Snow Plow Route Optimization in Delaware

By

Mingxin Li
Ardeshir Faghri
Dian Yuan
Wanxin Li
Qiuxi Li

April, 2018

Delaware Center for Transportation
University of Delaware
355 DuPont Hall
Newark, DE 19716
(302) 831-1446
The Delaware Center for Transportation is a university-wide multi-disciplinary research unit reporting to the Chair of the Department of Civil and Environmental Engineering, and is co-sponsored by the University of Delaware and the Delaware Department of Transportation.

**DCT Staff**

<table>
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<tr>
<th>Name</th>
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<tr>
<td>Christopher Meehan</td>
<td>Director</td>
</tr>
<tr>
<td>Jerome Lewis</td>
<td>Associate Director</td>
</tr>
<tr>
<td>Ellen Pletz</td>
<td>Business Admin I</td>
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<tr>
<td>Earl “Rusty” Lee</td>
<td>T² Program Coordinator</td>
</tr>
<tr>
<td>Matheu Carter</td>
<td>T² Engineer</td>
</tr>
<tr>
<td>Sandra Wolfe</td>
<td>Event Coordinator</td>
</tr>
<tr>
<td>Mingxin Li</td>
<td>Scientist</td>
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The research reported in this document was prepared through participation in an Agreement sponsored by the State of Delaware’s Department of Transportation and the Federal Highway Administration. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as presenting the official policies or position, either expressed or implied, of the State of Delaware’s Department of Transportation or the U.S. Federal Government unless so designated by other authorized documents.

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Department of Civil & Environmental Engineering
University of Delaware
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Mingxin Li, Ph.D., PTP, Scientist
Ardeshir Faghri, Ph.D., F.ASCE, Professor
Dian Yuan, Ph.D. Candidate
Wanxin Li, M. S.
Qiuxi Li, Ph.D. Candidate

prepared by

Delaware Center for Transportation
Department of Civil & Environmental Engineering
University of Delaware

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for the

Delaware Department of Transportation

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University of Delaware
Delaware Center for Transportation
Authors and Research Team
Mingxin Li, Ph.D., PTP, Scientist, Department of Civil & Environmental Engineering
Ardeshir Faghri, Ph.D., Professor, Department of Civil & Environmental Engineering
Dian Yuan, Ph.D. Candidate, Department of Civil & Environmental Engineering
Wanxin Li, M. S., Department of Computer and Information Sciences
Qiuxi Li, Ph.D. Candidate, Department of Geography

Delaware Department of Transportation
Matt Schlitter, Project Manager, Delaware Department of Transportation
Jason McCluskey, Project Manager, Delaware Department of Transportation
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<td>Winter road maintenance operations are of great importance for driver convenience, safety and mobility. For roadway that regularly encounters storms with snow and ice in an average year, removal of this snow and ice is essential for maintaining safe operations. This snow and ice removal must not only ensure safe operations but also must be efficient because efficient removal is crucial to reducing congestion and the resulting cost and impact that a snow storm has on a road. It is noteworthy to mention that snowplow operations involve more than simply sending out a fleet of snowplows when snow begins to accumulate at a depth of one inch or more on the street surface. Vehicle routing and scheduling problems require that a fleet of vehicles serves a number of requests in order to minimize operational costs. This research will conduct a critical examination of existing snow and ice control practices and procedures. The purpose of this study is to assist DelDOT in determining whether they are appropriately managing their snow and ice removal resources and applying engineering best practices. Specifically, the goal of this research is to develop a GIS-based approach for optimizing snow plow routing in order to minimize the total snow plow truck travel distance and travel times. GIS-based analyses were conducted to not only derive snowplow routing strategies using the proposed methodology, but also draw useful conclusions for winter road maintenance agencies. The research team summarized the results of tasks above, and incorporated the resultant insights and findings into a final report, which will describe how to apply various modeling tools for snow plow route optimization analysis.</td>
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<td>Winter Road Maintenance, Snow Removal, Snow Plowing, Vehicle Routing, GIS, Network Analysis, Route Optimization</td>
<td>No restrictions.</td>
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Executive Summary
Winter road maintenance operations are of great importance for driver convenience, safety and mobility. For roadway that regularly encounters storms with snow and ice in an average year, removal of this snow and ice is essential for maintaining safe operations. This snow and ice removal must not only ensure safe operations but also must be efficient because efficient removal is crucial to reducing congestion and the resulting cost and impact that a snow storm has on a road. It is noteworthy to mention that snowplow operations involve more than simply sending out a fleet of snowplows when snow begins to accumulate at a depth of one inch or more on the street surface. Vehicle routing and scheduling problems require that a fleet of vehicles serves a number of requests in order to minimize operational costs.

This research will conduct a critical examination of existing snow and ice control practices and procedures. The purpose of this study is to assist DelDOT in determining whether they are appropriately managing their snow and ice removal resources and applying engineering best practices. Specifically, the goal of this research is to develop a GIS-based approach for optimizing snow plow routing in order to minimize the total snow plow truck travel distance and travel times. GIS-based analyses were conducted to not only derive snowplow routing strategies using the proposed methodology, but also draw useful conclusions for winter road maintenance agencies. The research team summarized the results of tasks above, and incorporated the resultant insights and findings into a final report, which will describe how to apply various modeling tools for snow plow route optimization analysis.
1. INTRODUCTION

1.1 Problem Statement
According to the Federal Highway Administration, more than 70% of the nation’s roads are located in snowy regions\(^1\). Winter road maintenance operations are of great importance for driver convenience, safety and mobility. In the United States, road maintenance operations on snow and ice control operations consume over 2.3 billion dollars each year.

An important goal of winter maintenance is to keep roads for safe passage. It is noteworthy to mention that snowplow operations involve more than simply sending out a fleet of snowplows when snow begins to accumulate at a depth of one inch or more on the street surface. Vehicle routing and scheduling problems require that a fleet of vehicles serves a number of requests in order to minimize operational costs. Vehicle routing and scheduling problems play an important role in distribution management and have been investigated by several researchers.

The DelDOT snow plow fleet is fairly large, and the capabilities of the equipment have improved with time. Some advancement include: trucks with more plows on them, increased effectiveness of salt, and increased salt storage capacity. With these changes to DelDOT’s equipment, the fleet can be looked at and a determination can be made as to what the correct composition is of the snow plow fleet and what numbers of each class of truck should be operational for a given desired level of service. DelDOT’s performance standards for snow removal are: roadways clear and passable within 24 hours after the end of the snowfall when snowfall is less than 4 inches; between 4 and 8 inches, 48 hours; over 8 inches, 72 hours.

The problem, that this project investigates, is concerned with optimizing snow plow routing and the allocation and use of DelDOT resources with respect to the amount of equipment, supplies and personnel that are or should be available to address the impact snow and ice can have on transportation systems. Given their limited resources, it is essential that DelDOT appropriately manage these resources, ensure coordination of systems, apply appropriate engineering principles, and prevent congestion. The cost of being unprepared for a snow and ice storm can be quite high, but judgments must be made with regard to the amount of investment appropriate for DelDOT to be well equipped for an unusually large snow occurrence.

1.2 Motivation
The research presented here faces the following challenging questions:

\(^1\) http://www.ops.fhwa.dot.gov/weather/weather_events/snow_ice.htm

Snow Plow Route Optimization in Delaware
1. INTRODUCTION

- What is the best allocation of snowplow trucks to sites and routes to snowplow trucks so as to minimize overall deadhead miles?
- Can the current routes for snow removal and brine application be improved?
- What is the optimized route for snow removal and brine application for each DelDOT area yard?
- What parameters of individual routes are most important in terms of overall safety and operation efficiency?

These questions and more should be considered in the design of an effective strategy for conducting winter road maintenance. The recommended schedule that answers these questions must have the minimum total cost among all possible schedules.

The goal of this research project is to develop a model for optimizing snow plow routing in order to be as effective as possible while meeting DelDOT’s performance goals with the maximum efficiency: roadways clear and passable within 24 hours after the end of the snowfall when snowfall is less than 4 inches; between 4 and 8 inches, 48 hours; over 8 inches, 72 hours. The results will then be used by DelDOT to ensure that all primary road links are serviced and total operational costs are minimized.

This project will provide the following benefits:

- It will document the research current best practices with regard to snow plow route optimization.
- It will develop a model for optimizing snow plow routing in order to be as effective as possible.
- The method developed in this project is intended to be used for snow plow route management.

1.3 Report Outline
This report consists of four chapters, which are structured as follows: Chapter 1 gives a brief introduction to our research activities – the problem statement and motivation of our research, the research goal, and our approach.

Chapter 2 provides a comprehensive review of a large amount of previously published evidence about theoretical approaches conducted nationally and internationally as a basis of roadway snow and ice control for practitioners and researchers.

Chapter 3 describes describe the GIS-based snow plow route optimization approach.

Chapter 4 summarizes the findings. Concluding remarks, recommendations for implementation and future research extensions are given in this chapter.

Snow Plow Route Optimization in Delaware
2. LITERATURE REVIEW

2.1 Introduction
This task involves having a thorough understanding of current state of practice, and policies in winter highway maintenance, which is identified in a problem statement, conducting a critical examination of existing snow and ice control practices and procedures and to make recommendations to improve snow and ice control, and identifying the appropriate level of detail and tools. Evaluations of existing research conducted nationally and internationally will be synthesized for key lessons learned, and serve as a basis of roadway snow and ice control for practitioners and researchers.

Key National Snow Removal Analysis Resources
- Snow Removal/National Snow and Ice Data Center
- TRB Surface Transportation Weather Task Force
- TRB Surface Transportation Weather Program Subcommittee
- TRB Winter Maintenance Committee
- TRB Snow Removal and Ice Control Technology Program Subcommittee
- National Weather Service
- National Highway Traffic Safety Administration
- FHWA Safety Program
- AASHTO Highway Safety Manual
- AASHTO Snow and Ice Cooperative Program (SICOP)
- NOAA Surface Weather Program
- OFCM Weather Information for Surface Transportation (WIST)
- Aurora Program
- Clear Roads
- Enterprise Program

Key DelDOT Safety Analysis Resources
- Snow Information - Delaware Department of Transportation
- Snow Facts - Delaware Department of Transportation
- DEOS Snow Monitoring System
- Delaware Primary and Secondary Snow Routes
- Delaware Office of Highway Safety

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2 https://nsidc.org/cryosphere/snow/removal.html
3 http://www.trb.org/AH010/AH010.aspx
4 https://sites.google.com/site/trbcommitteeahd65/Home/subcommittees
5 http://www.erh.noaa.gov/phi
6 http://www.nhtsa.gov/
7 http://safety.fhwa.dot.gov
8 http://sicop.transportation.org/Pages/default.aspx
9 http://surfaceweather.noaa.gov/
10 http://www.ofcm.gov/wg-wist/wg-wist-index.htm
11 http://www.aurora-program.org/
12 http://clearroads.org/
13 http://www.enterprise.prog.org/
14 http://www.deldot.gov/information/community_programs_and_services/snow_prnews/index.shtml
15 http://www.deos.udel.edu/odd-divas/snow_current.php
16 http://www.deldot.gov/information/community_programs_and_services/snow

Snow Plow Route Optimization in Delaware
2. LITERATURE REVIEW

- DelDOT Road Design Manual
- Crash Analysis and Reporting

Academia
- Iowa State University, Center for Weather Impacts on Mobility and Safety
- University Corporation for Atmospheric Research
- University of North Dakota, Surface Transportation Weather Research Center

2.2 Existing numerical and analytical approaches for winter road maintenance

To a significant extent, previous research studies have examined the methods for determining correct snow plow fleet sizing (Table 1).

Table 1: Description of the methods and key findings

<table>
<thead>
<tr>
<th>Study</th>
<th>Key findings</th>
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<tbody>
<tr>
<td>Abdel-Malek, et al. (2014)</td>
<td>This paper considers various costs caused by under estimating and over estimating the needed snow plow fleet sizing for a forthcoming snow season.</td>
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<td>Bertsimas, et al. (1996)</td>
<td>This paper surveys new developments of vehicle routing problems with an emphasis on the insights gained on the algorithms proposed.</td>
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<tr>
<td>Boselly, et al. (2005)</td>
<td>This research used the level of service (LOS) goals from a maintenance management system (MMS) to make recommendations for improving procedures and acquiring resources in order to attain the LOS goals.</td>
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<td>Campbell, et al. (2000)</td>
<td>This research highlights the difficulty of the problems and the weaknesses of theoretical arc routing models for snow and ice control.</td>
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<tr>
<td>Cheung &amp; Powell (1996)</td>
<td>This research compares a successive convex approximation approach with two alternative methods on a set of dynamic fleet management problems.</td>
</tr>
<tr>
<td>Decker, et al. (2001)</td>
<td>Databases and resulting winter maintenance efficiency metrics were developed in this study.</td>
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17 http://www.intrans.iastate.edu/cwims/
18 http://www2.ucar.edu/
19 http://www.atmos.und.edu/
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<tr>
<th>Author(s)</th>
<th>Summary</th>
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<tbody>
<tr>
<td>Eiselt, et al. (1995)</td>
<td>This paper provided a two-part survey of the main known results on arc routing problems.</td>
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<tr>
<td>Fiedrich, et al. (2000)</td>
<td>A mathematical model allowing for calculation of an optimized resource schedule assigning resources in space and time to the affected areas is presented in this paper.</td>
</tr>
<tr>
<td>Funke, et al. (2005)</td>
<td>This paper proposes approach to find a local best neighbor and to reach a local optimum as quickly as possible.</td>
</tr>
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<td>Gendreau, et al. (1992)</td>
<td>This paper describes a new insertion procedure and a new post optimization routine for vehicle routing problem.</td>
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<tr>
<td>Gendreau, et al. (1996)</td>
<td>This paper provides a summary of the scientific literature on stochastic vehicle routing problems.</td>
</tr>
<tr>
<td>Glover (1992)</td>
<td>This paper introduces new ejection chain strategies designed to generate neighborhoods of compound moves with attractive properties for vehicle routing problems.</td>
</tr>
<tr>
<td>Godfrey &amp; Powell (2002)</td>
<td>This research considers a stochastic version of dynamic resource allocation problem.</td>
</tr>
<tr>
<td>Haghani &amp; Qiao (2001)</td>
<td>This research develops a decision support system for assisting the Maryland State Highway Administration Office of Maintenance staff in designing efficient routes for salting trucks in snow emergencies.</td>
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<tr>
<td>Hajibabai, et al. (2014)</td>
<td>A mixed integer linear program model is proposed to minimize the total operation time of all snowplow trucks.</td>
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<tr>
<td>Hanna (2009)</td>
<td>This digest summarizes the findings regarding performance measures of snow and ice control operations.</td>
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<tr>
<td>Jones &amp; Zydiak (1993)</td>
<td>This research develops models for determining optimal steady-state fleet designs.</td>
</tr>
<tr>
<td>Kallehauge, et al. (2005)</td>
<td>This document reviews the algorithms proposed in the last three decades for the solution of the vehicle routing problem.</td>
</tr>
<tr>
<td>Kuemmel (1994)</td>
<td>This document presents information on the state of the practice in managing roadway snow and ice control occurred during the past 20 years to improve winter maintenance.</td>
</tr>
<tr>
<td>Laporte (1992)</td>
<td>This paper surveys some of the main known results relative to the Vehicle Routing Problem.</td>
</tr>
<tr>
<td>Liu, et al. (2014)</td>
<td>This research uses a mathematical optimization model based on the capacitated arc routing problem (CARP) to derive snowplow routing strategies.</td>
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<tr>
<td>Reference</td>
<td>Description</td>
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<tr>
<td>Lotan, et al. (1996)</td>
<td>In this paper, a combined location and routing two-stage framework for salt spreading tours analysis is suggested.</td>
</tr>
<tr>
<td>Marks &amp; Stricker (1971)</td>
<td>A literature review and description of available methods of routing for public service vehicles is presented.</td>
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<tr>
<td>Maze, et al. (2008)</td>
<td>This research surveys snow and ice control organizations in the United States, Canada, Europe, and Asia to determine the current trends in performance measurement.</td>
</tr>
<tr>
<td>Nixon &amp; Foster (1996)</td>
<td>Two surveys were conducted in this report to review current strategies to improve winter maintenance practices.</td>
</tr>
<tr>
<td>Noble, et al. (2006)</td>
<td>This report presents a systematic, heuristic-based optimization approach to solve the primary problems involved in the winter road maintenance planning procedure.</td>
</tr>
<tr>
<td>Pallottino &amp; Scutella (1998)</td>
<td>This paper presents in a framework for solving the shortest path problems in the transportation field.</td>
</tr>
<tr>
<td>Perrier, et al. (2006)</td>
<td>These papers review optimization models and solution algorithms for spreading and plowing operations.</td>
</tr>
<tr>
<td>Perrier, et al. (2007)</td>
<td>This paper reviews optimization models and solution algorithms for the design of winter road maintenance systems for spreading and plowing operations.</td>
</tr>
<tr>
<td>Perrier, et al. (2007a, 2007b)</td>
<td>These papers review optimization models and solution algorithms for the design of winter road maintenance systems for spreading and plowing operations.</td>
</tr>
<tr>
<td>Perrier, et al. (2008)</td>
<td>This paper presents a model and two heuristic solution approaches for the problem of partitioning a road network into sectors and allocating sectors to snow disposal sites for snow disposal operations.</td>
</tr>
<tr>
<td>Pillac, et al. (2013)</td>
<td>This paper presents a comprehensive review of applications and solution methods for dynamic vehicle routing problems.</td>
</tr>
<tr>
<td>Powell &amp; Carvalho, (1998)</td>
<td>This paper presents new algorithms for updating the control variables in the dynamic fleet management problem.</td>
</tr>
<tr>
<td>Powell (1986)</td>
<td>This research presents an empty freight car distribution problem, where known supplies of cars must be allocated to different classification yards to meet uncertain demands.</td>
</tr>
<tr>
<td>Powell (1987)</td>
<td>This paper describes an alternative model which can be used in a real-time environment for determining how to manage a fleet of vehicles under uncertainty.</td>
</tr>
</tbody>
</table>
Regan, et al. (1996) | This paper evaluates the performance of assignment strategies for fleet management.
---|---
Salazar-Aguilar, et al. (2012) | This paper introduces an arc routing problem for snow plowing operation.
Salazar-Aguilar, et al. (2012) | This paper introduces an arc routing problem for snow plowing operation.
Scott & Rudd (2012) | This report provides "best practices" to Delaware local governments on tackling the issue of winter pedestrian-accessibility issues.
Sisiopiku (2011) | This paper reviews potential applications of ITS technologies and products for winter maintenance.
Sochor & Yu (2014) | This report focuses on route optimization for snowplows after snowfall.
Sugumaran, et al. (2005) | This research implements a web-based Winter Maintenance Decision Support System (WMDSS) to evaluate different procedures for managing snow removal assets optimally.
Wang, et al. (1995) | This research introduces a route design decision support system for maintenance engineers of the Indiana Department of Transportation (INDOT) to use in designing snow and ice control service routes.
Wilson, et al. (2003) | This research develops a simulation model of snowplow operations a conceptual design for a predictive maintenance system.
Wright (1988) | This report presents analytical procedure for performing route design and analysis.

### 2.3 Scan of state programs for roadway snow and ice control

Roadway snow and ice control is one of the most complex and fascinating venues for routing applications (Campbell & Langevin, 2000). The primary problems involved in winter road maintenance planning and operation procedure include defining a service level policy, locating depots and assigning arcs to sectors, routing service vehicles, scheduling vehicles, and configuring the vehicle fleet (Noble, et al., 2006). Over the years, a substantial body of research on various aspects of snow and ice control has been created, the majority of it focuses mainly on managing snow and ice operations during the winter months. The New York State Department of Transportation (NYSDOT 2012) developed a highway maintenance guideline for winter road maintenance. The Ohio DOT (2011) developed a guideline and classified road sections into three levels with different priorities for snow removal and deicing operations. The Missouri DOT (2011)
developed a systematic, heuristic-based optimization approach to integrate the winter road maintenance planning decisions and used the historical data to develop a statewide map of weather condition during winter season associated with winter maintenance operation parameters (i.e., winter severity index, winter stability index, and winter instability index. New Jersey Department of Transportation (NJDOT) utilizes contractors for plowing and spreading services in cold climates. Arizona DOT (ADOT) used the level of service (LOS) goals to make recommendations for improving procedures and acquiring resources in order to attain the LOS goals. For more information see Table 3.

2.4 Overview of DelDOT policies and programs

![Figure 1: Standard Operating Procedure](image-url)
2.5 A review of software developed for winter road maintenance

1. Service Autopilot

This management software offers user-friendly interfaces designed to work on mobile devices for snowplow service companies. There are a lot of features in this software, which focus on how to provide convenience and improve profit for snowplow service companies. The inputs include service type, address, date, assigned crew, rate, and hours. The output is GPS tracking.

![Screenshot illustration of Service Autopilot features](https://www.serviceautopilot.com/snow-removal-software)

Figure 2: Screenshot illustration of Service Autopilot features
(A) Calendar, (B) Dispatch Crews, (C) Check the Process of Crews, (D) Move Job and (E) Verify Competed Jobs.

There are a lot of features in this software, which focus on how to provide convenience and improve profit for snowplow service companies:
2. Literature Review

- Web-based
- Two Live 1-on-1 Custom Training Sessions
- Time Tracking & Time Cards
- Dashboards (graphs, charts, etc.)
- Task / To Do / Call Management
- Sales & Basic Marketing
- Email Tracking & Templates
- Advanced Estimating & Pricing System
- Job Costing & Analysis
- Asset Tracking (Installed Equipment)
- Knowledge Base (Wiki)
- Mobile GPS Tracking
- Automatic 2-Way QuickBooks Sync Option ($25/month)

2. Geo3o Snow Removal Tracking Software

---

21 http://geo3o.com/snow-removal/tracking-software/

Snow Plow Route Optimization in Delaware
The interface created in Geo3o provides a series of features to guide non-expert users in inputting the required information: Web-based

- Customize: “Many options are available to customize the application including road colors and action types (salt, plow, sand, etc).”
- GPS Enabled for Activity Tracking
- Alerts (road hazards, etc) can be created and displayed on map.
- Instant Search: “Search for roads instantly and see metrics like Last Pass Time, # of Plow Passes, Total Passes.”

3. C2RouteApp

---

Figure 3: Screenshot illustration of Geo3o Snow Removal Tracking Software

(A) Create Event, (B) Set Up Crews, (C) View an Event, (D) Satellite Map View of Tracking Activity (E) Map Setting and (F) Search.

http://geo3o.com/snow-removal/tracking-software
http://www.c2logix.com
https://c2routeapp.com
C2RouteApp produces the following table and feature as output: turn-by-turn travel directions, export files to a gps device, route statistics reports, truck loading plans and detailed maps as described in Figure 4.

4. Blizzard Buster

Blizzard Buster is desktop management software designed for snowplow service companies. It include full features from managing customers to routing (Figure 5).
Figure 5.: Screenshot illustration of Blizzard Buster\(^{24}\).

(A) Main Page, (B) Routing, (C) Add Route, (D) Calculate Estimated Hours and (E) Print Route List.

5. Jobber

Jobber Software offers the following features:

- GPS Tracking

\(^{24}\) https://www.adkad.com/learn-more/learn-more-blizzard-buster.cfm

Snow Plow Route Optimization in Delaware
- Web-based
- Customer relationship management.
- Invoicing
- Scheduling
- Team Management

Figure 6: Screenshot illustration of Jobber\textsuperscript{25}
(A) Dashboard, (B) Routing, (C) Management, (D) Clients and (E) Add employee.

\textsuperscript{25}https://getjobber.com

Snow Plow Route Optimization in Delaware
3 METHODOLOGY
The goal of this research project is to develop a model for optimizing snow plow routing in order to be as effective as possible while meeting DelDOT’s performance goals with the maximum efficiency: roadways clear and passable within 24 hours after the end of the snowfall when snowfall is less than 4 inches; between 4 and 8 inches, 48 hours; over 8 inches, 72 hours. The results will then be used by DelDOT to ensure that all primary road links are serviced and total operational costs are minimized.

3.1 Snow fact in Delaware

Snow Fact
- Approx. 45,000 Tons of Stored Salt in 20 stockpiles around the state
- On an average storm, 12,000 tons of salt used statewide
- 450 pieces of equipment
- 575 snow-fighting personnel (inc. volunteers)
- Over 13,450 lane miles maintained (not including subdivisions), 87%+ roads within the state.

Figure 7: Salt stockpiles and equipment
(Photo taken on January 4, 2018 Smyrna, DE)

The DelDOT is able to track its plows on the interactive map on the agency’s website or on its app available for Android devices and the iPhone during snow storms (Figure 8, Figure 9).
Figure 8: Screenshot illustration of snowplow tracking map
(03/21/2018 10:04 AM)
3.2 GIS-based snow plow route optimization

ArcGIS is one of the most widely used platforms with integrated collection of GIS software products. ArcMap, the main component of ArcGIS, has abundant sophisticated tools for spatial analysis, geographic data management and building maps. In addition, ArcGIS platform has a good scripting and model builder.

ArcMap Network Analyst provides network-based spatial analysis tools for solving complex routing problems. One of the essential functions of Network Analyst toolset is the Vehicle Routing Problem solver. The VRP solver’s goal is to develop optimized routing solution by minimizing the overall operation cost for the fleets. The VRP solver is developed based on Tabu search metaheuristic. It’s a method for mathematic optimization. The structure of the GIS-based snow plow route optimization method is described as a flowchart in Figure 10. For more information, see Appendix D: GIS-based network analyst and snow plowing route optimization tutorial.

A basic vehicle routing problem (VRP) usually presents a node-to-node routing problem, but our snow plow routing problem is a network covering problem. To convert snow plow routing problem to a basic VRP, some elements are added to the network.

Before solving snow plow routing problem with VRP solver, some preprocessing are needed for establishing a proper GIS map, such as road classification, number of lanes, alignment correcting intersection modification, etc.

Based on the DelDOT Snow Book, the snow plow classification information has been added to GIS map’s attribute table as a new field.

- Interstates – I-95, I-295, I-495
- Primaries (or Arterials) – SR 1, 7, 13, 40, etc.
- Secondaries – Harvey Rd, Pine Tree Rd, Hazelville Rd, Roxana Rd (SR 17), etc.

Snow Plow Route Optimization in Delaware
 Locals – Snuff Mill Road, Blue Jay Ln, Salt Barn Rd, etc.
 Subdivisions – Not in reimbursement program

After network modification, the next critical step is inserting and processing necessary data and information.

- Length Measurement (Using build-in tools to measure the length of each segment; Equidistance coordinate system);
- Travel Time Calculation (Travel Time = Length / Speed Limit);
- Direction information (One-way or Two-way; “FT”, Blank).

After new point layers are created, the nodes were added for every segment (a lane that linking two intersections is one segment). Each segment has at least one node. Since the vehicles are only allowed to make turns at intersections and dead-ends, if the node(s) along a segment is (are) visited, the segment is at least covered by one snow plowing route (Figure 11).

Snow Plow Route Optimization in Delaware
According to the Snow Book, there are two major models of snow removal trucks – 6-wheelers and 10-wheelers. To solve the routing problem, for several sectors, tests were taken within two scenarios. Results are recorded in the final report. For the first scenario, the size of truck was ignored; there was no limitation for 10-wheelers to access lower-class roadways. In the second scenario, the size of truck mattered. 10-wheelers only served primary and secondary roadways.

For example, according to Snow Book, there are three 6-wheelers and two 10-wheelers serving Area 5, Sector D. As mentioned, in the first scenario, both 6-wheelers and 10-wheelers could be assigned to serve low-class roadways; in the second scenario, only 6 wheelers can serve low-class roadways (*Figure 12*).
The following table shows the comparison of the test results for two scenarios. As shown, the access limitation under scenario 2 causes increasing on all statistics. But the total travel time increase is less than 10%; Because of the access limitation, the location of the depots and the proportion of lower-class roadways in network, the trucks might spend more time on necessary trips.

**Table 2: Example for scenario 2**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (Minutes)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>124.99</td>
<td>100.61</td>
</tr>
<tr>
<td>2</td>
<td>95.94</td>
<td>101.51</td>
</tr>
<tr>
<td>3</td>
<td>125.88</td>
<td>123.49</td>
</tr>
<tr>
<td>4</td>
<td>103.08</td>
<td>152.61</td>
</tr>
<tr>
<td>5</td>
<td>128.16</td>
<td>140.30</td>
</tr>
<tr>
<td>Sum</td>
<td>577.96</td>
<td>618.32</td>
</tr>
<tr>
<td>Min</td>
<td>95.94</td>
<td>100.61</td>
</tr>
<tr>
<td>Max</td>
<td>128.16</td>
<td>152.61</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>13.3665</td>
<td>20.7163</td>
</tr>
</tbody>
</table>

*Figure 12: Example for scenario 1*
4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions
The purpose of this study is to assist DelDOT in determining whether they are appropriately managing their snow and ice removal resources and applying engineering best practices. Specifically, the goal of this research is to develop a GIS-based approach for optimizing snow plow routing in order to minimize the total snow plow truck travel distance and travel times.

GIS-based analyses were conducted to not only derive snowplow routing strategies using the proposed methodology, but also draw useful conclusions for winter road maintenance agencies. The research team summarized the results of tasks above, and incorporated the resultant insights and findings into a final report, which will describe how to apply various modeling tools for snow plow route optimization analysis.

The GIS-based method provides a visually based route optimization tool that may be utilized by DelDOT highway maintenance personnel who perform snow and ice control activities. The GIS data and maps are processed for running routing solution. The model is able to create optimized snow plow routes for three counties in Delaware, as well as provide the total cycle times for completing each route. The method is examined repeatedly for different areas under different scenarios. A tutorial is accomplished for instruction.

4.2 Directions for Future Work
In this research, we have presents a route optimization model created for the snow plow routes maintained by the DelDOT. The future recommendation for Roadway snow and ice control operation may include how to assist DelDOT in determining whether they are appropriately managing their snow and ice removal resources and applying engineering best practices. Specifically, what is the correct size and composition of the DelDOT snow plow fleet for snow removal operations? Data collection and categorization will be conducted by means of an Excel spreadsheet to model the weather forecast data and information, pre-assigned vehicles, fleet size, service level and service routes. The input information, in turn, generates the output consisting of delays and costs associated with a given scenario. The analysis will evaluate DelDOT’s snow plow fleet size to determine an optimal size while still being able to effectively meet performance goals. Additionally, a sensitivity analysis will be performed to evaluate the impact of model parameters on the optimum solution.

It is noteworthy to mention that snowplow operations involve more than simply sending out a fleet of snowplows when snow begins to accumulate at a depth of one inch or more on the street surface. Vehicle routing and scheduling problems require that a fleet of vehicles serves a number of requests in order to minimize operational costs. A recent literature review was performed. The research presented here faces the following challenging questions:

- What is the correct size of the DelDOT snow plow fleet for snow removal operations?
4. CONCLUSIONS AND RECOMMENDATIONS

- What the correct composition is of the snow plow fleet?
- What numbers of each class of truck should be operational for a given desired level of service?

These questions and more should be considered in the future design of an effective strategy for conducting winter road maintenance. The goal of this research project is to evaluate DelDOT’s snow plow fleet size to determine an optimal size while still being able to effectively meet performance goals. This project will developed a methodology for efficient deployment of available crew, estimation of workforce requirements, and economic evaluation of the impact of using contract employees and split shifts.

In order to achieve these goals, a fundamental question that needed to be addressed first was the determination of the amount of work induced by different types of storms that occur in Delaware. The purpose of this study is to assist DelDOT in determining whether they are appropriately managing their snow and ice removal resources and applying engineering best practices. To achieve this objective, this project will:

- Analyze relevant snow storm data from a variety of weather reporting sources.
- Tabulate average snowfall for the DelDOT with an inventory of equipment and man power available to address the problems generated by the average snowstorm.
- Consider what can or should be done to prepare for exceptional circumstances and analyze whether or not the DelDOT are appropriately, under-, or over-prepared in being able to manage crisis level snow removal.
- Provide a basis that can potentially assist DelDOT and other agencies in determining whether they are correctly or under managing their winter resources.

The structure of the proposed framework and algorithms solved using a branch-and-bound method is described as a flowchart in Figure 13.
Figure 13: Proposed framework for determining the optimal size of the DelDOT snow plow fleet
REFERENCES


Snow Plow Route Optimization in Delaware


Snow Plow Route Optimization in Delaware


Snow Plow Route Optimization in Delaware


### Appendix A: Snow and ice removal studies by the state DOTs

#### Table 3: Snow and ice removal by various states

<table>
<thead>
<tr>
<th>State DOTs</th>
<th>Title of Documents</th>
<th>Year</th>
<th>Link</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Winter Road Maintenance Priority Map</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highway Winter Maintenance Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emerging Practices in Winter Highway Maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELDOT</td>
<td>South District Emergency Operations Manual</td>
<td>2017</td>
<td>N/A</td>
</tr>
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</table>

Snow Plow Route Optimization in Delaware
<table>
<thead>
<tr>
<th>State DOTs</th>
<th>Title of Documents</th>
<th>Year</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INDOT Plowing Procedures</td>
<td></td>
<td><a href="https://www.in.gov/indot/3222.htm">https://www.in.gov/indot/3222.htm</a></td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Snow removal operations</td>
<td>N/A</td>
<td><a href="https://iowadot.gov/maintenance/winter-operations/snow-removal-operations">https://iowadot.gov/maintenance/winter-operations/snow-removal-operations</a></td>
</tr>
<tr>
<td>KYTC</td>
<td>Snow and Ice - Knowing your salts</td>
<td>N/A</td>
<td><a href="https://transportation.ky.gov/DistrictEleven/Pages/Snow-and-Ice---Knowing-your-salts.aspx">https://transportation.ky.gov/DistrictEleven/Pages/Snow-and-Ice---Knowing-your-salts.aspx</a></td>
</tr>
<tr>
<td>State DOTs</td>
<td>Title of Documents</td>
<td>Year</td>
<td>Link</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Mn/DOT</td>
<td>Mn/DOT Anti-Icing Guide</td>
<td>2010</td>
<td><a href="https://www.dot.state.mn.us/maintenance/pdf/research/AntiicingGuide8Full.pdf">https://www.dot.state.mn.us/maintenance/pdf/research/AntiicingGuide8Full.pdf</a></td>
</tr>
<tr>
<td>NJDOT</td>
<td>NJDOT WINTER OPERATIONS</td>
<td>2015</td>
<td><a href="http://www.state.nj.us/transportation/about/winter/pdf/snowremovalcontractproposal2015.pdf">http://www.state.nj.us/transportation/about/winter/pdf/snowremovalcontractproposal2015.pdf</a></td>
</tr>
<tr>
<td>NDDOT</td>
<td>Snow and Ice Control</td>
<td>N/A</td>
<td><a href="http://www.dot.nd.gov/divisions/maintenance/snow-ice-control.htm">http://www.dot.nd.gov/divisions/maintenance/snow-ice-control.htm</a></td>
</tr>
<tr>
<td>State DOTs</td>
<td>Title of Documents</td>
<td>Year</td>
<td>Link</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>VDOT</td>
<td>VDOT and Emergency Response</td>
<td>2017</td>
<td><a href="http://www.virginiadot.org/about/emergency_response.asp">http://www.virginiadot.org/about/emergency_response.asp</a></td>
</tr>
<tr>
<td>WVDOT</td>
<td>Statewide Snow Removal &amp; Ice Control</td>
<td>2018</td>
<td><a href="https://transportation.wv.gov/winterdriving/Pages/Downloads.aspx">https://transportation.wv.gov/winterdriving/Pages/Downloads.aspx</a></td>
</tr>
</tbody>
</table>
Appendix B: Optimized routes

Sector Maps

Following maps present the snow-plowing classification maps for all sectors within Delaware’s South District of snow-plowing program. There are 5 snow-plowing roads classifications. They are “Primary”, “Secondary”, “Tertiary”, “Suburban” and “Reimburse”.

Table 4: List of the snow-plowing classification maps

<table>
<thead>
<tr>
<th>Area 1</th>
<th>Sector A</th>
<th>Sector B</th>
<th>Sector C</th>
<th>Sector D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 2</td>
<td>Sector A</td>
<td>Sector B</td>
<td>Sector C</td>
<td>Sector D</td>
</tr>
<tr>
<td>Area 3</td>
<td>Sector A</td>
<td>Sector B</td>
<td>Sector C</td>
<td>Sector D</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sector E</td>
</tr>
<tr>
<td>Area 4</td>
<td>Sector A</td>
<td>Sector B</td>
<td>Sector C</td>
<td>Sector D</td>
</tr>
<tr>
<td>Area 5</td>
<td>Sector A</td>
<td>Sector B</td>
<td>Sector C</td>
<td>Sector D</td>
</tr>
</tbody>
</table>
Figure 14: Snow Plow Roads Classification Map – Area 1, Sector A
Snow Plow Route Optimization in Delaware

Figure 15: Snow Plow Roads Classification Map – Area 1, Sector B
Figure 16: Snow Plow Roads Classification Map – Area 1, Sector C
Snow Plow Route Optimization in Delaware

Figure 17: Snow Plow Roads Classification Map – Area 1, Sector D
Figure 18: Snow Plow Roads Classification Map – Area 2, Sector A
Figure 19: Snow Plow Roads Classification Map – Area 2, Sector B
Figure 20: Snow Plow Roads Classification Map – Area 2, Sector C

Snow Plow Route Optimization in Delaware
Figure 21: Snow Plow Roads Classification Map – Area 2, Sector D
Figure 22: Snow Plow Roads Classification Map – Area 3, Sector A

Snow Plow Route Optimization in Delaware
Figure 23: Snow Plow Roads Classification Map – Area 3, Sector B

Snow Plow Route Optimization in Delaware
Figure 24: Snow Plow Roads Classification Map – Area 3, Sector C

Snow Plow Route Optimization in Delaware
Figure 25: Snow Plow Roads Classification Map – Area 3, Sector D
Figure 26: Snow Plow Roads Classification Map – Area 3, Sector E
Figure 27: Snow Plow Roads Classification Map – Area 4, Sector A

Snow Plow Route Optimization in Delaware
Figure 28: Snow Plow Roads Classification Map – Area 4, Sector B

Snow Plow Route Optimization in Delaware
Figure 29: Snow Plow Roads Classification Map – Area 4, Sector C

Snow Plow Route Optimization in Delaware
Figure 30: Snow Plow Roads Classification Map – Area 4, Sector D

Snow Plow Route Optimization in Delaware
Figure 31: Snow Plow Roads Classification Map – Area 5, Sector A
Figure 32: Snow Plow Roads Classification Map – Area 5, Sector B
Figure 33: Snow Plow Roads Classification Map – Area 5, Sector C
Snow Plow Route Optimization in Delaware

Figure 34: Snow Plow Roads Classification Map – Area 5, Sector D
Area 3 – Sector A

To test the ArcGIS based method to solve routing problem, three routing solution has been developed according to two different scenarios. For all scenarios, four vehicles are assumed to complete the snow plowing task for this area. The solution of the routing problem is time-based. The solution will develop the overall least-time-consuming route for each vehicle.

Snow Plow Route Optimization in Delaware
The Solution of Routing Problem - Scenario 1:

For this scenario, all specifications of snow-plow vehicles are ignored. Drivers are assumed to be able to operate all types of vehicles without difficulties on all level roadways.

Figure 36: Snow Plow Route Map – Area 3, Sector A. Scenario 1, Vehicle 1

Snow Plow Route Optimization in Delaware
Figure 37: Snow Plow Route Map – Area 3, Sector A, Scenario 1, Vehicle 2
The Solution of Routing Problem - Scenario 2:

For this scenario, the model of snow-plow vehicles was added into consideration. 10-Wheel snow-plowing trucks are only assigned to serve the primary and secondary roads. The 6-Wheel snow-plowing truck is assigned to serve other classes of roads – tertiary, suburban and reimburse. Figure 38 and Figure 39 present the routing problem solution for the 10-Wheels truck.
Figure 38: Snow Plow Route Map – Area 3, Sector A. Scenario 2, Vehicle 1

Figure 39: Snow Plow Route Map – Area 3, Sector A. Scenario 2, Vehicle 2
Result Comparison:

The snow plow routing results of two scenarios are shown below.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Scenario 1 (Minutes)</th>
<th>Scenario 2 (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>129.73</td>
<td>97.77</td>
</tr>
<tr>
<td>2</td>
<td>140.89</td>
<td>188.01</td>
</tr>
<tr>
<td>Sum</td>
<td>270.62</td>
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</tr>
<tr>
<td>Min</td>
<td>129.73</td>
<td>97.77</td>
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<tr>
<td>Max</td>
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<tr>
<td>STD</td>
<td>5.5800</td>
<td>45.1200</td>
</tr>
</tbody>
</table>

As shown by this table, the total travel times for the two scenarios are similar. Three scenarios have similar total travel time. The maximum of travel time under Scenario 1 are lower. But, the minimum travel time for Scenario 2 are lower. The standard deviation of travel time for Scenario 1 is smaller. However, by comparing the total travel time for all vehicles, it seems the results according to two scenarios are similar.
Area 4 – Sector B

To test the ArcGIS based method to solve routing problem, three routing solution has been developed according to two different scenarios. For all scenarios, four vehicles are assumed to complete the snow plowing task for this area. The solution of the routing problem is time-based. The solution will develop the overall least-time-consuming route for each vehicle.

Figure 40: Snow Plow Roads and Classification Map – Area 4, Sector B
The Solution of Routing Problem - Scenario 1:

For this scenario, all specifications of snow-plow vehicles are ignored. Drivers are assumed to be able to operate all types of vehicles without difficulties on all level roadways.

Figure 41: Snow Plow Route Map – Area 4, Sector B. Scenario 1, Vehicle 1.
**Figure 42: Snow Plow Route Map – Area 4, Sector B. Scenario 1, Vehicle 2.**
Figure 43: Snow Plow Route Map – Area 4, Sector B. Scenario 1, Vehicle 3.

Snow Plow Route Optimization in Delaware
Figure 44: Snow Plow Route Map – Area 4, Sector B. Scenario 1, Vehicle 4.
The Solution of Routing Problem - Scenario 2:

For this scenario, the model of snow-plow vehicles was added into consideration. 10-Wheels snow-plowing trucks are only assigned to serve the primary and secondary roads; 6-Wheels snow-plowing trucks are assigned to serve other classes of roads – tertiary, suburban and reimburse. Figure 45 and Figure 46 present the routing problem solution for two 10-Wheels trucks.

Snow Plow Route Optimization in Delaware
Snow Plow Route Optimization in Delaware

Figure 45: Snow Plow Route Map – Area 4, Sector B. Scenario 2, Vehicle 1.

Figure 46: Snow Plow Route Map – Area 4, Sector B. Scenario 2, Vehicle 2.
Figure 47: Snow Plow Route Map – Area 4, Sector B. Scenario 2, Vehicle 3.
Figure 48: Snow Plow Route Map – Area 4, Sector B. Scenario 2, Vehicle 4.

Snow Plow Route Optimization in Delaware
Result Comparison:

The snow plow routing results of two scenarios are shown below.

Table 6: Snow Plow Routing Results – Area 4, Sector B

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Scenario</th>
<th>1.00</th>
<th>2.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>112.91</td>
<td>125.80</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
<td>140.45</td>
<td>139.48</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
<td>155.38</td>
<td>158.67</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>141.05</td>
<td>179.63</td>
</tr>
<tr>
<td>Sum</td>
<td>1.00</td>
<td>549.79</td>
<td>603.58</td>
</tr>
<tr>
<td>Min</td>
<td>1.00</td>
<td>112.91</td>
<td>125.80</td>
</tr>
<tr>
<td>Max</td>
<td>1.00</td>
<td>155.38</td>
<td>179.63</td>
</tr>
<tr>
<td>STD</td>
<td>1.00</td>
<td>15.3758</td>
<td>20.2868</td>
</tr>
</tbody>
</table>

As shown by this table, the total travel times for the two scenarios are similar. Three scenarios have similar total travel time. The maximum of travel time under Scenario 1 are lower. Additionally, the standard deviation of travel time for Scenario 1 is smaller. However, by comparing the total travel time for all vehicles, it seems the results according to two scenarios are similar.
Area 4 – Sector D

To test the ArcGIS based method to solve routing problem, three routing solution has been developed according to two different scenarios. For all scenarios, four vehicles are assumed to complete the snow plowing task for this area. The solution of the routing problem is time-based. The solution will develop the overall least-time-consuming route for each vehicle.

Figure 49: Snow Plow Roads and Classification Map – Area 4, Sector D
The Solution of Routing Problem - Scenario 1:

For this scenario, all specifications of snow-plow vehicles are ignored. Drivers are assumed to be able to operate all types of vehicles without difficulties on all level roadways.

Figure 50: Snow Plow Route Map – Area 4, Sector D. Scenario 1, Vehicle 1
Figure 51: Snow Plow Route Map – Area 4, Sector D. Scenario 1, Vehicle 2
Figure 52: Snow Plow Route Map – Area 4, Sector D. Scenario 1, Vehicle 3

Snow Plow Route Optimization in Delaware
Figure 53: Snow Plow Route Map – Area 4, Sector D, Scenario 1, Vehicle 4
The Solution of Routing Problem - Scenario 2-1:

For this scenario, the model of snow-plow vehicles was added into consideration. 10-Wheels snow-plowing trucks are only assigned to serve the primary and secondary roads; 6-Wheels snow-plowing trucks are assigned to serve other classes of roads – tertiary, suburban and reimburse. Figure 54 and Figure 55 present the routing problem solution for two 10-Wheels trucks.
Figure 54: Snow Plow Route Map – Area 4, Sector D. Scenario 2-1, Vehicle 1

Figure 55: Snow Plow Route Map – Area 4, Sector D. Scenario 2-1, Vehicle 2

Snow Plow Route Optimization in Delaware
Figure 56: Snow Plow Route Map – Area 4, Sector D. Scenario 2-1, Vehicle 3
Snow Plow Routing Map - Area 4 - Sector D (Scenario 2)

Legend
- Depots
- Vehicle 4
- Roads

Figure 57: Snow Plow Route Map – Area 4, Sector D. Scenario 2-1, Vehicle 4

Snow Plow Route Optimization in Delaware
The Solution of Routing Problem - Scenario 2-2:

Under Scenario 2-1, as shown in Figure 58, the serving route of the vehicle 1 was too short. To improve the effectiveness of the routing result, the task to plow all primary roads are assigned to one vehicle instead of two. The vehicle 2 has been removed from the routing. The routing result was the same as the previous scenario for the vehicle 3 and 4.

Figure 58: Snow Plow Route Map – Area 4, Sector D. Scenario 2-2, Vehicle 1
Result Comparison:

The snow plow routing results of two scenarios are shown below.

Table 7: Snow Plow Routing Results – Area 4. Sector D

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Scenario</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2-1</td>
<td>2-2</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>74.05</td>
<td>22.12</td>
<td>114.08</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>88.97</td>
<td>94.21</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>116.56</td>
<td>158.67</td>
<td>158.67</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>169.07</td>
<td>180.00</td>
<td>180.00</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>448.65</td>
<td>455.00</td>
<td>452.75</td>
</tr>
<tr>
<td>Min</td>
<td></td>
<td>74.05</td>
<td>22.12</td>
<td>114.08</td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td>169.07</td>
<td>180.00</td>
<td>180.00</td>
</tr>
<tr>
<td>STD</td>
<td></td>
<td>36.22</td>
<td>61.61</td>
<td>27.46</td>
</tr>
</tbody>
</table>

As shown by this table, the total travel times for the two scenarios are similar. Three scenarios have similar total travel time. The maximum of travel time under Scenario 1 are lower. Additionally, the standard deviation of travel time for Scenario 1 is small.
Area 5 – Sector D

To test the ArcGIS based method to solve routing problem, two routing solution has been developed according to two different scenarios. For both scenarios, five vehicles are assumed to complete the snow plowing task for this area. The solution of the routing problem is time-based. The solution will develop the overall least-time-consuming route for each vehicle.

Figure 59: Snow Plow Roads and Classification Map – Area 5. Sector D
The Solution of Routing Problem - Scenario 1:

For this scenario, all specifications of snow-plow vehicles are ignored. Drivers are assumed to be able to operate all types of vehicles without difficulties on all level roadways.

Figure 60: Snow Plow Route Map – Area 5. Sector D. Scenario 1, Vehicle 3
Snow Plow Route Optimization in Delaware

**Figure 61: Snow Plow Route Map – Area 5. Sector D. Scenario 1, Vehicle 2**

**Figure 62: Snow Plow Route Map – Area 5. Sector D. Scenario 1, Vehicle 3**
Figure 63: Snow Plow Route Map – Area 5. Sector D. Scenario 1, Vehicle 4

Figure 64: Snow Plow Route Map – Area 5. Sector D. Scenario 1, Vehicle 5

Snow Plow Route Optimization in Delaware
The Solution of Routing Problem - Scenario 2:

For this scenario, the model of snow-plow vehicles was added into consideration. 10-Wheels snow-plowing trucks are only assigned to serve the primary and secondary roads; 6-Wheels snow-plowing trucks are assigned to serve other classes of roads – tertiary, suburban and reimburse. Figure 65 and Figure 66 present the routing problem solution for two 10-Wheels trucks.

Figure 65: Snow Plow Route Map – Area 5. Sector D. Scenario 2, Vehicle 1
Figure 66: Snow Plow Route Map – Area 5. Sector D. Scenario 2, Vehicle 2

Figure 67: Snow Plow Route Map – Area 5. Sector D. Scenario 2, Vehicle 3

Snow Plow Route Optimization in Delaware
Figure 68: Snow Plow Route Map – Area 5. Sector D. Scenario 2, Vehicle 4

Figure 69: Snow Plow Route Map – Area 5. Sector D. Scenario 2, Vehicle 5

Snow Plow Route Optimization in Delaware
Result Comparison:

The snow plow routing results of two scenarios are shown below.

Table 8: Snow Plow Routing Results – Area 5, Sector D

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>124.90</td>
<td>100.61</td>
</tr>
<tr>
<td>2</td>
<td>95.94</td>
<td>101.31</td>
</tr>
<tr>
<td>3</td>
<td>125.88</td>
<td>123.49</td>
</tr>
<tr>
<td>4</td>
<td>103.08</td>
<td>152.61</td>
</tr>
<tr>
<td>5</td>
<td>128.16</td>
<td>140.30</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>577.96</strong></td>
<td><strong>618.32</strong></td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td><strong>95.94</strong></td>
<td><strong>100.61</strong></td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td><strong>128.16</strong></td>
<td><strong>152.61</strong></td>
</tr>
<tr>
<td><strong>STD</strong></td>
<td><strong>13.3653538</strong></td>
<td><strong>20.71639891</strong></td>
</tr>
</tbody>
</table>

As shown by this table, the total travel times for the two scenarios are similar. The Scenario 1 has a lower total travel time than the other. The maximum and minimum and the standard deviation of travel time under Scenario 1 are lower.
## Appendix C: List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADOT</td>
<td>Arizona Department of Transportation</td>
</tr>
<tr>
<td>AHTD</td>
<td>Arkansas State Highway and Transportation Department</td>
</tr>
<tr>
<td>ALDOT</td>
<td>Alabama State Department of Transportation</td>
</tr>
<tr>
<td>Caltrans</td>
<td>California Department of Transportation</td>
</tr>
<tr>
<td>CDOT</td>
<td>Colorado Department of Transportation</td>
</tr>
<tr>
<td>CONNDOT</td>
<td>Connecticut Department of Transportation</td>
</tr>
<tr>
<td>DE</td>
<td>Delaware</td>
</tr>
<tr>
<td>DELDOT</td>
<td>Delaware Department of Transportation</td>
</tr>
<tr>
<td>ADOT&amp;PF</td>
<td>Alaska Department of Transportation and Public Facilities</td>
</tr>
<tr>
<td>DOTD</td>
<td>Louisiana Department of Transportation and Development</td>
</tr>
<tr>
<td>FDOT</td>
<td>Florida Department of Transportation</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>GDOT</td>
<td>Georgia Department of Transportation</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HDOT</td>
<td>Hawaii Department of Transportation</td>
</tr>
<tr>
<td>I</td>
<td>Interstate (route)</td>
</tr>
<tr>
<td>IDOT</td>
<td>Illinois Department of Transportation</td>
</tr>
<tr>
<td>INDOT</td>
<td>Indiana Department of Transportation</td>
</tr>
<tr>
<td>Iowa DOT</td>
<td>Iowa Department of Transportation</td>
</tr>
<tr>
<td>ITD</td>
<td>Idaho Transportation Department</td>
</tr>
<tr>
<td>KDOT</td>
<td>Kansas Department of Transportation</td>
</tr>
<tr>
<td>KYTC</td>
<td>Kentucky Transportation Cabinet</td>
</tr>
<tr>
<td>MaineDOT</td>
<td>Maine Department of Transportation</td>
</tr>
<tr>
<td>MassDOT</td>
<td>Massachusetts Department of Transportation</td>
</tr>
<tr>
<td>Max</td>
<td>Maximum</td>
</tr>
<tr>
<td>MDOT</td>
<td>Maryland Department of Transportation</td>
</tr>
<tr>
<td>MDOT</td>
<td>Michigan Department of Transportation</td>
</tr>
<tr>
<td>MDOT</td>
<td>Mississippi Department of Transportation</td>
</tr>
<tr>
<td>MDT</td>
<td>Montana Department of Transportation</td>
</tr>
<tr>
<td>Min</td>
<td>Minimum</td>
</tr>
<tr>
<td>MnDOT</td>
<td>Minnesota Department of Transportation</td>
</tr>
<tr>
<td>MoDOT</td>
<td>Missouri Department of Transportation</td>
</tr>
<tr>
<td>NCDOT</td>
<td>North Carolina Department of Transportation</td>
</tr>
<tr>
<td>NCHRP</td>
<td>National Cooperative Highway Research Program</td>
</tr>
<tr>
<td>NDDOT</td>
<td>North Dakota Department of Transportation</td>
</tr>
<tr>
<td>NDOR</td>
<td>Nebraska Department of Roads</td>
</tr>
<tr>
<td>NDOT</td>
<td>Nevada Department of Transportation</td>
</tr>
</tbody>
</table>
NHDOT  New Hampshire Department of Transportation
NJDOT  New Jersey Department of Transportation
NMDOT  New Mexico Department of Transportation
NYSDOT  New York State Department of Transportation
ODOT  Ohio Department of Transportation
ODOT  Oklahoma Department of Transportation
ODOT  Oregon Department of Transportation
PennDOT  Pennsylvania Department of Transportation
RIDOT  Rhode Island Department of Transportation
SCDOT  South Carolina Department of Transportation
SDDOT  South Dakota Department of Transportation
SR  State Route
STD  Standard Deviation
TDOT  Tennessee Department of Transportation
TxDOT  Texas Department of Transportation
UDOT  Utah Department of Transportation
US  United States (route)
USDOT  United States Department of Transportation
VDOT  Virginia Department of Transportation
VPH  Vehicles Per Hour
VTrans  Vermont Agency of Transportation
WisDOT  Wisconsin Department of Transportation
WSDOT  Washington State Department of Transportation
WVDOT  West Virginia Department of Transportation
WYDOT  Wyoming Department of Transportation

Snow Plow Route Optimization in Delaware
Delaware Center for Transportation
University of Delaware Newark,
Delaware 19716

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(302) 831-8063
titleixcoordinator@udel.edu

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(302) 831-4643

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