

Iowa DOT Office of Maintenance Snowplow Optimization

tech transfer summary

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RESEARCH PROJECT TITLE

Iowa DOT Office of Maintenance Snowplow Optimization

SPONSORS

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MORE INFORMATION

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Optimizing winter road maintenance operations could result in significant cost savings, improved safety and mobility, and reduced environmental and societal impacts.

Problem Statement

The current routes for Iowa Department of Transportation (DOT) District 3 are designed based on staff knowledge and past experience. Optimizing these routes may help reduce service distance and deadhead distance (i.e., the distance a truck travels while not performing maintenance service) and allow the routes to more efficiently meet service expectations.

Background

Winter road maintenance activities include removal of snow and ice from roadways and spreading materials (e.g., salt and sand) to increase friction and provide anti-icing and de-icing treatments. While winter road maintenance is essential for providing safe and efficient travel for road users, it is also expensive due to the high cost of equipment, crews, and materials.

Iowa DOT District 3, located in northwest Iowa, services about 4,000 lane miles of roadway—including Interstates, US highways, and Iowa roads—from 20 depots grouped into 6 sectors. Each depot has a defined area of responsibility and a fleet of both single and tandem trucks, each with different capacities.

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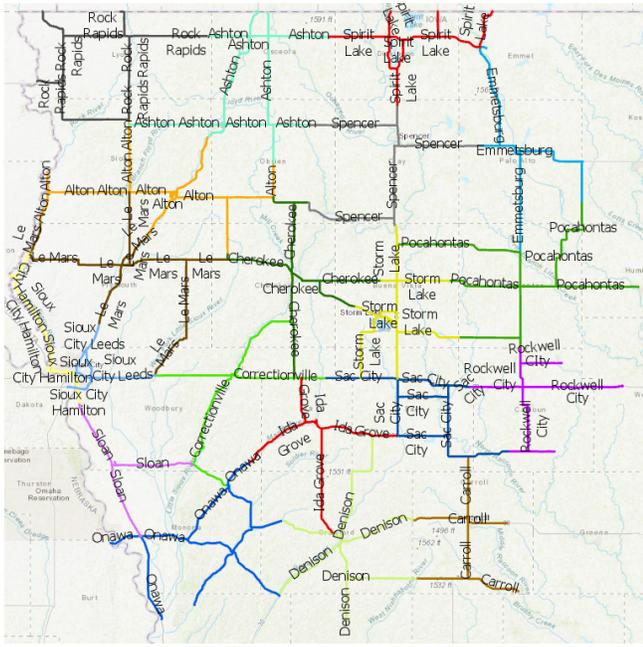
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The Iowa DOT services 24,000 lane miles of roadways, including Interstates, US highways, and Iowa roads, during winter road maintenance operations

Image: Iowa DOT



Service region of Iowa DOT District 3, with 20 depots color-coded and labeled

The district's roadways are categorized into different levels of service, with higher level roads serviced more frequently than lower level roads. Service Levels A, B, and C indicate high-, medium-, and low-priority roads, respectively, based on travel demand and facility type. In addition, urban roads are serviced more frequently than rural roads.

Project Objective

The objective of this project was to design optimized winter maintenance routes for Iowa DOT District 3. The two major tasks included designing optimized routes for the current depot responsibility areas and fleet sizes and designing optimized routes while also modifying the depot responsibility areas and fleet sizes.

Research Methodology

District 3 staff provided information on the district's current winter maintenance operations, including the current snowplow routes, area of responsibility maps, and fleet sizes and compositions for the district's 20 depots.

Automatic vehicle location (AVL) data for the trucks servicing District 3 were used to characterize the district's current operations. The total travel distances and turnaround points were calculated based on data from a test run conducted for this study in December 2017. The service speeds, deadhead speeds, and spreading rates were calculated based on data from three winter storm events in 2017 and 2018.

The Iowa DOT's Roadway Asset Management System (RAMS) was used to build the traffic network for this study. Information was compiled on roadway facility types and service levels and the winter maintenance system. The traffic network was manually processed to further characterize the serviced roads and to associate service and deadhead speeds with service road segments.

Four practical constraints were considered in this study: truck capacity, or the amount of material each truck can carry; the size and composition of the fleet assigned to each depot; road-truck dependency, or the requirement that specific roads be serviced by specific types of trucks; and road segment cycle time, or the frequency at which different roads must be serviced.

Two sets of optimized routes for the district were designed by estimating models to solve two problems, each with the objective of minimizing total travel distance. Both optimization problems were solved as capacitated arc routing problems (CARPs) using a memetic algorithm (MA) and considering the constraints noted above.

The first was a single-depot winter maintenance routing problem, where one depot at a time was considered and the routes were optimized for the district's current responsibility maps. In addition, a parallel metaheuristic approach was developed to improve solution quality and computational efficiency. To explore how the spreading rate might change the optimized routes, a sensitivity analysis with regard to the spreading rate was also conducted.

The second was a multiple-depot winter maintenance routing problem with reload/intermediate facilities, where the depot boundaries within each of the district's six sectors could be redesigned and each truck could reload at any depot or reload station (if any) within the sector.

Key Findings

- For the single-depot problem, the optimized routes reduced deadhead distance by 13.2% compared to current operations. These savings may be even larger in practice because while the optimized routes strictly satisfy all constraints, the current operations might not.
- The parallel metaheuristic approach used for the single-depot problem was found to enhance solution quality and computational efficiency.
- The sensitivity analysis of spreading rate showed that this parameter only impacts routes on Service Level C roadways, because routes on higher level or urban roadways are more strongly bound by the cycle time constraint than the truck capacity constraint.

- That is, trucks that service higher level roadways will exceed the cycle time constraint before using up their material. Meanwhile, trucks on Service Level C roadways will use up their material before exceeding the cycle time constraint if the route's deadhead time is relatively short compared to the service time.
- The total optimized travel distance for all sectors under the multiple-depot scenario is 4,859.8 miles, compared to 4,919 miles under the single-depot scenario. The deadhead distance savings in the multiple-depot scenario compared to the single-depot scenario are 1.2%.
- The difference between the optimized routes resulting from the multiple- and single-depot solutions is insignificant. Since individual depots must perform relatively efficiently under current operations, the district network has already been partitioned into individual depots such that no reload is required.

Recommendations for Future Research

- While this study treated the service cycle time as a hard constraint, in reality cycle time is not strictly enforced, and exceeding the cycle time by a few minutes might significantly improve operational efficiency. The cycle time constraint might better be considered as a penalty or soft constraint.
- This study assumed a fixed service speed and deadhead speed, but in real-world operations these speeds can vary. A stochastic programming approach can be explored to capture speed as a random parameter that follows a probability distribution.
- The parallel metaheuristic algorithm approach used in this study does not guaranteed an optimal result. By carefully tailoring the algorithm to the winter maintenance routing problem, the local optimal solution found through the algorithm could approach the global optimum in a statistical sense.

Implementation Readiness and Benefits

Optimizing winter road maintenance operations could result in significant cost savings, improved safety and mobility, and reduced environmental and societal impacts.

The methods proposed in this study can be used to generate optimized route designs and sector partitions. Inefficiencies in current operations might also be discovered by comparing current routes with optimized routes. Note that if any features of the current network should change, the agency should recalculate the optimized routes.

Given that different material spreading rates can yield different optimized routes and that spreading rate is highly related to snowfall amount, the agency might choose different plans to execute for the network based on storm severity.

The models developed for this study may not represent all practical considerations for real-world operations. The district maintenance manager should therefore be consulted regarding these practical concerns, and routes should be adjusted accordingly.