the case when paper routes are used in winter operations. If a driver has to stop in the middle of a route to attend to an emergency, the driver must figure out how to get back to where s/he left off to finish the route. The implemented system includes capabilities for a driver to track where s/he stopped to attend the emergency and provides dynamic routing instructions to navigate back, when the driver is ready to get back to the route. The dynamic routing capability provides the flexibility for drivers to handle exceptions in winter operations efficiently.

4.1.4 *Fleet Telematics*

The integrated tool is a cloud web-based solution for configuration, real-time management and update of GPS telematics during winter operation events, and winter operation data analytics for continuous improvement. Vehicle positions, vehicle status, and material application are automatically updated without any input from the end-user and available for supervisors and senior management to identify and address any operation issues. Some of the key capabilities to help winter operation management during a winter storm include:

- Data collection. Vehicle location and status data is collected in real-time, as well as data from the spreader control system. The collected data is stored on the local device installed on each vehicle, and then transmitted immediately once cell coverage is available and communication is established.
- Management portal. The collected data is available in real-time for supervisors and senior management to monitor ongoing winter operation events and addresses issues as they arise. For example, if a plow truck deviates from an assigned route unexpectedly, a supervisor can investigate the issue right away. If unusually high material application rates are detected, a supervisor can communicate with the driver to make sure the spreader controller has the right settings.
- Geofencing. Management can establish a geofence and get alerted if a truck enters an unexpected area and address the issue immediately.
- Public portal. A portal is available to the public to show where the plow trucks are and the roads that have been treated. The public can make more informed decisions on their commute and travel plans. This tool also reduces phone calls to inquire about winter operations status.

The implemented system also includes data analytics capabilities to help with winter operation continuous improvement. The collected data is processed and rolled up at different hierarchical levels in an organization to generate KPIs for continuous improvement. Management can drill down and across the organization hierarchy to investigate trends and anomalies. For example, supervisors can analyze route completion time, engine hours, odometer, the amount of fuel used, the run time, and the idling time between similar winter operations events or between divisions to detect and address anomalies. Material application rates between routes, or between drivers on the same route can be analyzed to detect any performance differences. Actual road treatment routes and the optimized routes can be compared and analyzed to identify improvement opportunities. The data analytics capabilities transform the collected raw data into decision-making knowledge and help management make effective and accurate decisions to improve winter operations.

4.2 Case Study and Results

4.2.1 *Case Study: City of Pittsburgh Snow Management and Route Optimization*

The primary goal of snow management and route optimization is to streamline winter snowplow operations across the City of Pittsburgh's (City) 2,400 plus lane mile street network and ensure every street within the City of Pittsburgh (under the jurisdiction and responsibility of the Department of Public Works) is treated with deicing materials efficiently, thereby reducing costs and maximizing equipment utilization and efficiency. This goal is being accomplished by integrating, developing, and implementing network planning and optimization strategies that address transportation constraints and improve operational efficiency with a cloud-based event management solution, route navigation and

AVL/Telematics systems. The integrated solution has greatly improved efficiency and reduced costs.

Additional details of the City of Pittsburgh implementation include the following:

1. The City has three roadway classes by which routes are defined: Primary, Secondary, and Tertiary.
2. There are approximately sixty-six (66) total employees in the DPW driver unit, on average 13 drivers work within each of the five (5) divisions. Currently, there are a total of 143 vehicles that are utilized for deicing/plow removal operations. Because snow events cannot always be well-planned ahead of time, drivers may not be available to come to work as a winter weather event. Therefore, during winter weather events, resource bottlenecks may relate to the lack of available drivers.
3. DPW's fleet consists of the following general vehicle types:
    a. 20-ton capacity;
    b. 10-ton capacity;
    c. 8-ton capacity;
    d. 5-ton capacity;
    e. 1-ton capacity and
    f. Industrial tractors.
4. There are many narrow streets in the City, and many of these narrow streets also allow parking on one or both sides of the street. As such, the ten-, eight- and five-ton trucks are not able to physically traverse many streets in the City.
5. In some cases, the one-ton trucks are not able to traverse through certain streets (those with parking on both sides) with the plow down, which causes the City to leave certain areas of the City unplowed.
6. Fuel and salt stations are located in various locations throughout the City. Network design and optimization is a math and database approach applied to complex problems, those with multiple variables and multiple solutions, in order to produce a "best" solution based on the users' stated objectives and available data. In this instance, the objective is to identify the optimal snowplow routes and flow through the City's street network that minimize costs with the resource constraints, such as truck and driver availability and salt depot operation hours.

Return on investment is achieved via improved operational efficiency, a reduction in operating costs by minimizing deadhead miles by five to twenty percent depending on the neighborhoods, eliminating redundant plowing and salting, reducing fuel, salt, labor and equipment usage, and improving service levels. The City of Pittsburgh realized $1 million in salt savings alone in first year of operation. “The technology is already paying for itself and will only lead to more savings year after year.” [10]

4.2.2 *Case Study: Province of New Brunswick Route Optimization Services*

The Province of New Brunswick is conducting a route optimization project along with route optimization management services for approximately 450 vehicles, including plow trucks, graders and loaders. The Province is comprised of six districts with approximately 18,000 lane-km and historically has utilized paper-based routes for plowing, sanding and/or salt operations.

The project scope of work includes building a route optimization model, generating optimized routes and deploying an optimization tool for ongoing route management, which will support the New Brunswick Department of Transportation and Infrastructure’s (DTI) provincial-wide snow management operations. The optimization approach utilizes several optimization algorithms to develop an optimized route structure. The outcome of this project will enable

DTI to streamline their snow removal processes, reorganize snow routes to reduce operational costs, such as a reduction in dead head distance and potentially reconfiguring divisional boundaries to maximize efficiency across the network.

Based on preliminary key performance indicator analysis, the route optimization project is expected to improve safety, better serve the Province's customers, and effectively and efficiently provide comprehensive snow management solutions while reducing costs associated with materials, labor and equipment.

5 SUMMARY

Utilizing a stacked winter maintenance operation technology framework assists public agencies in addressing the number of challenges they face to providing a safe road network in a cost-effective manner. The framework allows agencies to evaluate alternate routing strategies that minimize deadhead miles while improving service levels as well as the locations of material stockpiles and depots. The framework also helps agencies plan for optimal operations based on varying staffing numbers and experience levels, equipment types and quantities, and changes to the road network while ensuring road segments are not missed in a dynamic environment. Lastly, the framework can help agencies respond to resident complaints with up-to-date information as well as communicate in real time the location of snowplows and the fleets' progress in treating and plowing the road network.

The framework is not limited to improving the efficiency of winter maintenance operations. Other public agency responsibilities utilizing routes and work orders can take advantage of the stacked technologies as well. For example, street sweeping and refuse collection both follow regularly travelled, pre-planned routes where route optimization, operations management, fleet telematics, and analytics and reporting would improve performance and efficiency. State and local agencies responsible for mowing grass in public right of ways and spaces would also benefit from having the work optimized, turn-by-turn directions, and task management.

Future work for the framework and winter maintenance operations will focus on further integration of public plow web sites. This integration will communicate a number of items to the general public, including the location of the plow fleet, the status of roads (cleared and/or treated versus not cleared and/or treated), as well as estimates of when roads will be cleared and/or treated by utilizing the location, speed, and historical performance.

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