ROUTE OPTIMIZATION

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16. Abstract

For winter maintenance purposes, the Ohio Department of Transportation (ODOT) deploys a fleet of approximately 1,600 snow plow trucks that maintain 43,000 lane miles of roadway. These trucks are based out of 200 garages, yards, and outposts that also house 650,000 tons of salt (ODOT, 2011). The deployment of such a large number of trucks over a vast maintenance area creates an operational problem in determining the optimal maintenance routes and fleet size. In recent years, several advances have been made in route optimization that may aid in determining the required number of trucks and the area that these trucks should maintain throughout the state of Ohio. Traditionally, ODOT has used county borders as maintenance boundaries for ODOT garages. However, by removing these borders and optimizing the snow plow routes, ODOT may benefit from a significant time and cost savings. For the purpose of route optimization, ODOT Districts 1, 2, and 10 have been selected to serve as case studies for this project.

The results of this project will provide ODOT a tool to determine the minimum number of trucks needed to maintain the necessary roadways within Districts 1, 2, and 10. In addition, the project provides ODOT a tool to assign assets to specific facilities and the most optimal routes for each truck in the district. This research may result in a reduction of fleet sizes and a significant cost savings while maintaining an equal or better LOS.

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Customary Unit	SI Unit	Factor	SI Unit	Customary Unit	Factor
Length			Length		
inches	millimeters	25.4	millimeters	inches	0.039
inches	centimeters	2.54	centimeters	inches	0.394
feet	meters	0.305	meters	feet	3.281
yards	meters	0.914	meters	yards	1.094
miles	kilometers	1.61	kilometers	miles	0.621
Area			Area		
square inches	square millimeters	645.1	square millimeters	square inches	0.00155
square feet	square meters	0.093	square meters	square feet	10.764
square yards	square meters	0.836	square meters	square yards	1.196
acres	hectares	0.405	hectares	acres	2.471
square miles	square kilometers	2.59	square kilometers	square miles	0.386
Volume			Volume		
gallons	liters	3.785	liters	gallons	0.264
cubic feet	cubic meters	0.028	cubic meters	cubic feet	35.314
cubic yards	cubic meters	0.765	cubic meters	cubic yards	1.308
Mass			Mass		
ounces	grams	28.35	grams	ounces	0.035
pounds	kilograms	0.454	kilograms	pounds	2.205
short tons	megagrams	0.907	megagrams	short tons	1.102

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LIST OF ACRONYMS

lbs/ln mile	Pounds per Lane Mile
ODOT	Ohio Department of Transportation
GIS	Geographic Information System
GPS	Global Positioning System
VRP	Vehicle Routing Problem
ROM	Route Optimization Model
LOS	Level of Service
TIMS	Transportation Information Mapping System

CHAPTER I INTRODUCTION

For winter maintenance purposes, the Ohio Department of Transportation (ODOT) deploys a fleet of approximately 1,600 snow plow trucks that maintain 43,000 lane miles of roadway. These trucks are based out of 200 garages, yards, and outposts that also house 650,000 tons of salt (The Ohio Department of Transportation, 2011). The deployment of such a large number of trucks over a vast maintenance area creates an operational problem in determining the optimal maintenance routes and fleet size. In recent years, several advances have been made in route optimization that may aid in determining the required number of trucks and the area that these trucks should maintain throughout the state of Ohio. Traditionally, ODOT has used county borders as maintenance boundaries for ODOT garages. However, by removing these borders and optimizing the snow plow routes, ODOT may realize a significant time and cost savings.

1.1 Purposes and Objectives

The purposes of this project are to optimize snow and ice routes for ODOT's snow plow trucks in Districts 1, 2, and 10 while eliminating county border restrictions. In order to ensure that the purposes of this project were satisfied, the University of Akron research team developed the following objectives:

- Objective One – Digitize base routes and input ODOT facilities and plowing locations;
- Objective Two – Remove county border restrictions and optimize routes for each truck;
- Objective Three – Place GPS recorders in trucks and collect data regarding actual cycle times; and
- Objective Four – Set maximum cycle times and determine which garages may remove trucks and which need additional trucks.

1.2 Benefits from this Research

There are numerous benefits expected from the outcome of this project. One important benefit will be an analysis that justifies the fleet size in three of ODOT's twelve districts and, accordingly ensures that ODOT maintains all of the required roadways within the involved districts in an efficient and economical manner. In addition, each facility within Districts 1, 2, and 10 will know the specific roadways that it must maintain, regardless of the amount of resources available during winter maintenance operations. Another benefit of this research is that the Route Optimization Model (ROM) serves as a tool to analyze new equipment technology and new operational considerations. This tool is invaluable for ODOT district leadership as they determine where to allocate limited resources within the district. This benefit extends further by revealing areas of concern within the district, thus guiding future facility location and construction.

1.3 Organization of this Report

This report is divided into ten chapters. Chapter 1 introduces the topic and defines the objectives to be completed for this research project. Chapter 2 provides background information obtained prior to the beginning of the project as well as the tools that were utilized. Chapter 3 provides information of the project setting, in particular, the districts involved and their characteristics. Chapter 4 presents the methodology of the route optimization. Chapter 5 consists of an analysis of the current routes being used for winter maintenance operations. Chapter 6 presents the results obtained from the initial optimized routes. Chapter 7 provides the route verification process and results for each district. Chapter 8 summarizes the fleet optimization for each district. Chapter 9 presents the vulnerable areas for each district. Chapter 10 presents the implementation plan for the optimized trucks within each district's fleet.

CHAPTER II BACKGROUND

This chapter provides information regarding the background of the project to include a literature review and route optimization tools used for the project. This chapter is divided into two sections:

- Section One – Literature review; and
- Section Two – Route optimization tools.

2.1 Literature Review

Upon determining the potential cost savings regarding the optimization of winter maintenance operations, the research team conducting a literature review on how optimization models were created and implemented within other agencies and organizations. The literature review consists of articles published academically and a look at state Departments of Transportation regarding the optimization of fleets or individual vehicles. A summary of the findings is shown in Table 2.1 below.

Table 2.1: Literature Review Summary

Project Goal	**Methodology**	**Findings**	**Reference**
Provide a sustainable optimization of winter maintenance service by maximizing the potential of the service to ensure steady traffic conditions for Kraljevica, Croatia.	Develop a model to take route optimization away from human managers and use computer models based on the Soyster Heuristic.	The analysis shows that current maintenance fleet numbers and depot locations are sufficient for optimal road maintenance of the city.	(Gudac, Hanak, & Marovic, 2014)
Develop snow and ice control operations storm specific routes designed to maximize the efficiency of the service provided in terms of man-hours and fuel.	Optimize the vehicles by garage based on the combined service time/fuel consumption metric. Evaluate the competing vehicle allocations based on the speed with which high priority roads are serviced.	Allocations based on Roadway NRI allowed the state to optimize both man hours and fuel consumption.	(Dowds, Novak, Scott, & Sullivan, 2013)
Implement a synchronized routing problem for the snow plowing operations	Develop a model to synchronize arc routing for winter maintenance operations.	An improvement was added to the optimizing algorithm that resulted in significant improvement to the efficiency of the plowing model.	(Salazar-Aguilar, Langevin, & Laporte, 2012)

Optimize the routes and fleet allocations for Missouri DOT to provide a sufficient level of service (LOS).	Develop an integrated algorithm for Missouri DOT to determine the most efficient route plans and fleet allocations	A list of various conditions and response as needed for the Missouri DOT.	(Jaung, 2011)
Determine optimal workforce planning and shift scheduling for snow and ice removal.	Develop a methodology for deployment of available crews and equipment to maintain the most efficient implementation of resources.	Use of contract employees reduces the total cost to Missouri DOT.	(Gupta, 2010)
Develop a data model to represent the transportation network of an urban area to be used for route planning.	Develop an urban transportation network using standard and customized GIS software tools.	A model was developed that incorporated a multimodal network with restrictive attributes to represent real world scenarios.	(Mandloi & Thill, 2010)
Determine methods for producing optimal deployment schedules to conduct winter maintenance operations.	Develop a model to take into account a variety of road and weather conditions to aid in winter maintenance operations planning.	Provides a method to produce optimal deployment schedules and a framework to compare future research.	(Fu, Trudel, & Kim, 2009)
Enhance a decision support system for assisting the Maryland State Highway Administration's Office of Maintenance staff in designing snow emergency routes for Calvert County, MD.	Assign segments of the treated road network to trucks so that the number of trucks is minimized and all routes are continuous.	The Genetic Algorithm with First Fit heuristic reduces the number of minimum trucks for Calvert County from 14 to 12 trucks (14%).	(Haghani & Hamedi, 2002)
Determine how to use arc routing methods to determine routing.	Analyze arc routing methods and applications.	Developed a list of steps to use for conducting arc routing methods.	(Assad & Golden, 1995)
Develop a model to predict costs and benefits of winter maintenance operations in the state of Idaho.	Using historical data, develop a model for each district to accurately predict costs and benefits of winter maintenance operations.	The model assists in estimating the benefits to safety, travel time, and fuel cost.	(Haber & Limage, 1990)
Provide a description of a computer application to assist in determining the routing of street sweepers.	Use computer programs to optimize the routes for street sweeping trucks.	Provides a list of steps to create route optimizing models.	(Bodin & Kursh, 1979)

The findings listed in Table 2.1 on the previous page support the idea that the optimization of ODOTs winter maintenance fleet may result in cost savings while maintaining current levels of service (LOS) within the districts. In addition, the findings from the literature review assisted the research team in developing a methodology to conduct the route optimization within ODOT Districts 1, 2, and 10.

2.2 Route Optimization Tools

The research team performed the route optimization work using ArcGIS, a geographic information system (GIS) platform developed by Esri (based in Redlands, California) to produce optimized routes in the form of GIS-based maps. Since ODOT is already familiar with this program, the results of the proposed project may be easily incorporated into ODOT's current maintenance operations. While complex optimization algorithms are performed in the ArcGIS program, no computations or coding are required by the end users, which will make it easy for ODOT winter maintenance personnel to implement the optimized routes.

2.2.1 Network Analyst

Within ArcGIS is the Network Analyst extension which allows users to conduct analyses on transportation networks (Esri, 2016). Network Analyst was used to create an accurate Network Dataset that facilitated the optimization of the snow and ice routes within the involved ODOT districts. The Network Dataset included all roadways within the districts with turning, speed, and elevation data that accurately represented real world conditions. Further details regarding the creation of the Network Dataset may be found in Chapter Four of this report.

2.2.2 Vehicle Routing Problem

Upon completion of developing an accurate Network Dataset within the Network Analyst extension, the Vehicle Routing Problem (VRP) tool was used to generate optimized routes for the three districts involved with the project. The VRP was initially created by Esri to allow organizations to determine the most efficient route (or routes when considering a fleet of vehicles) to service orders, thus saving time and money. For the purposes of this project, the orders that were to be serviced were roadways that ODOT is responsible to maintain. More details regarding the utilization of the VRP to determine the optimized routes for snow and winter maintenance may be found in Chapter Four of this report.

2.2.3 QTravel

The research team validated the proposed routes from the ROM by utilizing the computer program QTravel. This program was created by QStarz, a business based in Taipei, Taiwan whose goal is to "bring GPS and Bluetooth technology into the consumer mainstream" (Qstarz, 2013). The software and GPS Travel Recorders produced by QStarz were essential in collecting and analyzing the data obtained from driving the optimized routes. Further details regarding the validation of the optimized routes may be found in Chapter Four of this report.

CHAPTER III PROJECT SETTING

This chapter provides information about the geographical setting for the project. This chapter is divided into four sections:

- Section One – Project Setting;
- Section Two – ODOT District 1;
- Section Three – ODOT District 2; and
- Section Four – ODOT District 10.

3.1 Project Setting

The route optimization project was conducted in ODOT Districts 1, 2, and 10. As shown in Figure 3.1 below, these districts represent the Northwestern and Southeastern corners of the State, areas that possess unique geographic and meteorological demands when conducting winter maintenance operations.

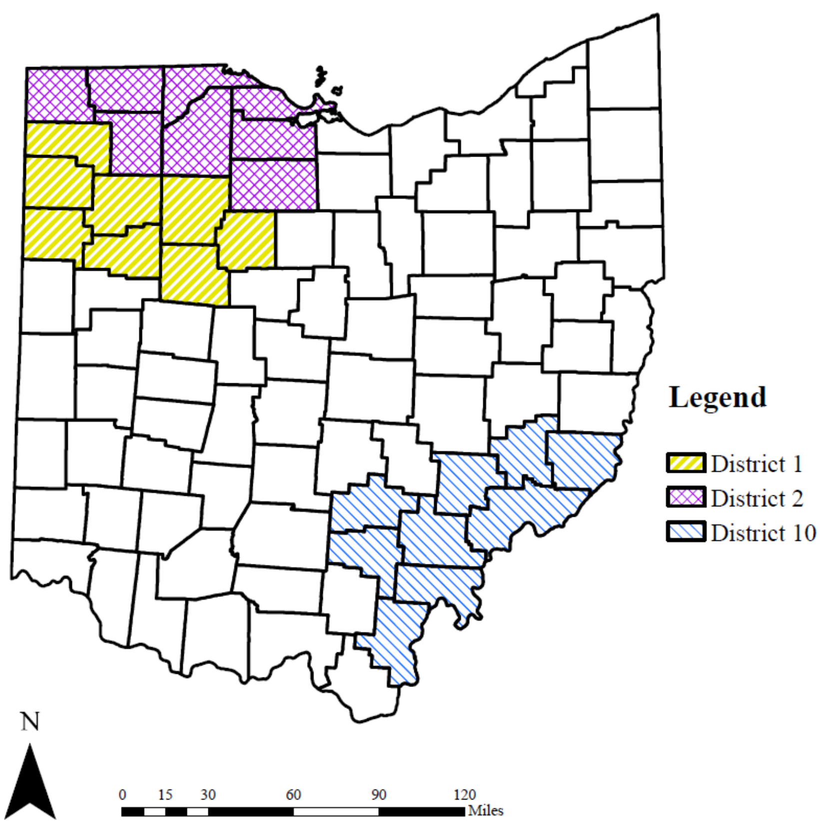
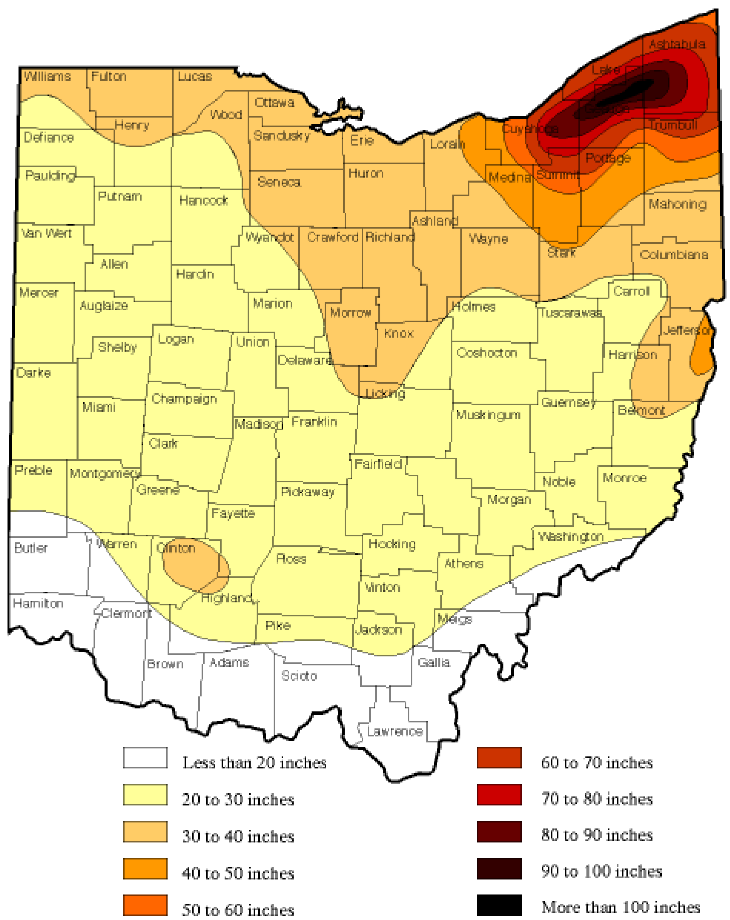


Figure 3.1: ODOT Districts involved with the Route Optimization Project.

Figure 3.2 below shows the average annual snowfall throughout the state of Ohio (The Ohio Department of Transportation, 2011). As observed from Figures 3.1 and 3.2, the three districts involved with the Route Optimization Project do not receive the greatest amounts of snowfall within the state. However, as described in the following sections of this chapter, the Northwest and Southeast regions of the state possess unique geographic challenges that may be mitigated through the use and implementation of the optimized routes derived from this project.



Obtained from ODOT Snow and Ice Practices, 2011

Figure 3.2: Average Yearly Snowfall in Ohio.

The snowfall ranges in these three districts vary from less than 20 inches to 40 inches on average. However, a wide range of factors impact winter maintenance treatment. More details about these districts are presented in this chapter.

3.2 ODOT District 1

ODOT District 1 is located in the Northwestern Region of Ohio and consists of Allen, Defiance, Hancock, Hardin, Paulding, Putnam, Van Wert, and Wyandot counties (The Ohio Department of Transportation, 2016). The geography of the region primarily consists of level terrain as shown in Figure 3.3.

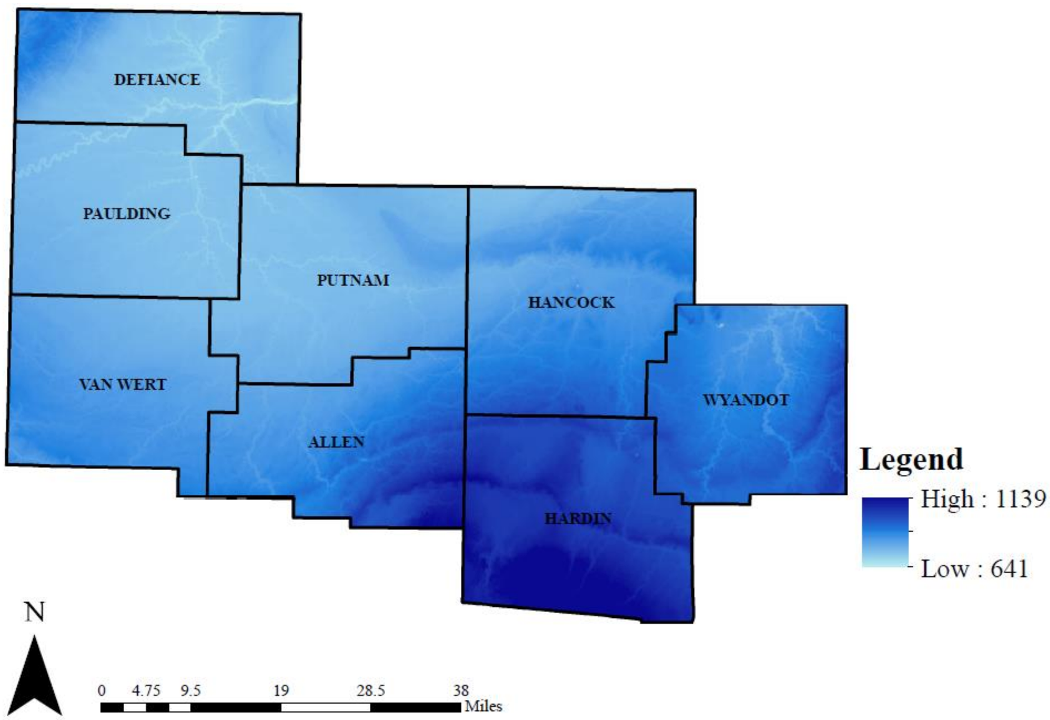


Figure 3.3: District 1 Elevation.

The data showing that the terrain within ODOT District 1 remains relatively level throughout the area may be found in Figure 3.3. As observed from Figure 3.3, the elevation changes throughout the district are gradual with the highest elevation of 1,139 ft in the southern area of Harding County to the lowest elevation of 641 ft in Defiance County. Though this is a 498 ft difference, in comparison to the rest of the state, and since these changes are gradual, this area is consider level.

The level terrain leaves the district vulnerable to snow blowing onto the roads while conducting snow and winter maintenance operations. The snow blowing onto the roads presents an operational challenge as roads must continue to be treated after the snowfall has ceased. An example of snow blowing onto the roads is shown in Figure 3.4.

Obtained from Saugeentimes, 2014.

Figure 3.4: Example of Snow Blowing onto Road.

District 1 is responsible for maintaining approximately 3,200 lanes miles of state and federal roadways (The Ohio Department of Transportation, 2016) as shown below in Figure 3.5.

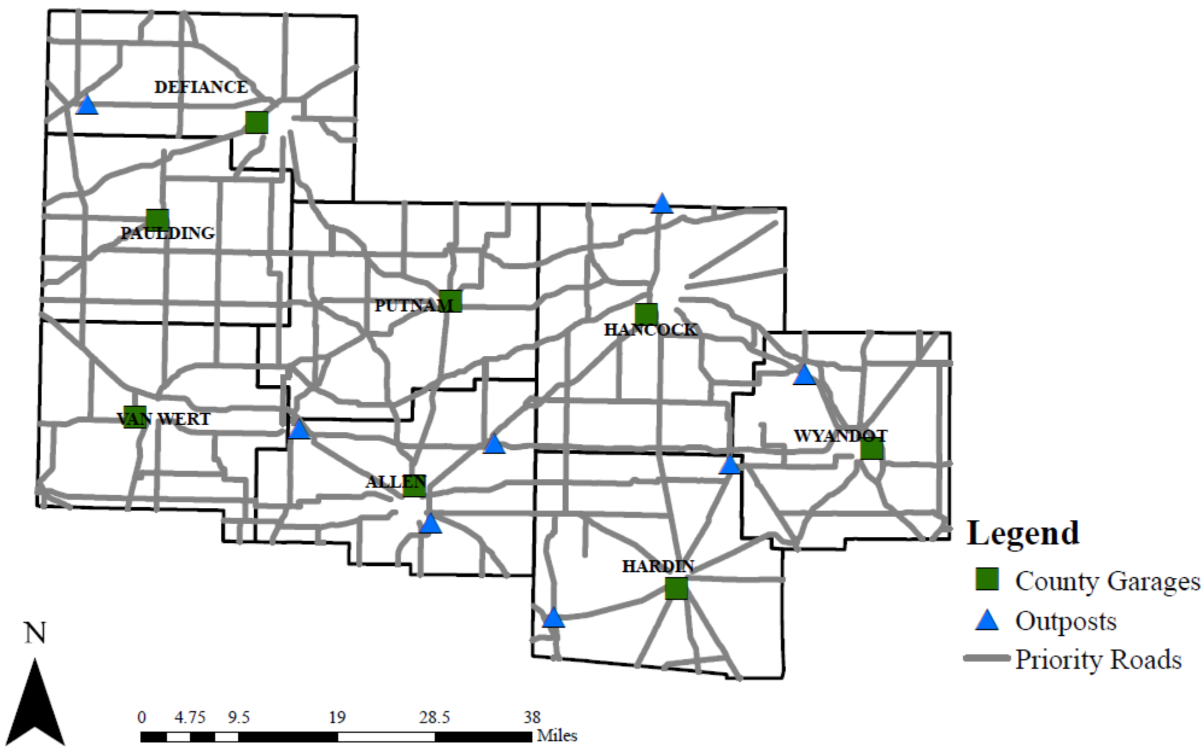


Figure 3.5: District 1 Routes and Facility Locations.

In order to effectively maintain these roadways, the district operates with eight county garages and nine outposts including the future South Wood Outpost and the removal of the Findlay Outpost. Due to the removal of the Findlay Outpost currently underway, the route optimization within District 1 did not incorporate the Findlay Outpost in Hancock County and instead implemented the planned South Wood Outpost. In addition to implementing the South Wood Outpost, the lane addition to I-75 in Hancock County planned to be constructed in 2017 was also implemented into the Route Optimization project.

3.3 ODOT District 2

ODOT District 2 is located in the Northwestern corner of the state, immediately north of District 1. The district serves Fulton, Henry, Lucas, Ottawa, Sandusky, Seneca, Williams, and Wood Counties (The Ohio Department of Transportation, 2016). The geography of the region is similar to District 1 in that the terrain is relatively level with a difference between the highest and lowest elevations being 606 ft. Figure 3.6 shows the change in elevation throughout the district.

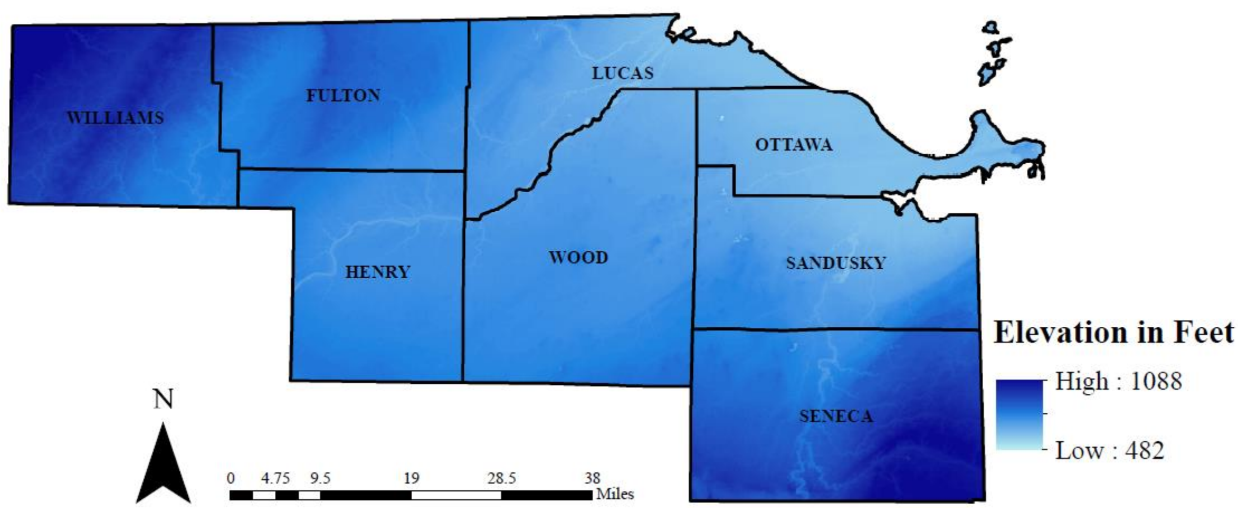


Figure 3.6: District 2 Elevation.

District 2 is responsible for maintaining approximately 3,381 miles of roadways within the district. These roadways are currently maintained by utilizing eight county garages and two outposts. For the purposes of this project, the research team optimized the deployment of trucks within the district under three different scenarios, consisting of implementing new facilities and relocating current county garages in order to observe any potential time and cost saving by constructing and implementing new garages and outposts. A summary of the different scenarios are as follows:

- Part 1 – Current facility locations and additional I-75 lane;
- Part 2 – Additional South Wood Outpost, relocation of Sandusky County Garage, and additional I-75 lane; and
- Part 3 – Additional South Wood Outpost, relocation of Sandusky and Wood County garage, and additional I-75 lane addition.

Further details regarding the different scenarios may be found in subsequent subsections of this report.

3.3.1 District 2 Part 1

Part 1 of District 2 consisted of optimizing the routes with an additional I-75 lane and the current garage locations. This scenario was completed by removing county border restrictions and setting an average treating speed of 30 mph. The treating speed was determined after surveying county managers on the current winter maintenance operations, in particular, the typical speeds traveled during snow and ice events. A district level overview of the facility locations within this scenario is shown in Figure 3.7.

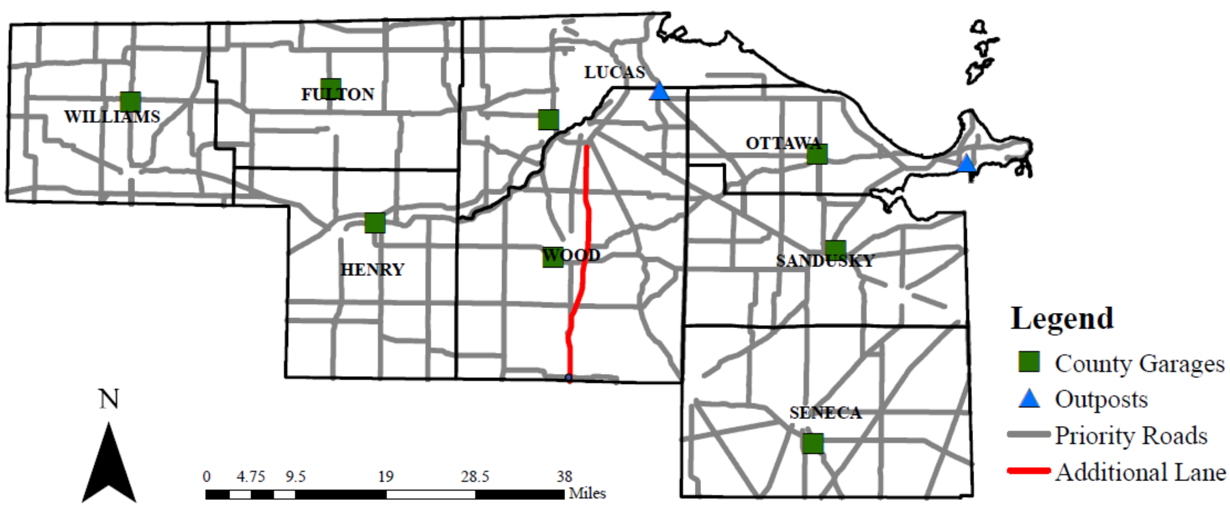


Figure 3.7: District 2 Part 1 Route Optimization Facility Locations.

Figure 3.7 above provides a visual representation of the roadways that must be maintained and the current facility locations. The data regarding current facility locations and roadways to be treated helped the research team to ensure an accurate and thorough analysis was conducted for District 2 Part 1.

3.3.2 District 2 Part 2

Optimizing the routes within District 2 Part 2 consisted of keeping the additional I-75 lane increase as observed in Part 1 , a newly constructed outpost in southern Wood County, and a new county garage location in Sandusky County. The outpost in southern Wood County will be shared amongst Wood County in District 2 and Hancock County in District 1. The intent of adding this outpost is to ensure that an adequate LOS is maintained on I-75 in both Districts 1 and 2. Figure 3.8 below provides a district level overview of the facility locations.

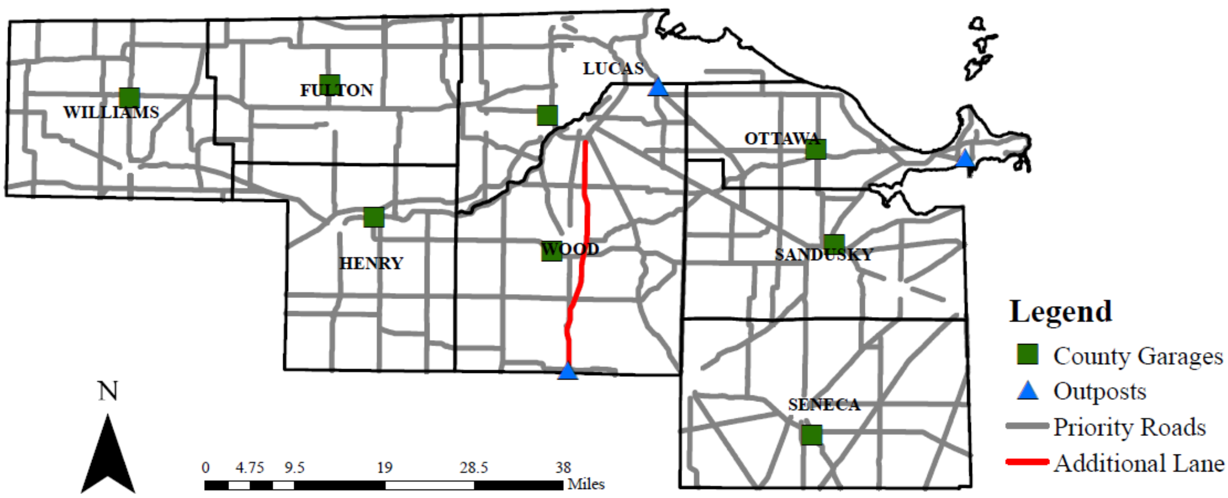


Figure 3.8: District 2 Part 2 Route Optimization Facility Locations.

In order to clearly show the changes that occurred from Part 1 to Part 2, Figure 3.9 and Figure 3.10 show a zoomed-in map of the changed areas in Wood and Sandusky Counties. Figure 3.9 on the following page shows the location of the proposed outpost in Wood County.

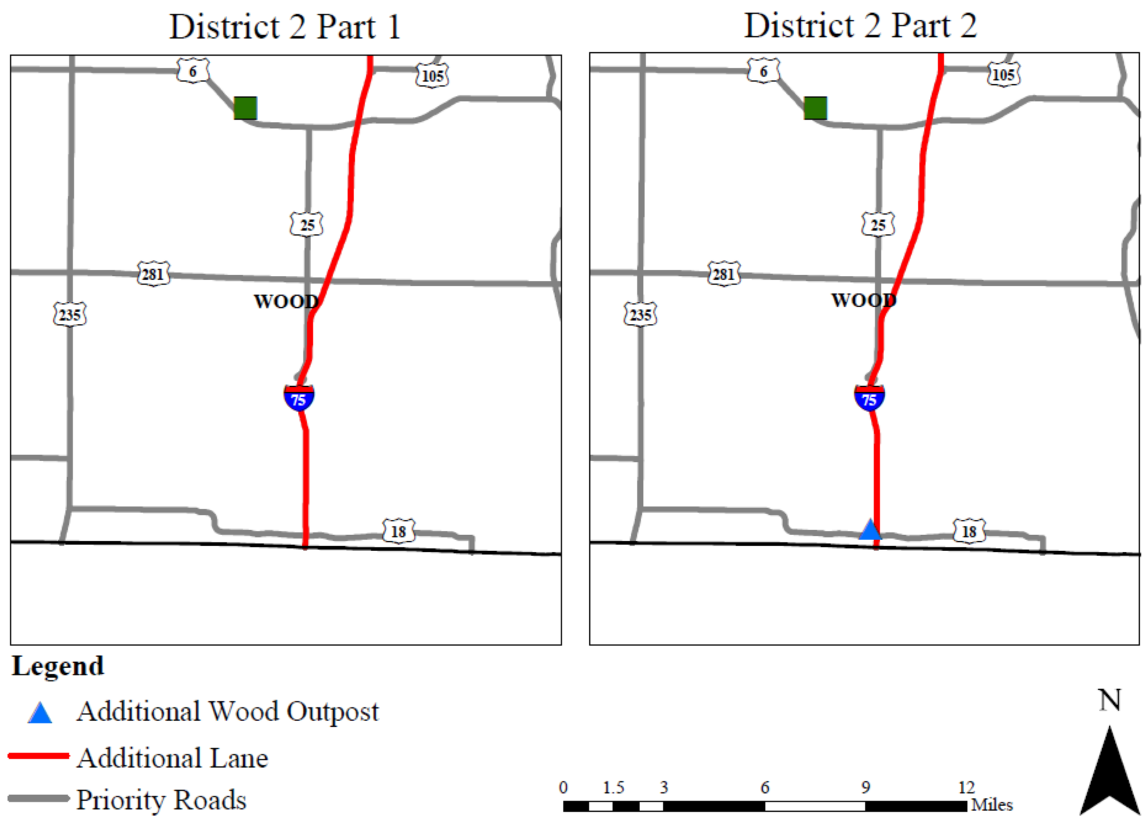


Figure 3.9: Additional Outpost in Wood County.

As may be observed from Figure 3.9, the additional outpost to be added to District 2 Part 2 was located at the northwest corner of Mercer Rd. and Middleton Pike. The outpost was incorporated into the District 2 Part 2 analysis for the potentially increased efficiency in winter maintenance operations. Another aspect of the District 2 Part 2 route optimization consisted of relocating the Sandusky County Garage, shown in Figure 3.10.

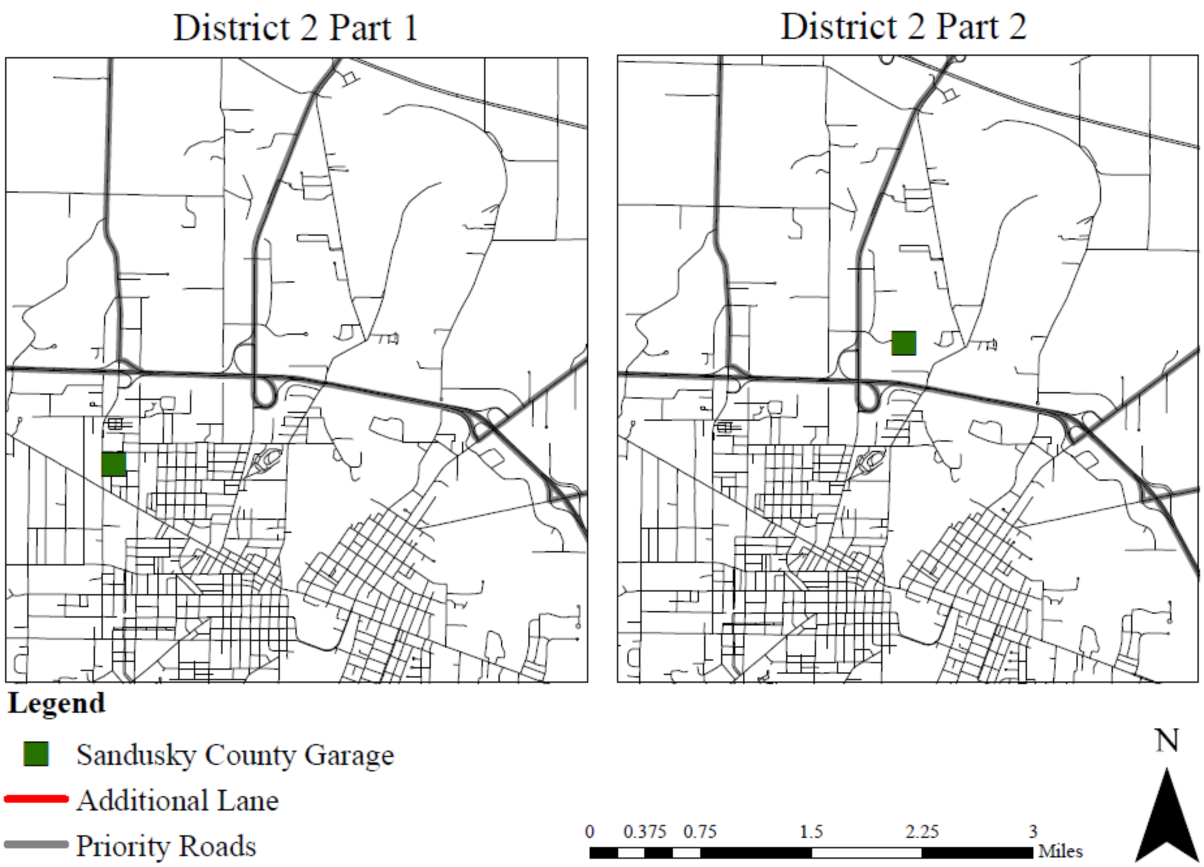


Figure 3.10: Change in Sandusky County Garage Location.

Figure 3.10 above shows the current location of the Sandusky County Garage (left) at the northeast corner of Oak Harbor Road and Sugar Street and the new location north of US-20 along SR 53 (right).

3.3.3 District 2 Part 3

District 2 Part 3 consisted of keeping the additional lane on I-75, the outpost in southern Wood County, and the new Sandusky County Garage location as seen in Part 2. Part 3 also consisted of moving the Wood County Garage from its current location to the proposed location on SR 582. Figure 3.11 provides a district level overview of the facility locations within this scenario.

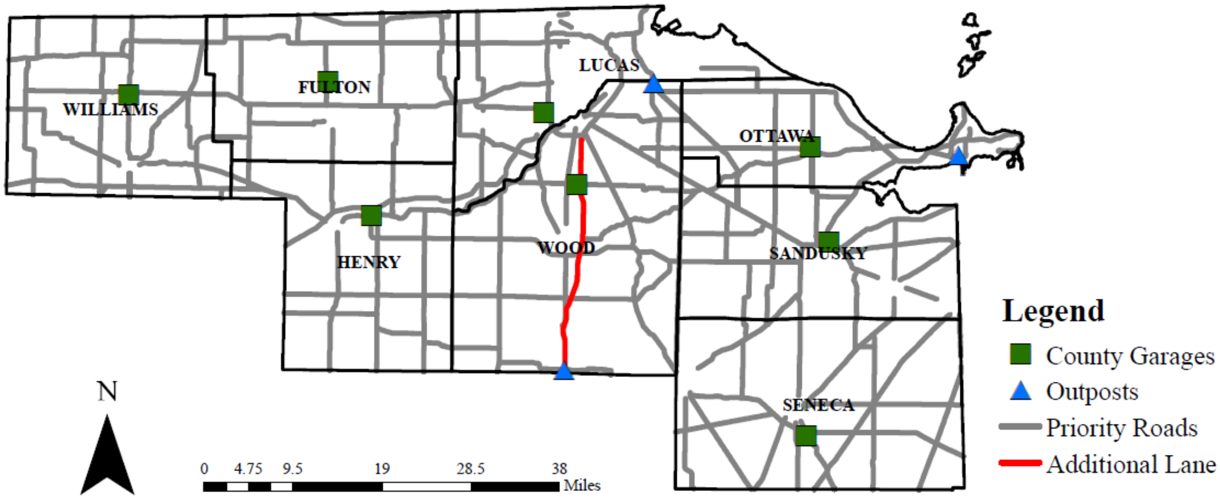


Figure 3.11: District 2 Part 3 Route Optimization Facility Locations.

The largest consideration in the Part 3 route optimization is the analysis of the relocation of the Wood County Garage. In order to better show the relocation of the Wood County Garage, Figure 3.12 provides a zoomed-in view of the current location and the proposed location of the Wood County Garage.

Figure 3.12: District 2 Part 3 Wood County Garage Change in Location.

The current location of the Wood County Garage that was utilized for the Parts 1 and 2 analysis is shown in the zoomed-in section to the left in Figure 3.12. The zoomed-in section to the right in Figure 3.12shows the proposed location on SR 582.

3.4 ODOT District 10

ODOT District 10 is located in the Southeastern corner of the state and consists of Athens, Gallia, Hocking, Meigs, Monroe, Morgan, Noble, Vinton, and Washington Counties (The Ohio Department of Transportation, 2016). As shown in Figure 3.13, the region consists of mountainous terrain with an elevation difference of 933ft between the highest and lowest points. In addition, Figure 3.2 on page 8 shows that District 10 annually receives less than twenty to thirty inches of snow (The Ohio Department of Transportation, 2011). The combination of mountainous terrain and consistent snowfall presents a challenge for winter maintenance operations in the district due to the winding rural roads, making them difficult to treat in a safe and timely manner.

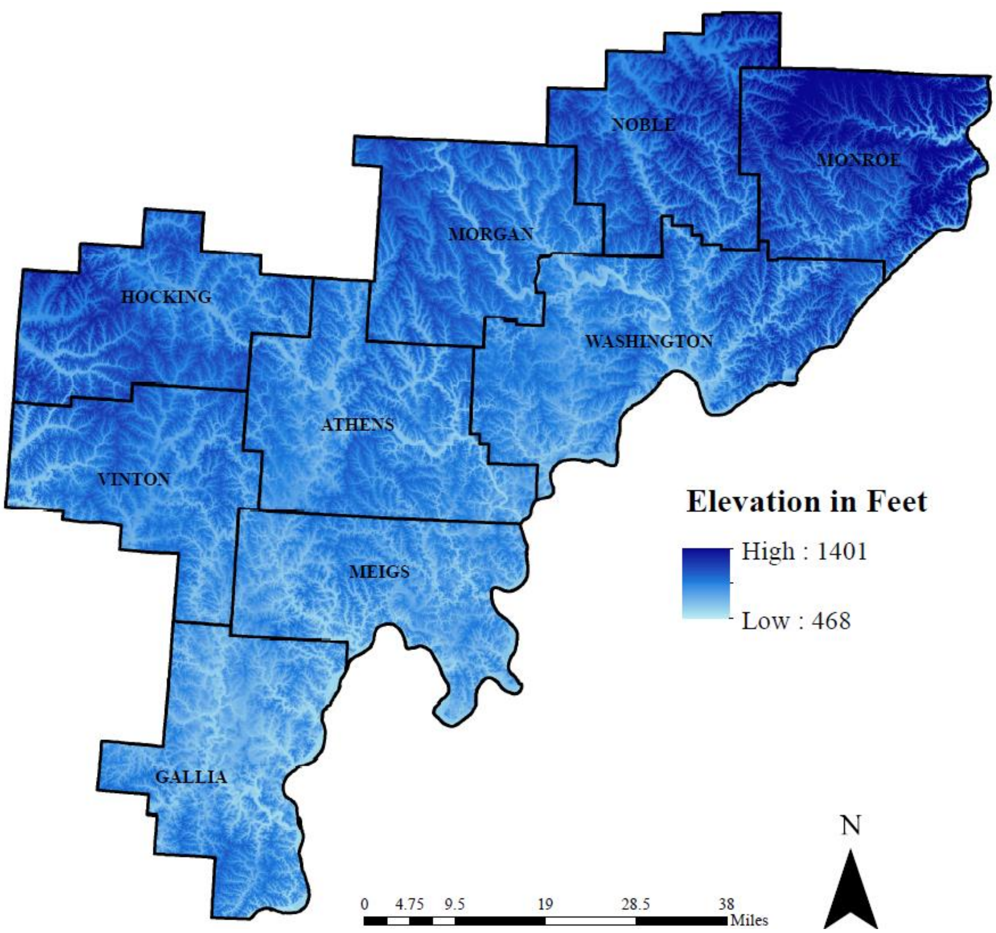
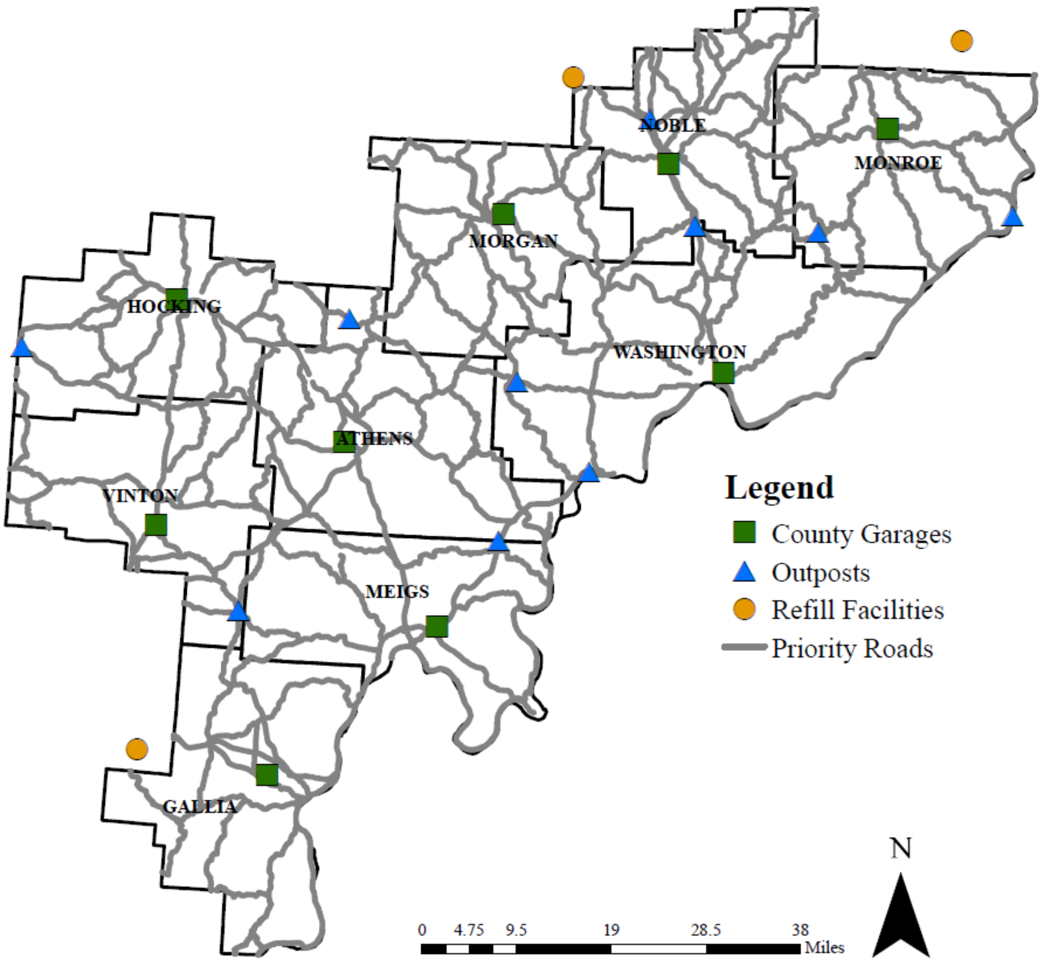


Figure 3.13: District 10 Elevation.

District 10 is responsible for maintaining over 4,000 lane miles of state highways within the district (The Ohio Department of Transportation, 2016). A district level map of the roadways that the district must maintain and the facility locations is shown in Figure 3.14.



Note: Some of the refill facilities are located outside of the District but are utilized by District 10.

Figure 3.14: District 10 Routes and Facility Locations.

As may be seen in Figure 3.14, the transportation system within the district consists of winding roads reflective of the mountainous terrain of the region. In order to ensure the roads in the district are treated within the acceptable LOS, the district utilizes nine county garages, eight outposts, and three refill facilities located along the perimeter of the district.

CHAPTER IV ROUTE OPTIMIZATION METHODOLOGY

The methodology section is divided into two sections. The first section discusses the general development of the ROM in ArcGIS, including the input and data requirements. The second section describes the status of the data collection and inputting for the ROM for this project, including the digitization of ODOT maintenance routes and information regarding ODOT facilities and the trucks used for winter maintenance.

4.1 Initial Model Creation

In order to develop the initial ROM, the research team followed the process described in Figure 4.1 below. It is a summary of the process to develop the initial ROM. The following subsections of this report describe the data collected and the parameters implemented to ensure the ROM's capability of effectively optimizing the operational trucks in each district.

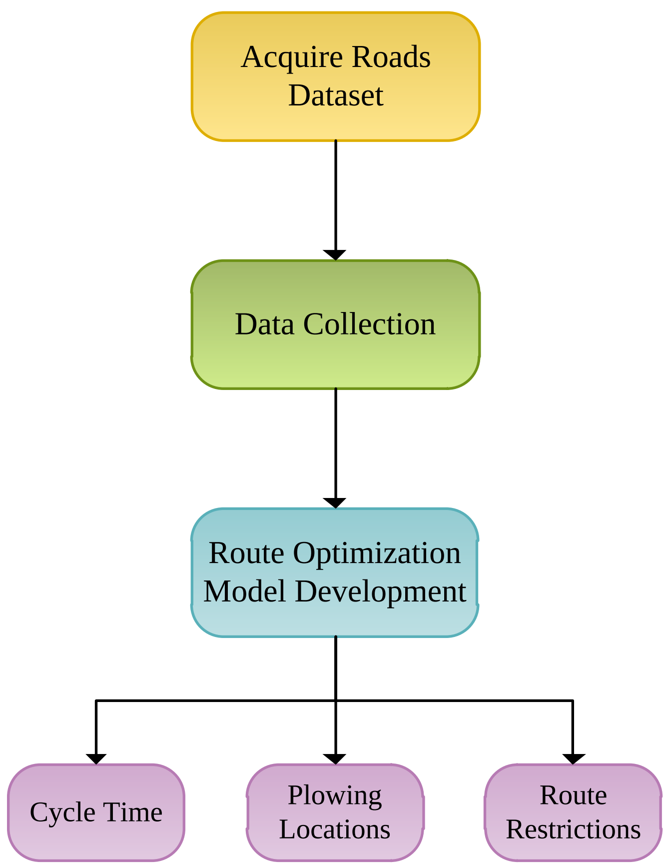
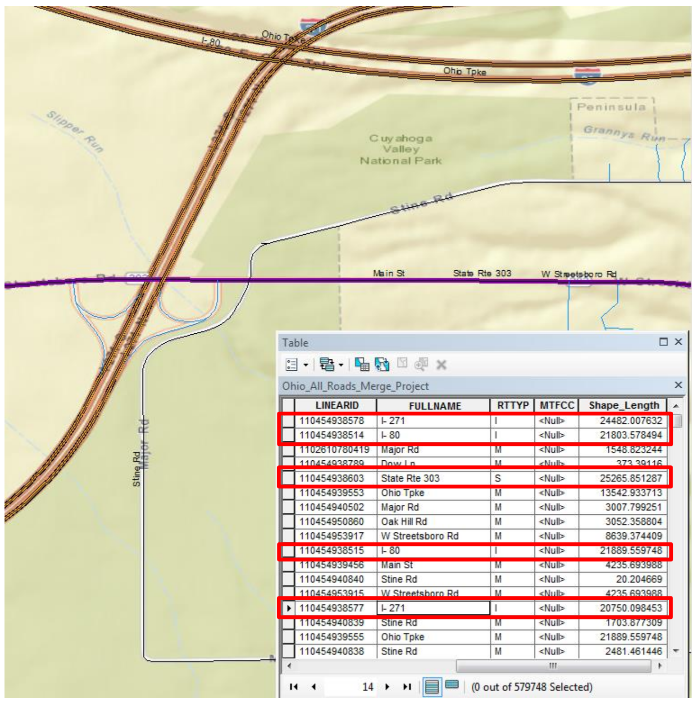


Figure 4.1: Initial Route Optimization Model Development.

The development of the route optimization began with the preparation of data in the form of layers for the map of the state of Ohio with additional layers for each category of input data. The first additional layer was the roads dataset for the entire state of Ohio. Once all the roads in Ohio were uploaded, a network analyst dataset was created in order to define the roadway edges and capture elevation differences. The importance of defining roadway edges was seen in locations that include a highway overpass: in two dimensions, a highway overpass appeared to be an intersection with the road beneath it; when the edges are used by the model, an elevation difference is applied to the two roads, allowing the program to recognize the road configuration as an overpass rather than an intersection. An example of the roads dataset is presented in Figure 4.2.



Obtained from ODOT Transportation Information Mapping System (TIMS)

Figure 4.2: Example of Elevation Differences and Directionality for Roads.

In addition to elevation differences, network attributes in the road layer included road hierarchy (freeway, arterial, collector, or local road), direction of travel (two-way vs. one-way roads), cost attributes (such as travel time), and distance. The one-way road attribute is utilized to ensure the model does not route a vehicle in the wrong direction. The directional basis of the roads, which is an especially important consideration when routing on divided highways, was built into the road layer. Once the network attributes were defined and the lengths of all roads determined, travel times were calculated based on the length and the typical speed traveled during snow events for each road segment.

4.2 Data Collection

The ROM required information on all of the snow and ice routes that ODOT maintains in the state of Ohio. Districts 1, 2, and 10 provided the route information in a variety of formats, including digital maps that were created by using spatial software as well as printed maps with hand drawn routes. Once acquired, the routes were digitized for use as a base map that included all the routes to be optimized. The digitized ODOT snow and ice routes for the districts involved with the project are shown in Figure 4.3. This map shows the current routes that each district is responsible to maintain. The format of this map allowed it to be utilized as a base layer during route optimization. This layer was broken down by district, and it did not contain any additional information.

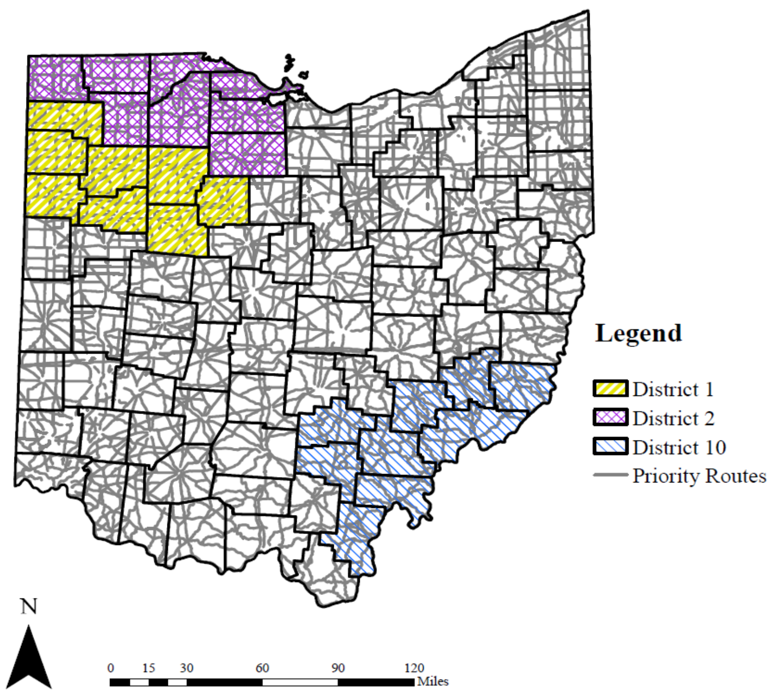


Figure 4.3: ODOT Snow and Ice Routes.

Once the routes were digitized, the next step was to locate the garages and outposts within ArcGIS to begin the optimization process. This information was obtained from ODOT leadership and implemented into the ROM. The current number of trucks stationed at each garage, outpost, and refill facilities were inputted to be used in the model. Plowing locations were then added along the snow and ice routes provided by ODOT so that trucks could be routed from each garage along the routes. For a particular plowing location, the optimization model was capable of accounting for salt application. Additionally, each truck was assigned an associated capacity so that the model could account for the fact that a truck will run out of material and will need to refill its hopper.

4.3 Creating the Route Optimization Model

After collecting the necessary data to develop the ROM, the research team utilized the available tools within Esri's VRP to create and finalize the model before optimizing the routes within the districts. The following applications were addressed to create and finalize the ROM within each district:

- Loading plowing locations to be used in the VRP;
- Limiting trucks from traveling on county and township roads; and
- Assigning cycle times to ensure LOS was maintained.

4.3.1 Loading Plowing Locations

The data collected on the plowing locations were used to create the ROM in each district. In order for the VRP to recognize these plowing locations, the research team identified necessary additional steps to create the ROM. Figure 4.4 below provides an example of the snow and ice routes in District 10 based on the data collected for this project.

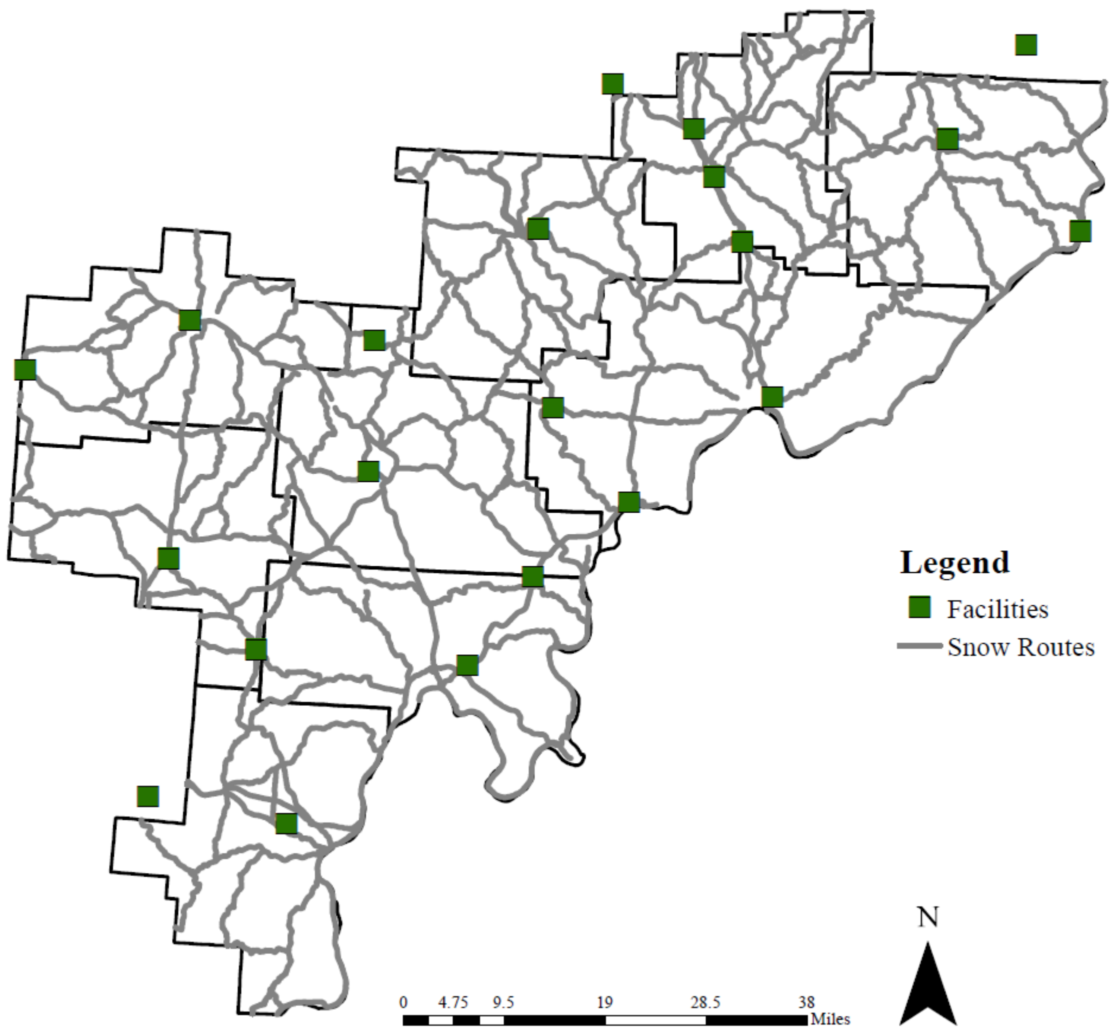


Figure 4.4: Snow and Ice Routes within District 10.

Even though Figure 4.4 above shows the snow and ice routes within District 10, the VRP tool that optimized the routes was not able to operate solely on the data shown. In order for the VRP to be able to use the data, the research team manually inserted point locations along the roadways that the VRP refers to as “orders”. Figure 4.5 shows the plowing locations of the district as a whole.

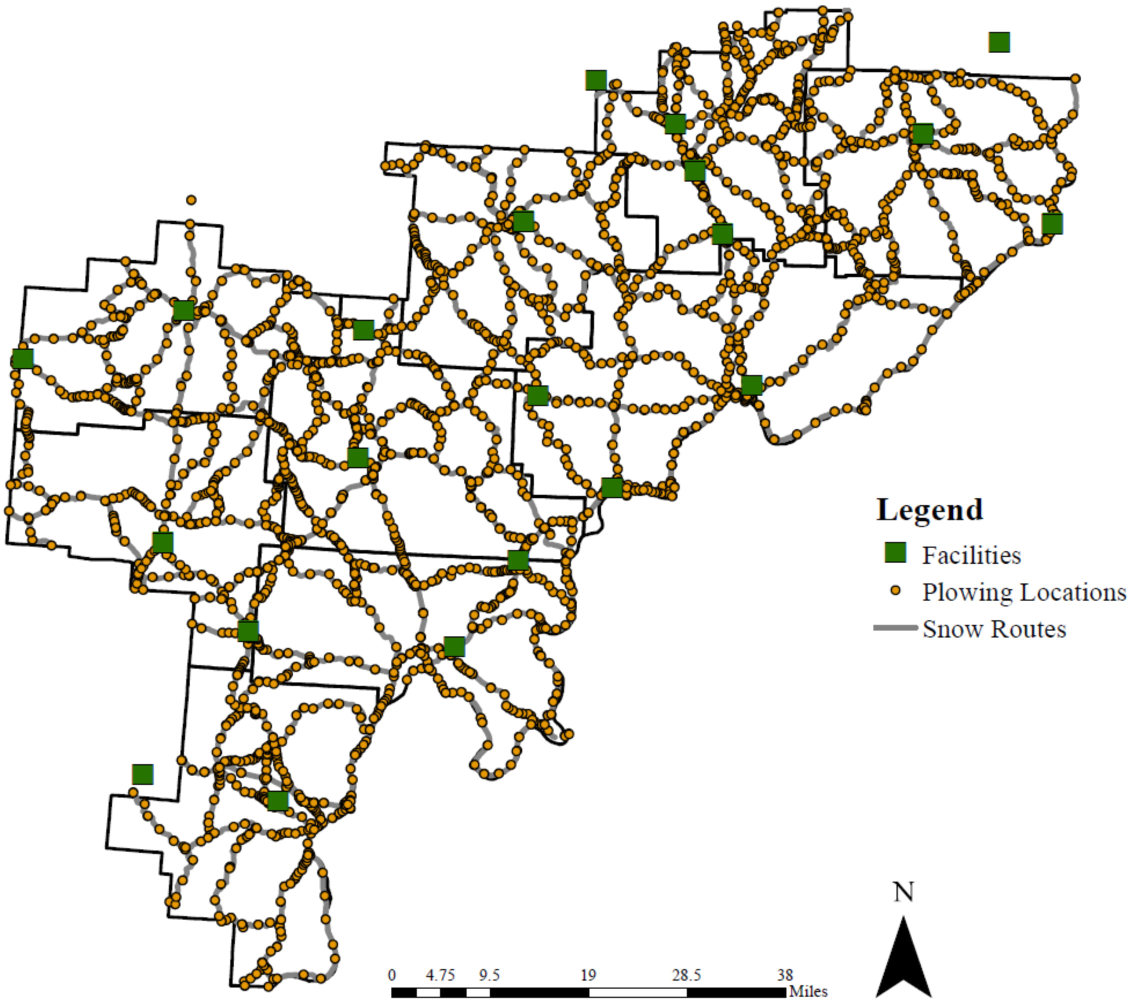


Figure 4.5: Plowing Locations within District 10

As may be observed from Figure 4.5 above, the plowing locations were placed along all roadways that must be treated within the district during snow and ice events. Within each of these orders were attributes that allowed the research team to input the application rate of salt to be used within the model as well as the time windows to prioritize the routes. Both of these parameters were able to be modified to account for various application rates and the unique cycle time requirements within each district.

4.3.2 Route Restrictions

After uploading the plowing locations and determining the application rate and cycle times, the ROM ought to be capable of optimizing the routes within the district. However, the model would have allowed for trucks to travel along all roadways within the district, an action that was determined to be undesirable after numerous meetings with ODOT leadership. To prevent the trucks within the ROM from traveling along these county and township roads, the research team implemented route restrictions in each of the districts. An example of the route restrictions being implemented in District 10 may be found in Figure 4.6.

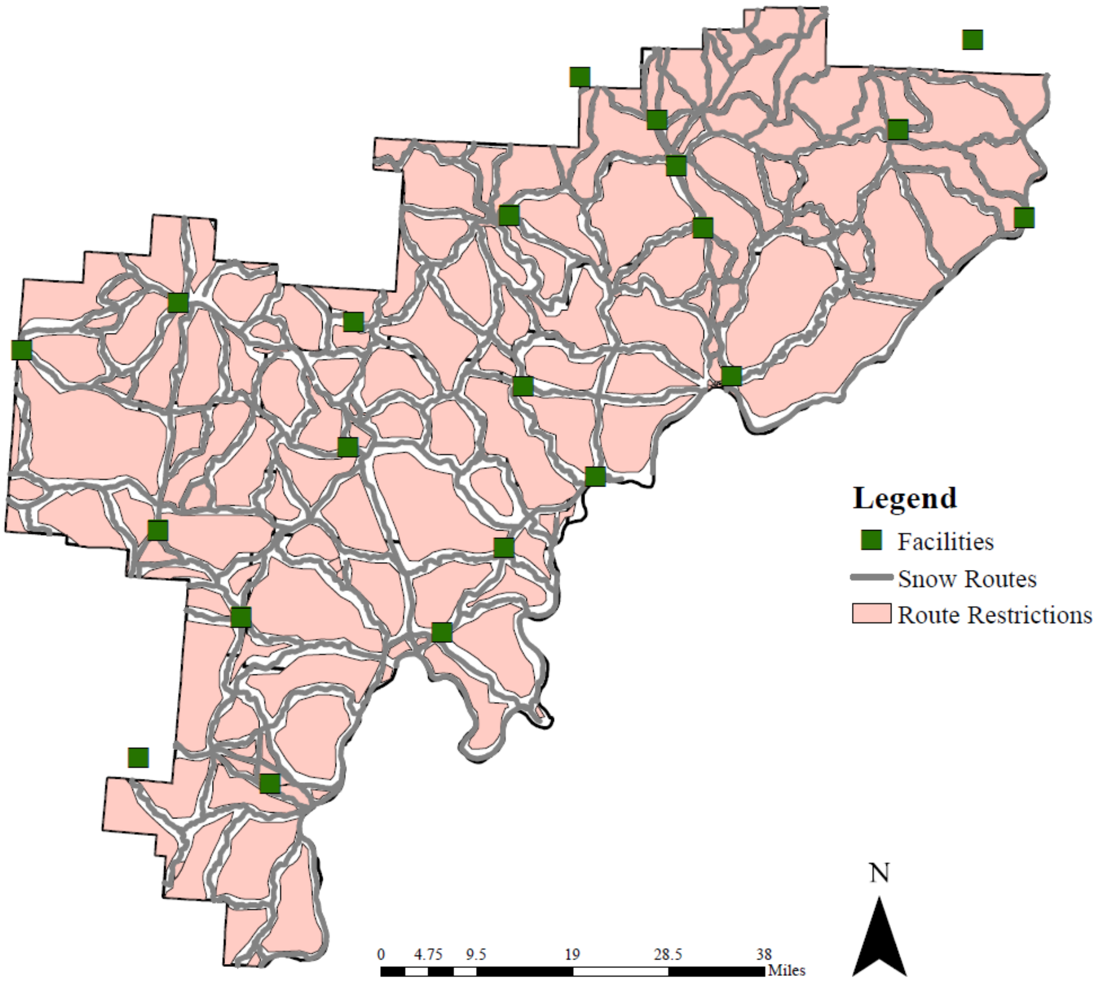


Figure 4.6: Example of Route Restriction Implementation in District 10.

The route restrictions shown in Figure 4.6 were polygon barriers that were manually drawn within the VRP. Once the restrictions were drawn, the VRP was able to optimize the routes within each district while limiting them from traveling on county and township roads.

4.3.3 Assigning Cycle Times

In general, cycle times for each route within a district were determined from the LOS requirements that the district must uphold. Because cycle times are directly related to the LOS requirements, the cycle times were important parameters within the Route Optimization project and thus required diligent inputs into the ROM. In order to incorporate the cycle times into the model, the research team added attributes to each plowing location and truck to be used within the model for each district.

As previously mentioned in this report, each plowing location was assigned a time window in which it would be able to be treated. This time window pertained to the LOS requirement for the route priority of each plowing location, which means that priority one plowing locations had a shorter time window than other plowing locations. That is, priority one routes would be treated in a lesser cycle time than priority three routes.

Table 4.2: Level of Service within ODOT Districts 1, 2, and 10.

	Level of Service		
District	**Priority 1 (min)**	**Priority 2 (min)**	**Priority 3 (min)**
1	60	90	120
2	60	90	120
10	90	120	150

Note: The LOS requirements shown above were acquired from each District's leadership.

As may be seen from Table 4.2 above, District 1 maintains a LOS requirement that priority one routes must be treated within 60 minutes while priority three routes were to be treated within 120 minutes. In order to implement these LOS requirements into the plowing locations within the ROM, the time window for priority one plowing locations was set to 60 minutes and the priority three time window was set to 120 minutes.

Apart from adding time windows at each plowing location, the research team also limited the time during which that each truck was available to travel after leaving the facility. Similar to the time windows used for the plowing locations, the time allotted for each truck was dependent on the priority of the route that the truck was to treat. Using the same LOS requirements previously described for the plowing locations, trucks that were to treat priority one routes were allowed to leave the facility for 60 minutes while trucks for priority three routes were allowed to leave the facility for 120 minutes. The limitation of how long trucks may be traveling outside of the garage helped to ensure that the LOS was maintained for all priority routes within each district.

4.4 Initial Route Optimization

In order to optimize the routes within a district, the research team first utilized the ROM with the entire truck inventory that each district maintained. By first utilizing all trucks within a district, the ROM was able to provide a baseline of the area that each facility was most capable of maintaining while satisfying the LOS requirements within the district. The initial route optimization was accomplished by restricting the trucks from traveling on county and township roads, by normalizing driving at typical treating speeds for each district, and by utilizing an application rate of 250 lbs/ln mile. This initial optimization of routes also took into account the removal of county border limits within the district, thus allowing the ROM to determine the most efficient routes and treating areas for each facility. By following the parameters previously described, the research team was able to produce district overview maps, individual route maps, and individual route descriptions for Districts 1, 2, and 10. Further details regarding the initial route optimization may be found in Chapter 6 of this report.

4.5 Verification Process

Due to unique challenges each district faces, a specific verification plan was developed for each district to minimize work disruption and for providing data in a timely manner. All plans involved the initial optimized routes to be driven at typical treating speeds and an additional iteration of a current route for snow and winter maintenance. The data for the driven routes were collected from GPS transponders (QStarz model Travel Recorder XT data loggers, as shown in Figure 4.7) and further analyzed with the Qtravel software. Further details regarding the verification process may be found in Chapter 7 of this report.

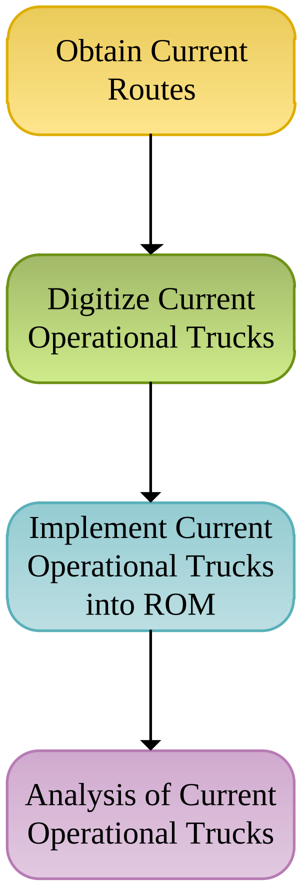
Figure 4.7: The GPS Transponder for Collecting Data from Driving the Proposed Routes.

4.6 Fleet Optimization Methodology

The fleet optimization portion of the Route Optimization project consisted of optimizing the fleet within each district to determine which garages and outposts may remove trucks and which facilities may need additional trucks to maintain the current LOS within each district. By determining which facilities may remove trucks or require additional trucks, ODOT may experience significant cost savings while continuing to effectively conduct winter maintenance operations. In order to conduct fleet optimization the research team began with the initial ROM that utilized all of the trucks available within the district and followed the process described in Chapter 8 of this report to determine the minimum number of trucks needed to treat all roads within the district under a worst-case scenario of winter maintenance operations. The parameters used to construct a worst-case scenario of winter maintenance operations consisted of the desired cycle times (relating to the LOS requirements), the typical driving speeds during snow events, and the application rate. The desired cycle times and typical driving speeds for winter maintenance operations are unique for each district, but all districts were optimized to account for a 400 lbs/ln mile application rate. The 400 lbs/ln mile application rate was determined through meetings with ODOT leadership to be an acceptable application rate to into account a worst-case scenario for winter maintenance operations. Additional information regarding the Fleet Optimization may be found in Chapter 8 of this report.

CHAPTER V CURRENT ROUTE ANALYSIS

In order to ensure that a thorough analysis was conducted regarding potential time savings from current winter maintenance operations to the optimized operations, the research team determined that an analysis of the current routes being utilized from Districts 1,2, and 10 would be necessary. In order to ensure the current route analysis was properly conducted, the research team followed the process shown in Figure 5.1 below.



Note: The analysis conducted on the current operational trucks in each district was the same analysis conducted on the optimized routes discussed in this report.

Figure 5.1: Current Route Analysis Methodology.

The current routes were obtained in two primary formats, 1) maps of routes currently being utilized for winter maintenance operations and 2) detailed route descriptions that distinguish the start and end points of each route's treating area and the designated truck starting facility.

Upon receiving the current routes, the research team digitized the routes in ArcGIS. After completing digitizing all of the received routes, the research team then generated route descriptions in the same format as the optimized routes. The same process to describe the optimized routes was used to calculate the treating distance, deadhead, and total cycle times of the current routes. Analyzing the current routes in this manner was conducted for the current routes within district 1, 2, and 10.

This chapter is divided into three sections with each section describing the status of the current routes within each district. Each section consists of the following sub-sections:

- Amount of operations trucks currently utilized;
- The expected time to treat all roadways once; and
- The percent of routes that satisfy the LOS requirements within the district.

5.1 District 1 Current Routes Overview

Through collaboration with the county managers within District 1, the research team was able to acquire all routes currently being used to conduct winter maintenance operations within the district. An overview of the treating areas for each facility within District 1 may be seen in Figure 5.2.

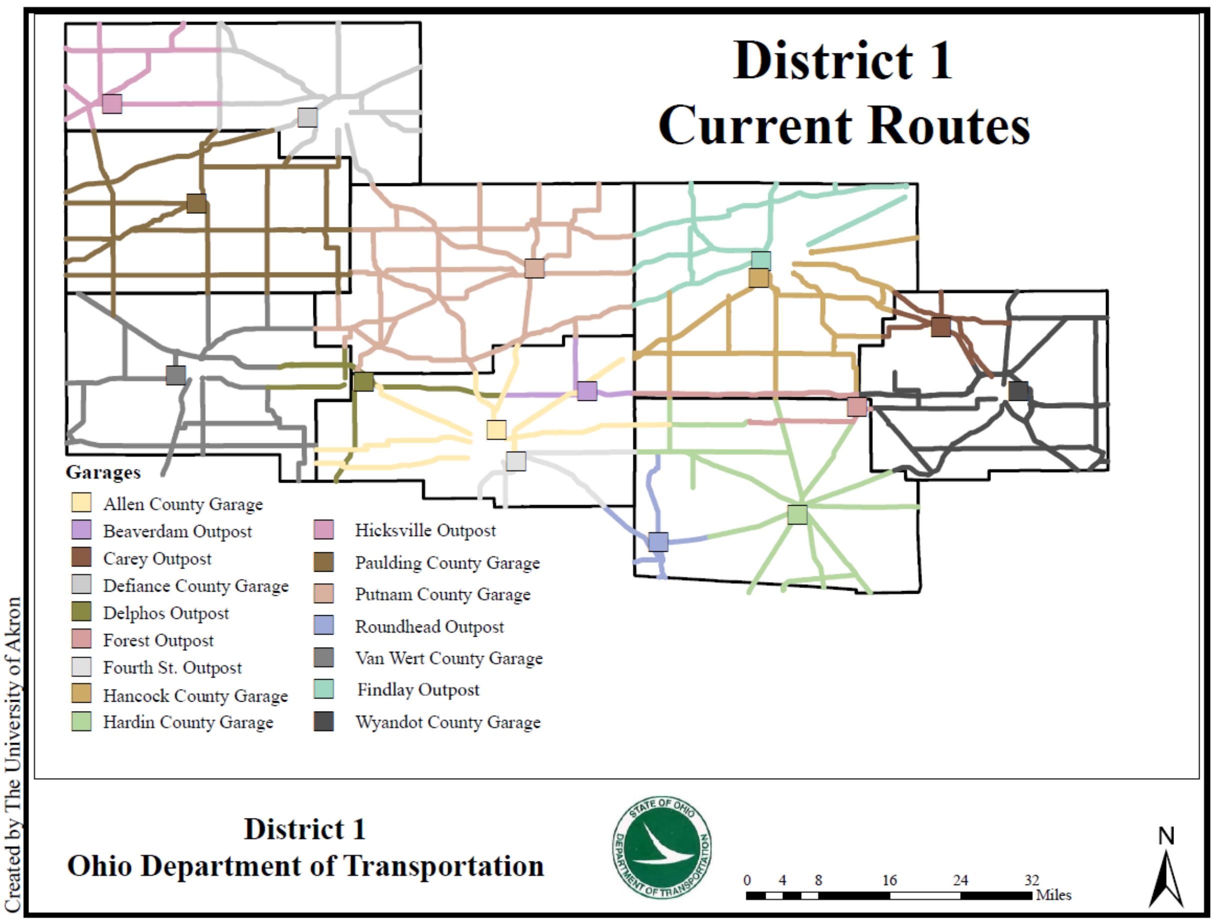


Figure 5.2: District 1 Current Route Overview.

Figure 5.2 provides a district-level overview of the treating areas for each facility within District 1. The figure also shows that the routes currently used are primarily restricted to county borders. Despite such restriction, outposts located along county borders are typically shared amongst the full service facilities and with treating areas that extend into numerous counties.

5.1.1 District 1 Current Route Analysis

As previously mentioned in this chapter, the current routes were analyzed in the same manner as the optimized routes presented later in this report. The primary parameters used for this analysis consisted of the LOS requirements, the average speed a truck travels, the time required for refill, and the capacity of each truck. In regards to the LOS requirements, the following are the LOS restrictions as determined by District 1:

- Priority One - 60 minutes;
- Priority Two - 90 minutes; and
- Priority Three - 120 minutes.

The LOS requirements represent the maximum time required for a road to be treated and are a primary factor in comparing the current routes to the optimized routes. A route was considered to satisfy the LOS if the truck was able to leave the facility, treat the assigned roadways, return to the facility, and then refill. If the truck was able to complete a full cycle under the LOS requirements, it was determined that the truck satisfied the LOS.

In regards to the average speed expected from a truck conducting winter maintenance, District 1 leadership determined that 40 mph for priority one routes and 30 mph for priority two and three routes were acceptable speeds to use for the route optimization project. These traveling speeds were implemented into ArcGIS to determine the cycle times for each route.

The capacity of each truck in the district directly relates to the efficiency calculations for the individual routes, each facility, and the district as a whole. It is important to note that the efficiency is not a fixed value but rather a range of values dependent on the application rate. The highest efficiency that a truck may possess incorporates the potential for numerous cycles to be completed at an application rate of 250 lbs/ln mile. The lowest efficiency is due to the worst-case scenario of 400 lbs/ln mile with each truck being able to complete one cycle before requiring a refill.

From the parameters previously described, the research team was able to determine the results shown in Table 5.1.

Table 5.1: District 1 Current Route Analysis.

District 1 Current Route Analysis

Operational Trucks		109
Fleet Size		127
Total Travel Time (Minutes)		7,651
Percent LOS Maintained		53
District Efficiency Range	Low	77
	High	87

Note: The operational trucks are trucks that conduct winter maintenance operations. The fleet size is the total number of trucks in the district's truck inventory. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allows routes to complete numerous cycles before a truck returns to the garage for refilling.

As may be observed from Table 5.1 above, District 1 currently utilizes 109 operational trucks with a total fleet size of 127 trucks. The non-operational trucks are inoperable during winter maintenance due to mechanical issues. With 109 operational trucks, the district is able to treat all roadways in 7,651 minutes (127 hours) with 53% of the routes satisfying the district LOS requirements. The district efficiency ranges from 77% to 86%, depending on the application rate utilized.

5.2 District 2 Current Route Overview

District 2 provided the research team with all routes currently used for winter maintenance operations except for trucks leaving from Lucas County Garage and Northwood Outpost. Both the Lucas County Garage and Northwood Outpost experience varied winter conditions that have resulted in constantly varied routes depending on the conditions of the roadways. Even though routes were not acquired for these facilities, the treating areas for the remaining facilities were acquired and digitized in ArcGIS. In addition, the current facility treating areas were obtained as shown in Figure 5.3.

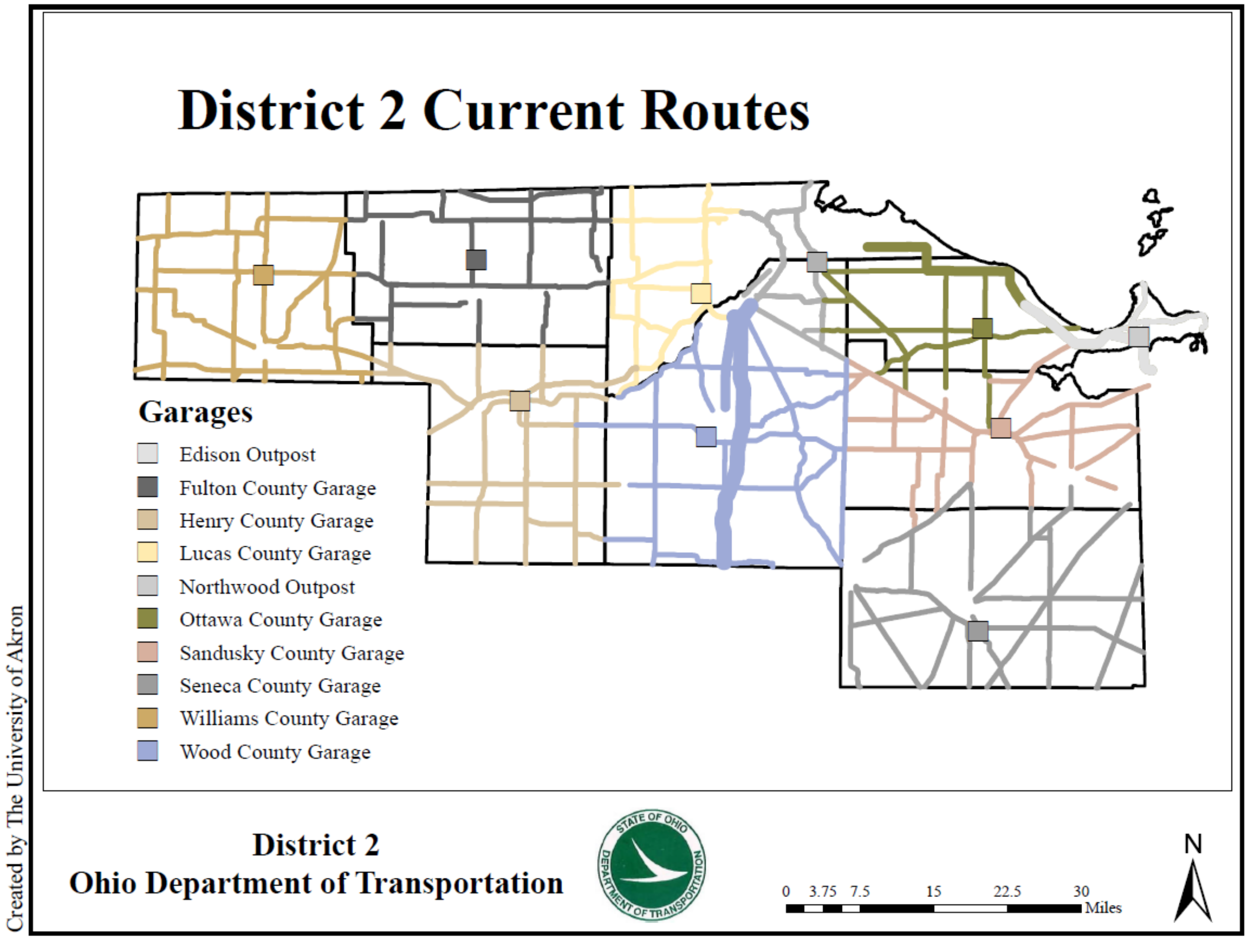


Figure 5.3: District 2 Current Treating Areas by Facility.

As may be observed from Figure 5.3, the treating areas for each facility are primarily limited to the county borders within the district.

5.2.1 District 2 Current Route Analysis

The current routes utilized within District 2 were analyzed in the same manner as the optimized routes presented later in this report. Similar to District 1, the primary parameters used for this analysis consisted of the LOS requirements, the average speed a truck travels, the time required for refill, and the capacity of each truck. In regards to the LOS requirements, the following are the LOS restrictions as determined by District 2:

- Priority One - 60 minutes;
- Priority Two - 90 minutes; and
- Priority Three - 120 minutes.

In addition to the LOS requirements within the district, the typical traveling speed used throughout the district during winter maintenance operations was an important parameter when analyzing the current routes. District 2 leadership determined that 30 mph for all roadways within the district would accurately represent the average speed traveled while treating the roads. By applying the speed parameter to the routes received from District 2, the research team was able to calculate the cycle times for each operational truck within the district.

Table 5.2 shown below provides the number of operational trucks (excluding Lucas County Garage and North Wood Outpost), fleet size, the expected time to treat all roads once, the percent of routes that satisfy the LOS requirements, and the district efficiency range.

Table 5.2: District 2 Current Route Analysis.

District 2 Current Route Analysis

Operational Trucks		85
Fleet Size		126
Total Travel Time (Minutes)		7,698
Percent LOS Maintained		18
District Efficiency Range	Low	76
	High	83

Note: The operational trucks in this table do not take into account trucks from Lucas County Garage or the North Wood Outpost due to trucks being deployed on an as needed basis. The operational trucks are trucks that conduct winter maintenance operations. The fleet size is the total number of trucks in the district's truck inventory. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allows routes to complete numerous cycles before a truck returns to the garage for refilling.

Table 5.2 shows that approximately 18% of the routes currently used by District 2 satisfy the district LOS requirements. This is primarily due to the lack of outposts throughout the district and the LOS requirements that the district wishes to maintain. By increasing the LOS requirements by thirty minutes for priority one, two, and three routes, the research team concluded that the percent of trucks that satisfy the modified LOS requirements within the district increase to 62%.

In addition to the LOS requirements affecting the percent of routes that satisfy the district LOS requirements, approximately 50% of the routes obtained from District 2 maintain mixed priority routes. This affects the percent of routes that satisfy the LOS requirements due to mixed priority routes being analyzed by the strictest LOS requirements. An example of this is if a route maintains a priority one road and a priority three road, the LOS requirement for the route relates to priority one.

5.3 District 10 Current Route Overview

District 10 leadership provided all routes currently being used to conduct winter maintenance operations. The routes were received in a table with specific start points, end points, and starting facility locations. These data facilitated the digitization of the current routes within District 10 in ArcGIS. The facility treating areas are shown in Figure 5.4.

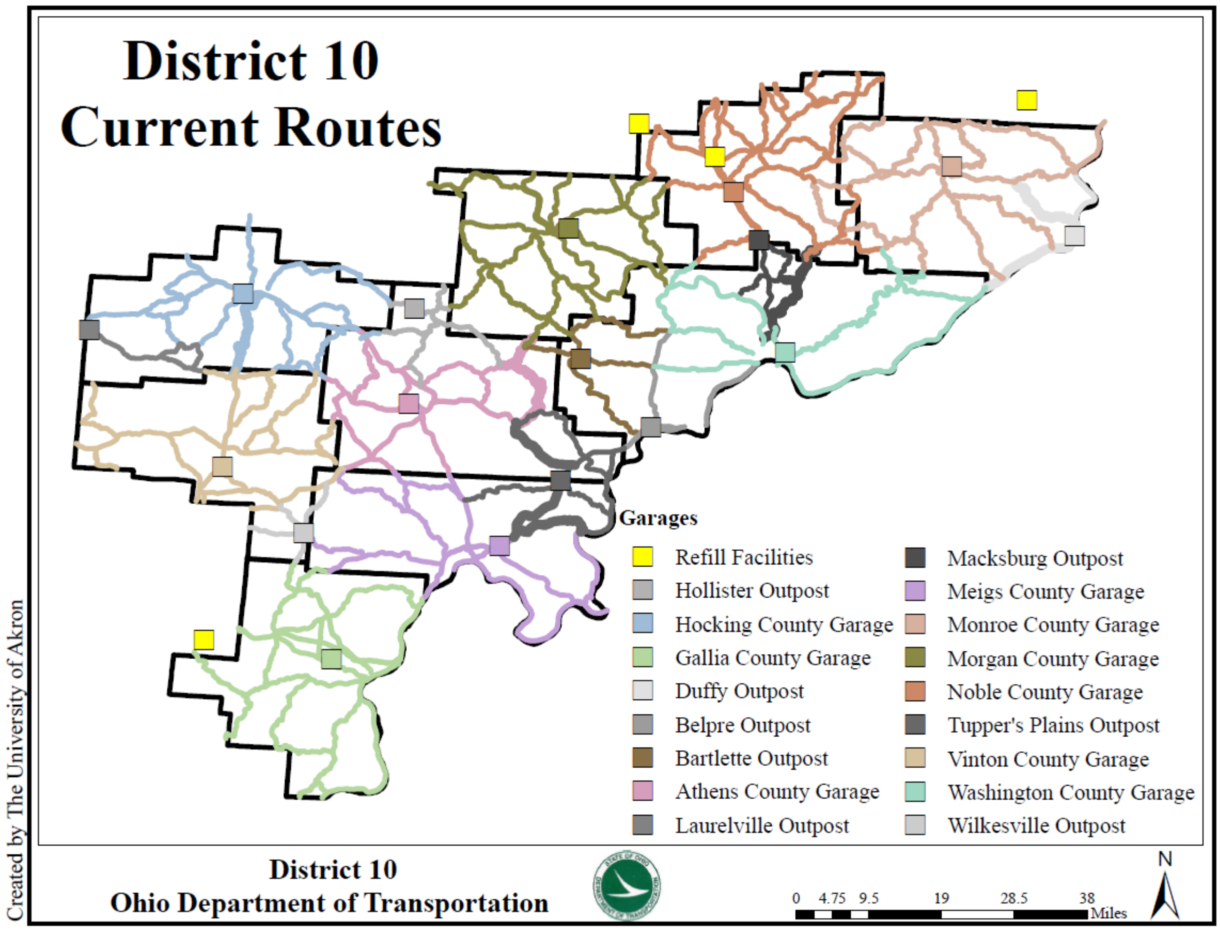


Figure 5.4: District 10 Current Treating Areas by Facility.

Similar to Districts 1 and 2, District 10 has primarily restricted the routes to the county borders. The exceptions are the outposts located near county borders, in which case multiple counties may station trucks at the outposts to treat roads in remote areas of the district or provide a higher LOS to priority one roads.

5.3.1 District 10 Current Route Analysis

Similar to the previous districts, all current routes were analyzed using the same methods as the optimized routes presented in the following chapters of this report. The parameters include the district LOS requirements, typical speeds traveled during winter maintenance, the time required for refill, and the capacity of each truck. The LOS requirements within District 10 differ from those in Districts 1 and 2 due to the terrain of the area, with the LOS requirements are as follows:

- Priority One - 90 minutes;
- Priority Two - 120 minutes; and
- Priority Three - 150 minutes.

This change in terrain has resulted in a 30-minute increase for each road classification in the LOS requirement in District 10. The terrain also influences the speed at which trucks travel during winter maintenance operations with the following being the average speeds for each priority road:

- Priority One – 35 mph;
- Priority Two – 25 mph; and
- Priority Three – 20 mph.

By utilizing the speeds listed above and the data obtained from District 10, the research team was able to determine the cycle times for each route within the district. The cycle times were then used to determine the percent of routes that satisfy the district LOS requirements. Table 5.3 provides a summary of the current trucks used for winter maintenance operations within District 10.

Table 5.3: District 10 Current Route Analysis.

District 10 Current Route Analysis		
Operational Trucks		116
Fleet Size		128
Total Travel Time (Minutes)		12,650
Percent LOS Maintained		60
District Efficiency Range	Low	81
	High	86

Note: The operational trucks are trucks that conduct winter maintenance operations. The fleet size is the total number of trucks in the district's truck inventory. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allows routes to complete numerous cycles before a truck returns to the garage for refilling.

As may be observed from Table 5.3 above, District 10 currently utilizes 116 operational trucks to conduct winter maintenance operations. The fleet consists of 128 trucks, including those unavailable for use due to mechanical or other issues. The total time required to treat the district for one iteration is 12,650 minutes and the percent of trucks that satisfy the LOS throughout the district is 60%. The range of efficiency is 81% at an application rate of 400 lbs/ln mile and 86% at an application rate of 250 lbs/ln mile. The higher efficiency is observed at a lower application rate due to more cycles being completed before requiring a refill at the nearest facility.

5.4 Current Route Analysis Summary

In summary, the results presented in this chapter provide the research team with a baseline District LOS satisfaction requirement that facilitated the optimization of each district's fleet as discussed in Chapter 8 of this report. Specifically, the current route analysis allowed the research team to determine how many trucks could be removed from each district's fleet to maintain a similar LOS. The current route analysis also allowed the research team to determine the potential time savings to treat each district, a valuable tool when considering the potential cost savings within ODOT and increases in safety for the drivers during snow and ice events.

CHAPTER VI INITIAL ROUTE OPTIMIZATION

The initial route optimization consisted of utilizing the ROM within the entire truck inventory that each district maintained. This optimization of the fleet size instead of the number of operational trucks currently used provided a baseline of the treating areas of each facility as well as the LOS maintained with the additional trucks utilized to conduct winter maintenance operations. As previously mentioned in Chapter 4 of this report, the routes were optimized by removing the county border limits, trucks traveling at typical treating speeds, and utilizing an application rate of 250 lbs/ln mile. By implementing these parameters into the ROM, the research team produced district overview maps, individual route maps, and individual route descriptions for Districts 1, 2, and 10. A summary of the initial route optimization process is shown in Figure 6.1.

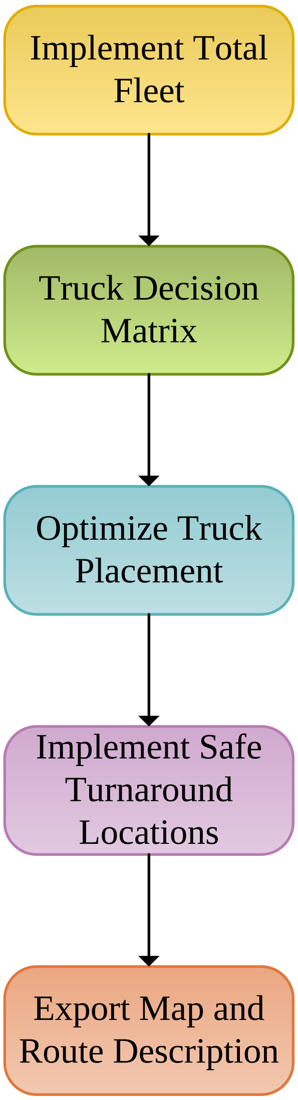


Figure 6.1: Initial Route Optimization Methodology.

An example of the district overview map for District 2 Part 1 is shown below in Figure 6.2.

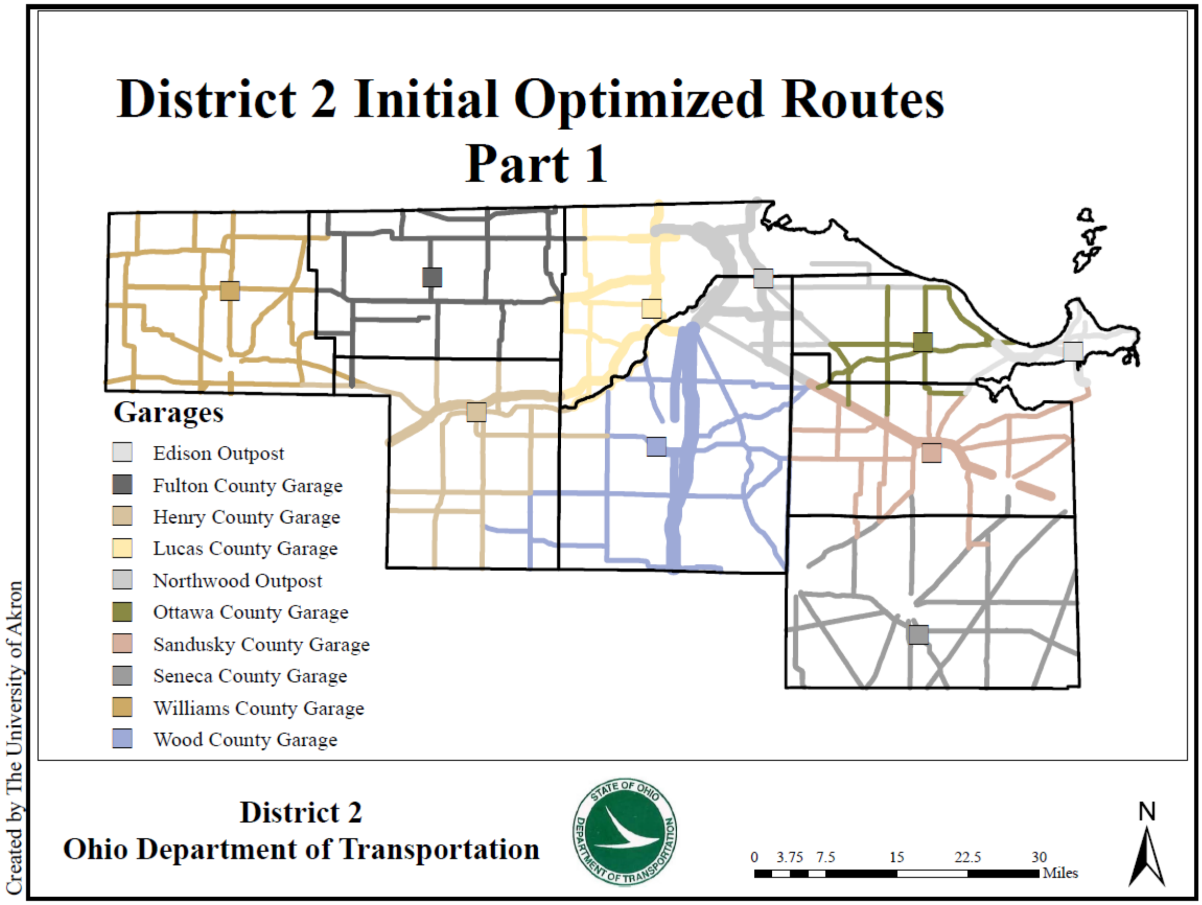


Figure 6.2: Example of District 2 Part 1 Overview Map.

As shown in Figure 6.2, the district overview map provides the audience with a simple visual aid to see the area that the ROM initially determined each facility should maintain when utilizing all trucks within the district. It is important to note that the thicker lines in Figure 6.2 represent multi-lane roads, further showing where each facility is conducting maintenance operations. District overview maps were created for all districts involved in the Route Optimization Project.

In addition to determining the optimal treating areas for each facility, the research team provided detailed maps and route descriptions for the individual routes within each district. Numerous meetings were held at the district and county levels to take into account areas of unique concern, such as steep inclines requiring slow speeds or preventing trucks from turning around at potentially dangerous locations. The comments from these meetings and the implementation of the ROM generated the optimized routes maps for each route and facility within Districts 1, 2, and 10. An example of the initial optimized route map that utilized all trucks within the district is shown in Figure 6.3.

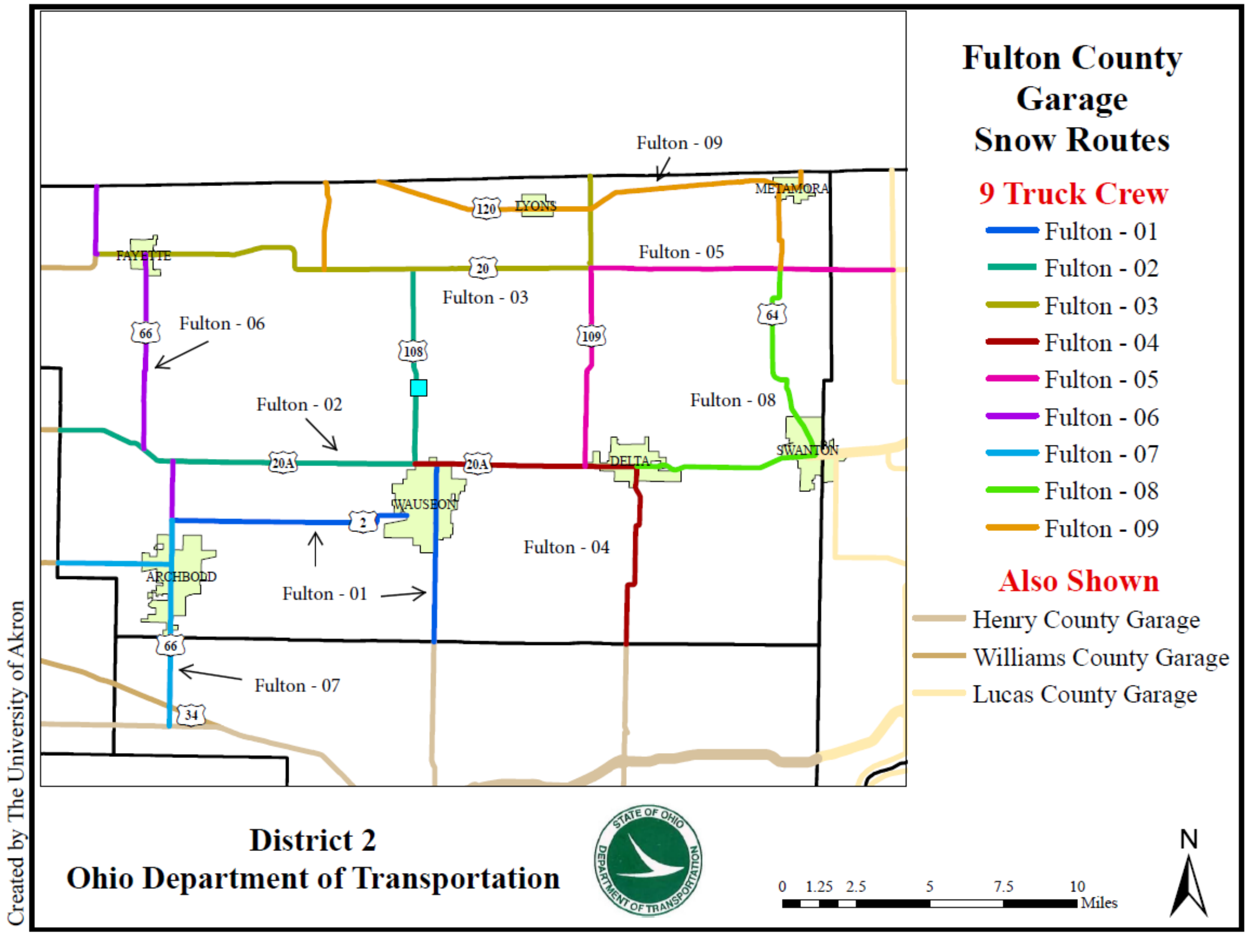


Figure 6.3: Example of a Map produced from the Initial Optimized Routes in Fulton County.

Figure 6.3 shows an example of the facility maps of the individual routes within the district. The maps were created for all facilities in the districts involved with this project and provide the audience with the initial description of the optimized routes. In order to provide further details of the routes, the research team developed a route description template to be used in conjunction with the facility maps. An example of the route descriptions used to accompany the facility maps is shown in Figure 6.4.

ODOT District 2 Part 1 Initial Optimized Snow and Ice Routes Fulton County Garage (9 Truck Crew)										
Garage	Route Number	Recommended Truck Type	Route Priority	Total Time Traveled (min)	Dead Head Time (min)	Treated Cycle Time (min)	Lane Miles Treated	Efficiency		Route Description
								Low	High	
Fulton	1	Tandem	1	75.4	17.0	58.4	29.2	77	91	Treat SR 108 from US 20A to southern county border. Treat SR 2 from Wauseon to SR 66.
Fulton	2	Single	1	74.4	0.0	74.4	37.2	100	100	Treat SR 108 from US 20A to US 20. Treat US 20A from SR 108 to western county border.
Fulton	3	Single	1	97.8	15.6	82.2	41.1	84	84	Treat US 20 from US 127 to SR 109. Treat SR 109 from US 20 to northern county border.
Fulton	4	Single	1	65.9	10.4	55.5	27.8	84	91	Treats on US 20A from SR 108 to SR 109. Treat SR 109 from US20A to southern county border.
Fulton	5	Single	1	101.2	33.2	68.0	34.0	67	67	Treat SR 109 from US 20A to US 20. Treat US 20 from SR 109 to SR 295 (Lucas County).
Fulton	6	Tandem	2	96.9	53.2	43.7	21.9	45	77	Treat SR 66 from SR 2 to US 20. Treat US 127 from US 20 t0 northern county border.
Fulton	7	Single	2	93.7	50.4	43.3	21.6	46	63	Treat SR 66 frm SR 2 to US 6 (Henry County). Treat SR 2 from SR 66 to western county border.
Fulton	8	Single	2	93.1	40.1	53.0	26.5	57	73	Treat US 20A from SR 109 to SR 64. Treat SR 64 from US 20A to US 20.
Fulton	9	Single	3	112.3	27.8	84.4	42.2	75	75	Treat SR 108 from US 20 to northern county border. Treat SR 120 from northern county border to SR 64. Treat SR 64 from US 20 to northern county border.

Figure 6.4: Example of the Route Descriptions used to accompany the Facility Maps.

As shown in Figure 6.4, the route description table provides additional data on each route that is not available on the facility map. The data included in the route descriptions are the priority of the route, the total time traveled, deadhead and treated cycle times, the lane miles treated, the efficiency of each route, and a written description of where each route is treated. The definitions of each of the categories used for the route descriptions are as follows:

- Route priority – The priority of the roads that the truck maintains;
- Total Time Traveled – The calculated time to complete one cycle;
- Deadhead Time – The time to drive to and from the treating area for each truck; and
- Treated Cycle Time – The time to drive and treat the optimized roads for each truck.

The efficiency of each route is determined from the application rate applied and the capacity of the truck. This creates a range of efficiencies rather than a specific efficiency value, where the low efficiency is calculated by determining the amount of cycles that may be completed by using 400lbs/ln mile application rate and the high efficiency determined from the amount of cycles that may be completed at a 250 lbs/ln mile application rate. The equation used to calculate the low and high efficiencies for each route is shown in Equation 6.1.

$$Individual\ Truck\ Efficiency = \frac{\text{TCT}}{\text{TCT} + \text{DHT}} \qquad Equation\ 6.1$$

where,

TCT=Treated cycle time, and

DHT= Deadhead time.

The route descriptions allow the observers to quickly analyze the individual routes and obtain an estimated cycle time and the lane miles treated. In addition, the written description is particularly helpful in defining where a route begins and ends.

Another aspect that was considered when presenting the initial optimized routes was the amount of cycles that could be completed before a refill was needed. This analysis was conducted for each route within the involved districts and determined the number of cycles that could be completed if the truck assigned to the route was a single or tandem axle truck. The difference between the two types of trucks is the capacity each possesses: single-axle trucks have an eight ton capacity while tandem axle trucks have eleven. The variance in capacity is directly related to the amount of cycles that could be completed at various application rates. Figure 6.5 provides an example of how these data were presented to accompany the facility maps and route descriptions previously described.

ODOT District 2 Part 1 Initial Optimized Snow and Ice Routes
Number of Cycles Before Refill - Fulton County Garage (9 Truck Crew)

Garage	Route Number	Truck Description	100 lb/lm	200 lb/lm	250 lb/lm	300 lb/lm	400 lb/lm
Fulton	1	Single	5.5	2.7	2.2	1.8	1.4
		Tandem	7.5	3.8	3.0	2.5	1.9
Fulton	2	Single	4.3	2.2	1.7	1.4	1.1
		Tandem	5.9	3.0	2.4	2.0	1.5
Fulton	3	Single	3.9	1.9	1.6	1.3	1.0
		Tandem	5.4	2.7	2.1	1.8	1.3
Fulton	4	Single	5.8	2.9	2.3	1.9	1.4
		Tandem	7.9	4.0	3.2	2.6	2.0
Fulton	5	Single	4.7	2.4	1.9	1.6	1.2
		Tandem	6.5	3.2	2.6	2.2	1.6
Fulton	6	Single	7.3	3.7	2.9	2.4	1.8
		Tandem	10.1	5.0	4.0	3.4	2.5
Fulton	7	Single	7.4	3.7	3.0	2.5	1.8
		Tandem	10.2	5.1	4.1	3.4	2.5
Fulton	8	Single	6.0	3.0	2.4	2.0	1.5
		Tandem	8.3	4.2	3.3	2.8	2.1
Fulton	9	Single	3.8	1.9	1.5	1.3	0.9
		Tandem	5.2	2.6	2.1	1.7	1.3

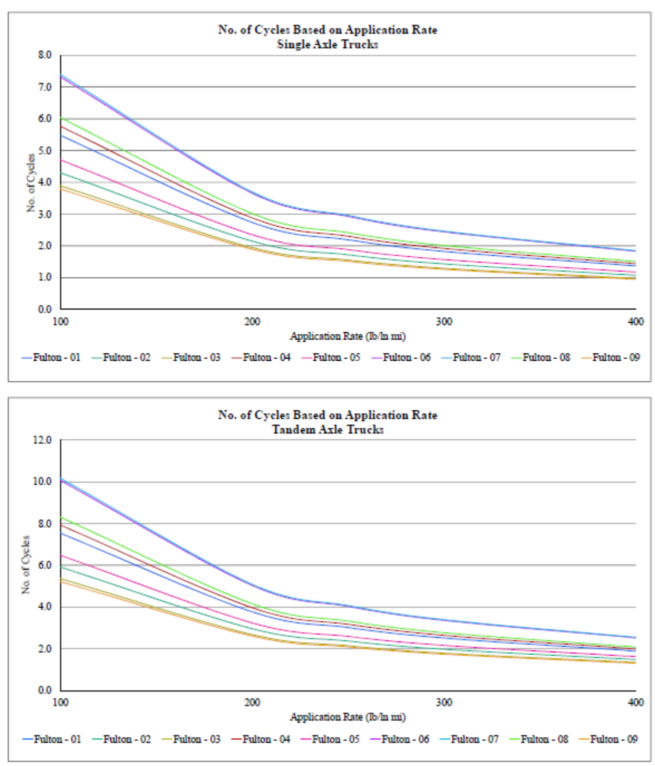


Figure 6.5: Example of Table and Graphs Produced to Show Number of Cycles Before Refill.

Figure 6.5 above provides an example of the table produced for each facility showing the number of cycles that may be completed based on the capacity of the truck and the application rate. The data presented in Figure 6.5 is valuable to the county managers as they determine which routes the trucks with larger capacities should treat based on the amount of snowfall in an area (ex. If half of the county is experiencing heavy snowfall while the other half is not, the managers may assign tandem axle trucks to the side experiencing heavy snowfall and know the amount of cycles they could complete).

Once the initial optimized routes were created and finalized by ODOT leadership, the research team was able to proceed with developing and implementing a route verification plan for each district. The routes produced from the initial optimization would be the routes used to determine the accuracy of the ROM. The maps of the initial optimized routes from a district and facility overview may be found in Appendix A of this report.

CHAPTER VII ROUTE VERIFICATION

In order to validate the accuracy of the cycle times acquired from the VRP, the research team developed and implemented a plan for each district to have the initial optimized routes driven with GPS units. The GPS units collected data on the total time to drive the optimized routes and the average speed driven. A summary of the route verification process is described in Figure 7.1 below.

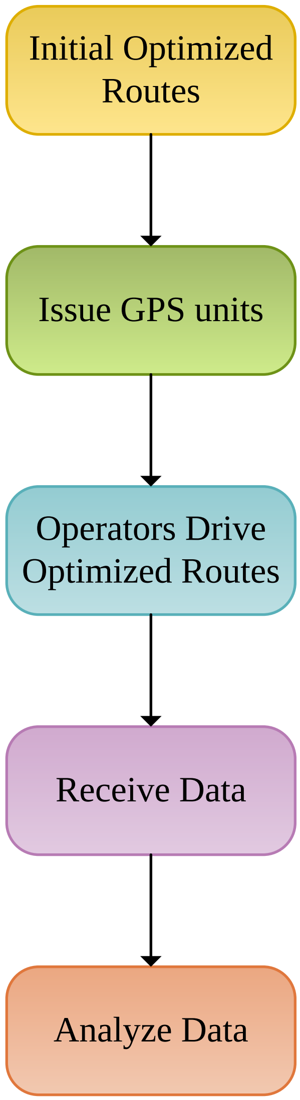


Figure 7.1: Route Verification Process.

Upon receiving the data, the research team was able to determine routes that maintained contradictory cycle times by analyzing the percent difference between the model's predicted times to the actual times obtained from driving the proposed route. Equation 7.1 was used to determine the percent difference between the times obtained from driving the routes and the calculated times from the ROM.

$$Percent\ Difference = \frac{(Dt - Mt)}{D_t} X\ 100 \qquad Equation\ 7.1$$

where,

D_t =Time acquired from driving the route; and

M_t = Calculated time from the ROM.

After applying Equation 7.1 to determine the percent difference between the time obtained from driving the route and the calculated time from the ROM, each route was classified into three tiers:

- Tier One – Within 10%;
- Tier Two – Within 10-15%; and
- Tier Three – Greater than 15%.

The routes were classified into three tiers to categorize the cycle times that were acceptable from the cycle times that may need modification within the ROM to the accurate cycle times of the optimized routes. Routes classified as Tier One were determined to be acceptable as it allowed the model to produce realistic times while allowing a 10% variance to account for the many variables of winter maintenance operations. The routes classified as Tier Two were typically driven at speeds slightly slower or faster than the speeds utilized within the ROM. Routes classified as Tier Three were typically routes that were driven incorrectly. Routes classified as Tier Two or Three were deemed to be further analyzed as the percent difference was too great to predict accurate route completion times. This analysis consisted of information on whether the driver drove the correct route, whether the driver stopped to yield to traffic flow, and whether the driver drove significantly faster or more slowly than the speed used in the model. The most common issues were the route being driven incorrectly and at fast speeds.

To ensure that the ROM produced accurate times for the route, the model was run at the average speed obtained through the verification. After running the model with the speed obtained from driving the route, Equation 7.1 was again applied to the data to calculate the percent difference. If the percent difference between the new model time and the actual time acquired from driving the route could be classified as a Tier One route, the issue was considered resolved. By calculating the percent difference a second time, the research team was able to show that the model would have produced accurate cycle times had the speed within the model been the same as the average speed traveled. This verification may be useful in future ROMs that allow the user to select unique speeds.

Once the data were collected, tables and graphs were created to show the relationship between the time obtained from driving the route and the projected time from the model. The results for each district may be found in the following subsections of this chapter.

7.1 District 1 Route Verification Overview

Figure 7.2 provides a visual representation of the route verification plan for District 1. The district was divided into two groups (distinguished as either red or blue) with each group containing six GPS transponders that were used to acquire data from driving the proposed routes. By dividing the district into two separate groups, the routes were able to be driven in a timely manner without interfering with the day to day responsibilities of the garages.

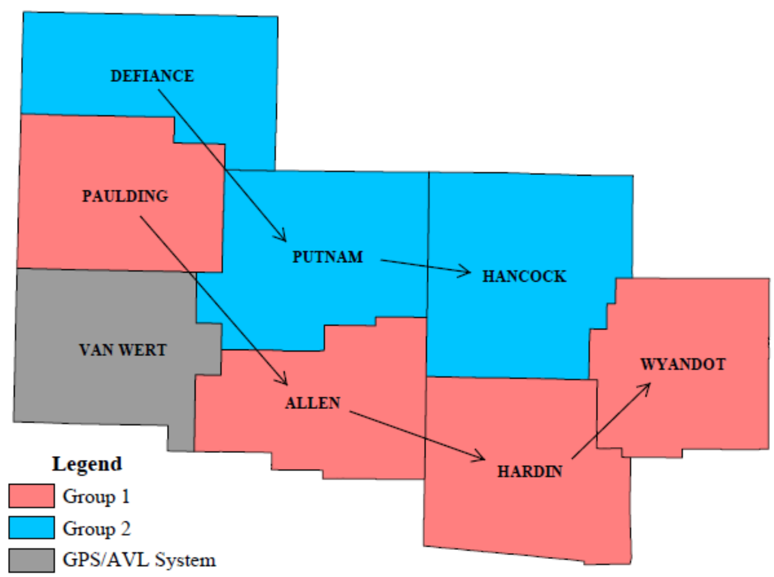
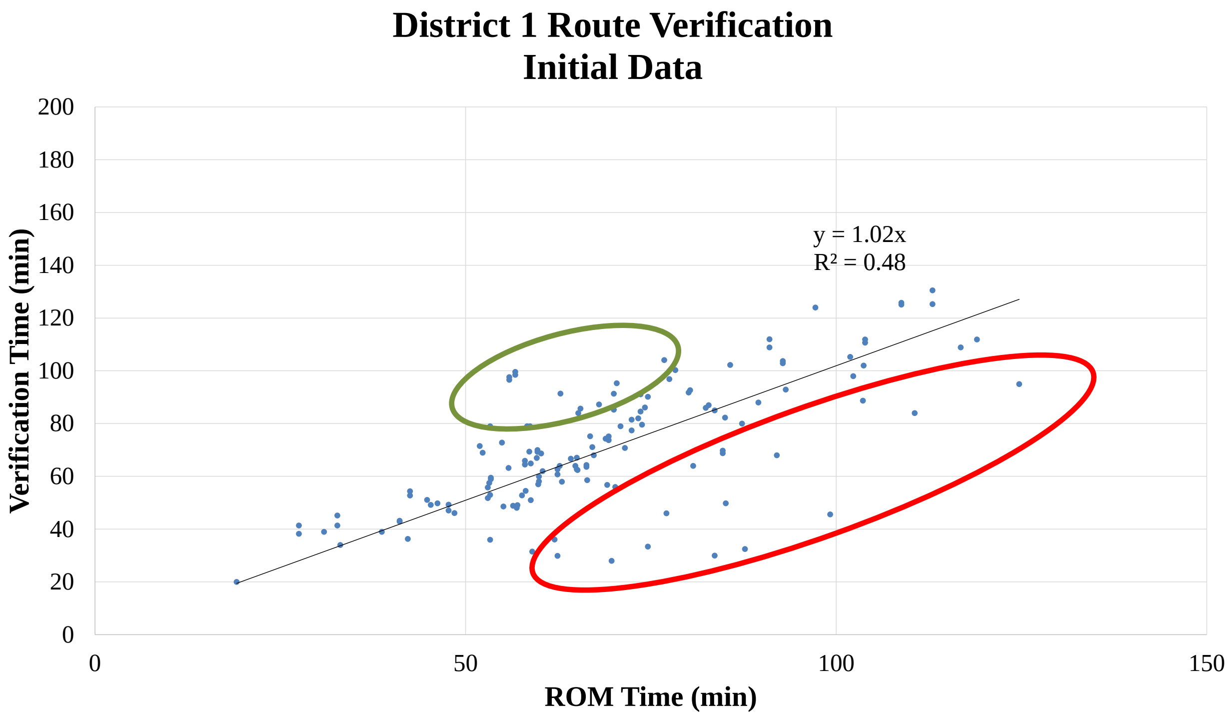


Figure 7.2: Map of Verification Plan for ODOT District 1.

As shown in Figure 7.2 above, the county of Van Wert was not incorporated into the previously mentioned groups. This was due to the fact that the county already possesses GPS/AVL units in its vehicles. With the technology available and already installed, the research team was able to acquire all of the Van Wert County data from driving the routes through the ODOT website that manages the data.

7.2 District 1 Route Verification Results

By following the same process described at the beginning of this chapter regarding the analysis of the data collected from driving the proposed routes, the research team was able to initially determine the difference between the time produced from the ROM and the time acquired from driving the routes. Of the 115 initial optimized routes, data for 115 routes were collected, constituting 100% of all routes. The results from the initial data gathered are shown in Figure 7.3.



Note: The points above the line of best fit as shown in the green oval represent the cycle times obtained from routes that were driven slower than the expected speeds as determined by District 1 leadership. In addition, the points within the red oval represent the routes that were driven at a higher average speed. These variations in speed may have occurred due to the routes being driven in the spring, causing the speeds to fluctuate due to a higher level of traffic than experienced during the snow and ice season.

Figure 7.3: District 1 Initial Route Verification Data.

Figure 7.3 above shows the graph of the data collected for the initial optimized routes in District 1. The line of best fit, set to intercept the origin, has a slope of 1.02. This slope represents a 2% difference between the data collected and the calculated cycle times. In addition, the line of best fit maintains a coefficient of determination of 48%, meaning that the cycle times produced from the ROM explains 48% of the variability between the acquired and calculated cycle times.

The primary reason for the variance in the cycle times acquired from driving the routes and the cycle times from the ROM is that the operators drove at speeds significantly higher than the speeds utilized in the ROM due to safety concerns regarding driving heavily traveled roads in the spring and summer seasons. To determine if the ROM was capable of determining accurate cycle times from the speed utilized within the model, the research team ran the ROM with the average speed acquired from driving the initial optimized routes. The results of reconfiguring the ROM to utilize the higher speeds are shown below in Figure 7.4.

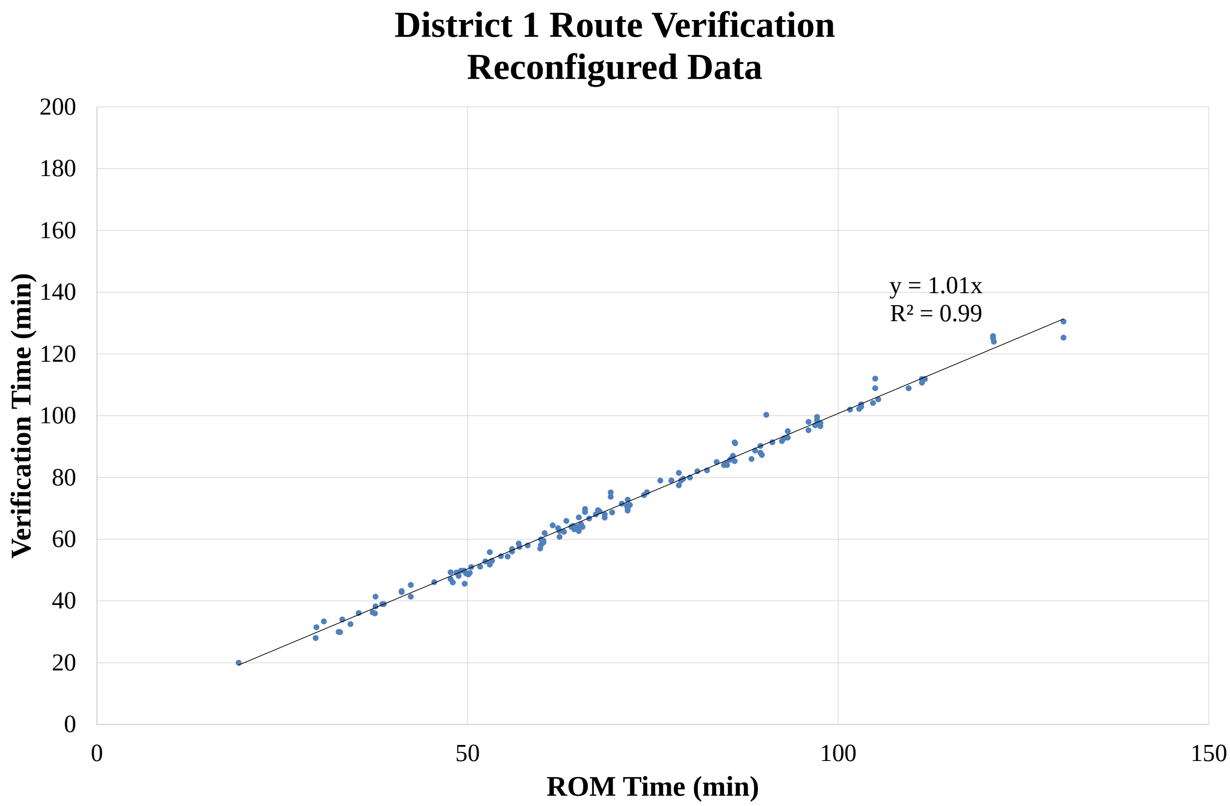


Figure 7.4: District 1 Reconfigured Verification Data.

Adopting the higher speeds in the ROM resulted in a 1% difference between the cycle times calculated from the ROM and the time acquired from driving the initial optimized routes. In addition, the coefficient of determination increased from the previous 62% to 99%, that is, 99% of the variance is now predictable when comparing the ROM cycle times to the acquired cycle times. The results of this analysis show that the speeds utilized in the ROM will accurately calculate the real world cycle times if the speeds used in the ROM are the same as those used for real world snow and ice events.

7.3 District 2 Route Verification Overview

Similar to District 1, District 2 was divided into separate groups in order to facilitate the route verification data collection (as shown in Figure 7.5). Of the three groups, the first consisted of Williams, Fulton, and Henry Counties. The second group consisted of Lucas and Wood Counties; and the third group of Ottawa, Sandusky, and Seneca Counties. The groups were determined by the number of routes that needed to be driven and the geographic location of the counties in each group.

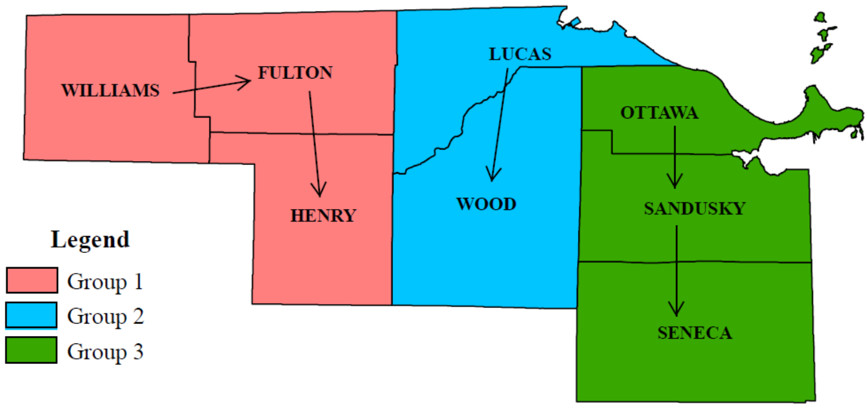


Figure 7.5: Map of Verification Plan for ODOT District 2.

7.4 District 2 Route Verification Results

In order to present the route verification data in an organized manner, this section is organized into three subsections. Each subsection presents the results from each scenario analyzed for District 2 and contains information regarding the initial data obtained and the reconfigured cycle times.

7.4.1 District 2 Part 1 Route Verification Results

The results from the route verification process for District 2 Part 1 showed that 126 of the 126 routes were driven. The route verification results from District 2 Part 1 have resulted in 100% of the routes were classified as Tier One after operating the ROM at the speeds acquired from driving the routes. Figure 7.6 shows the data acquired before running the model at the average speeds driven.

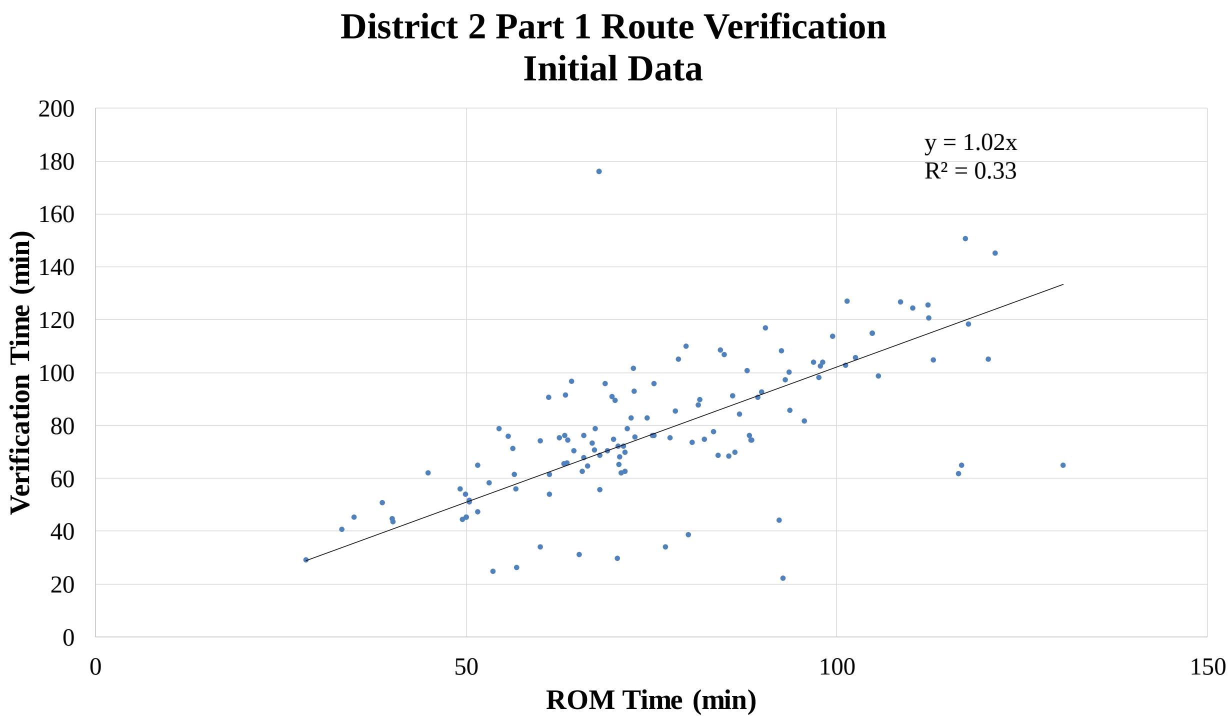


Figure 7.6: District 2 Part 1 Initial Route Verification Data.

As may be observed from Figure 7.6, the initial data obtained driving the routes does not match the line of best fit, as shown by the coefficient of determination being 33%. The primary reason for the variance in the cycle times acquired from driving the routes and the cycle times from the ROM is that the operators drove at speeds significantly higher than the speeds utilized in the ROM due to safety concerns of driving at winter maintenance speeds during the summer months. In addition, there was a significant amount of road construction projects being completed in District 2 during the time of verifying the routes, resulting in sporadic cycle times. To determine if the ROM was capable of determining accurate cycle times from the speed utilized within the model, the research team ran the ROM with the average speed acquired from driving the initial optimized routes. The results of reconfiguring the ROM to utilize the higher speeds are shown in Figure 7.7.

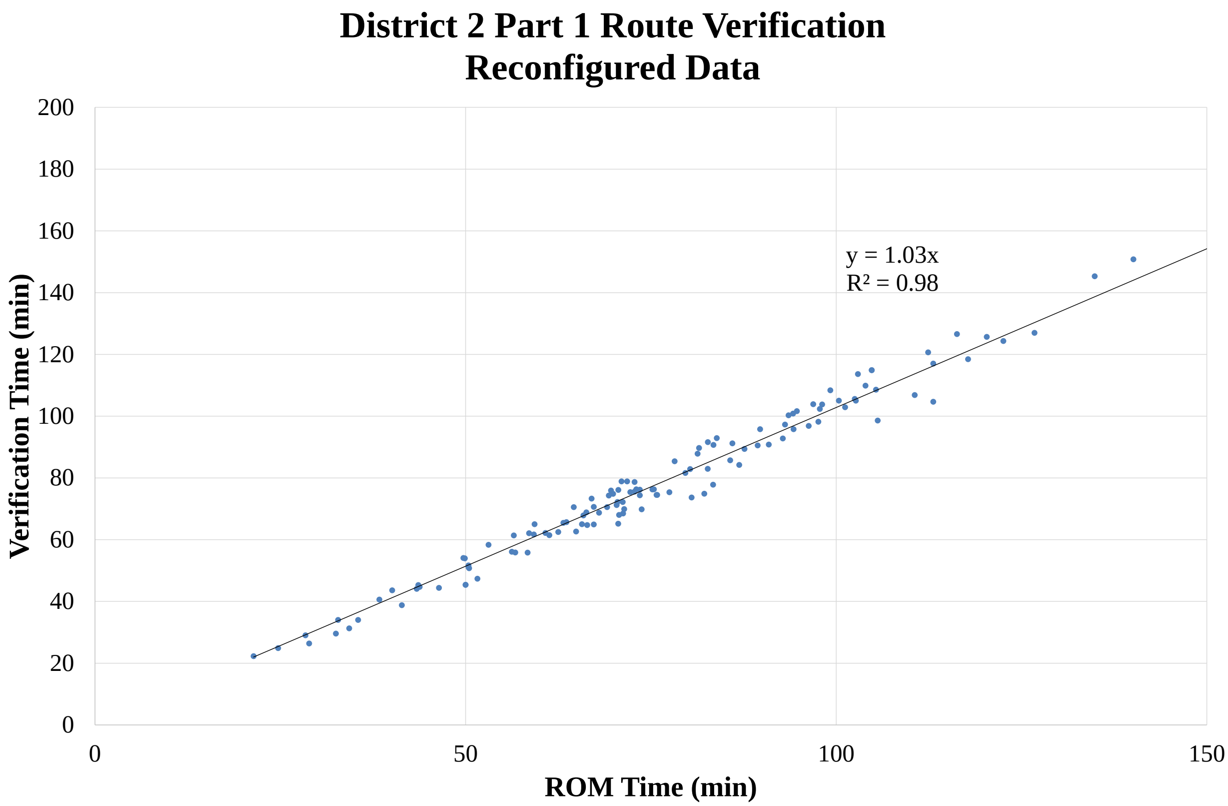


Figure 7.7: District 2 Part 1 Reconfigured Verification Data.

Adopting the speeds obtained from driving the routes in the ROM resulted in a 3% difference between the cycle times calculated from the ROM and the time acquired from driving the initial optimized routes. In addition, the coefficient of determination increased from the previous 33% to 98%, meaning 98% of the variance is now predictable when comparing the ROM cycle times to the acquired cycle times. The results of this analysis show that the speeds utilized in the ROM will accurately calculate the real world cycle times if the speeds used in the ROM are the same as those used for real world snow and ice events.

7.4.2 District 2 Part 2 Route Verification Results

The results from the route verification process for District 2 Part 2 showed that 126 of the 126 routes were driven. The route verification results from District 2 Part 2 have resulted in 100% of the routes were classified as Tier One after operating the ROM at the speeds acquired from driving the routes. Figure 7.8 shows the data acquired before running the model at the average speeds driven.

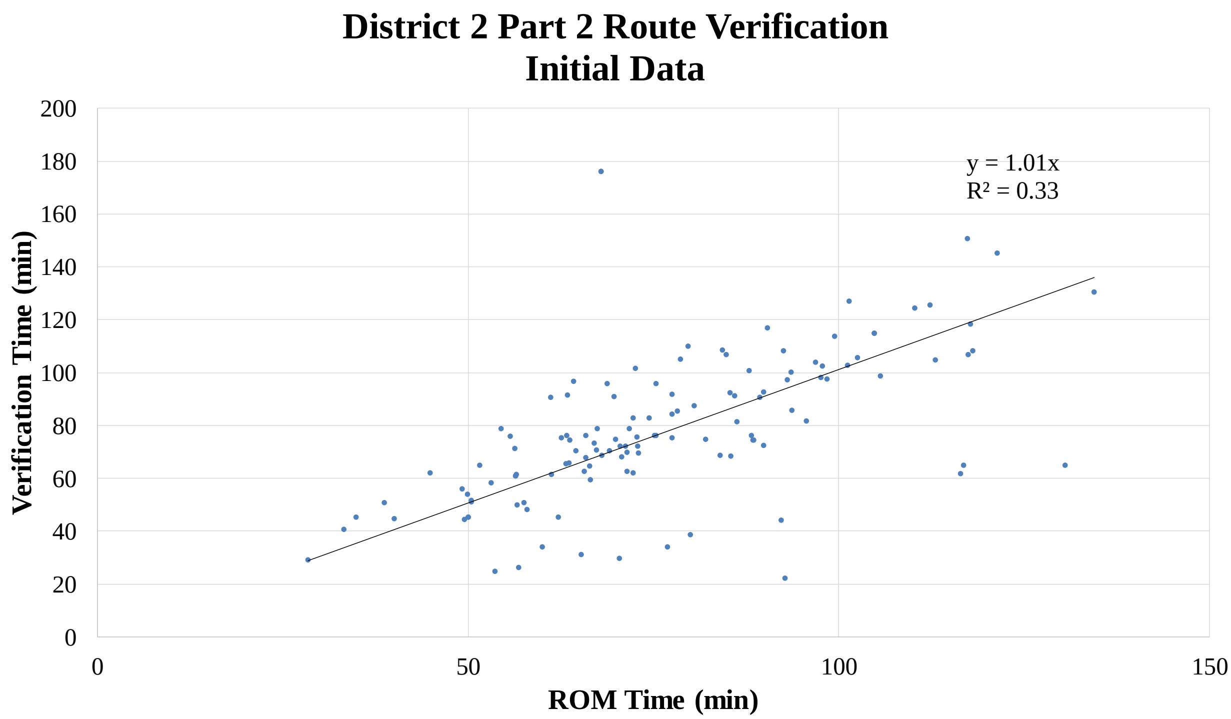


Figure 7.8: District 2 Part 2 Initial Route Verification Data.

Similar to the route verification results presented in District 2 Part 1, the initial data obtained from driving the routes does not match the line of best fit, as shown by the coefficient of determination being 33%. The variance in the cycle times acquired from driving the routes and the cycle times from the ROM is that the operators drove at speeds significantly higher than the speeds utilized in the ROM due to safety concerns of driving at winter maintenance speeds during the summer months. The road construction projects being completed in District 2 also resulted in higher cycle times. To determine if the ROM was capable of determining accurate cycle times from the speed utilized within the model, the research team ran the ROM with the average speed acquired from driving the initial optimized routes. The results of reconfiguring the ROM to utilize the acquired speeds are shown below in Figure 7.9.

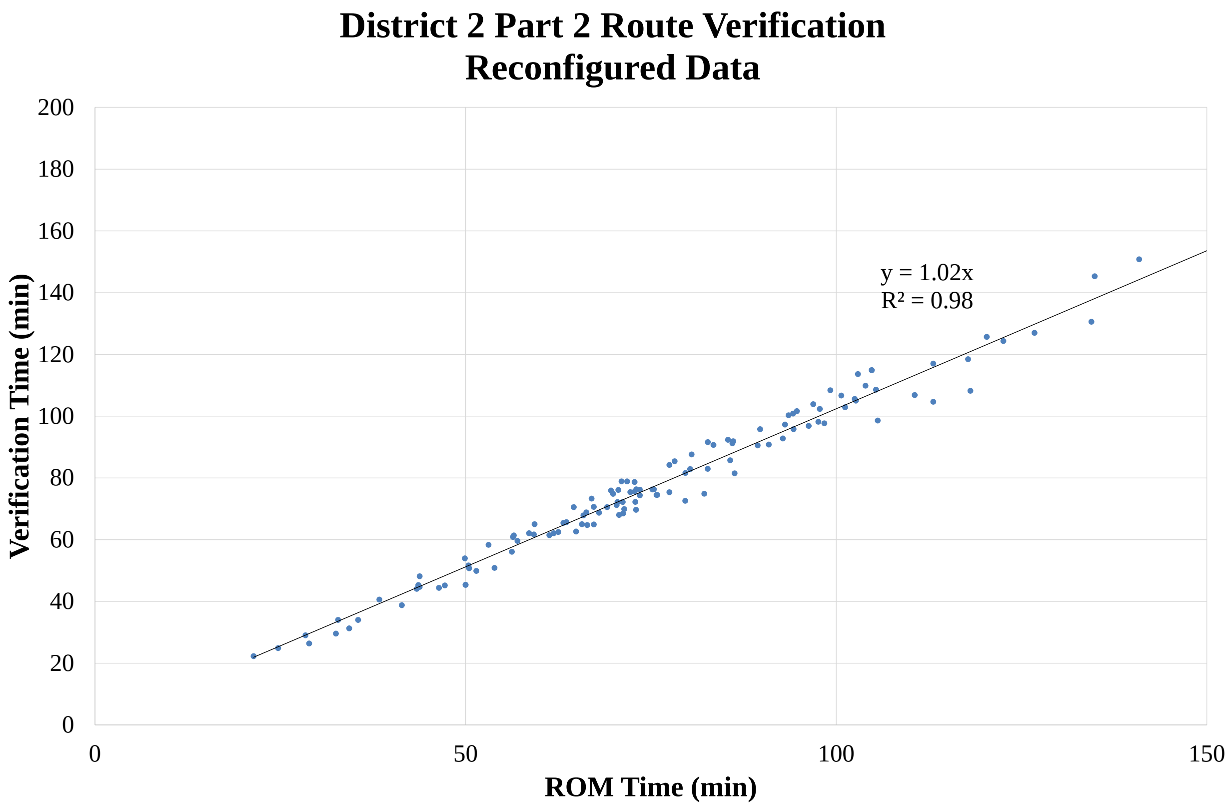


Figure 7.9: District 2 Part 2 Reconfigured Verification Data.

Implementing the speeds obtained from driving the routes into the ROM resulted in a 2% difference between the cycle times calculated from the ROM and the time acquired from driving the initial optimized routes. In addition, the coefficient of determination increased from the previous 33% to 98%, that is, 98% of the variance is now predictable when comparing the ROM cycle times to the acquired cycle times. The results of this analysis show that the speeds utilized in the ROM will accurately calculate the real world cycle times if the speeds used in the ROM are the same as those used for real world snow and ice events.

7.4.3 District 2 Part 3 Route Verification Results

The results from the route verification process for District 2 Part 3 showed that 126 of the 126 routes were driven. The route verification results from District 2 Part 3 have resulted in 100% of the routes were classified as Tier One after operating the ROM at the speeds acquired from driving the routes. Figure 7.10 shows the data acquired before running the model at the average speeds driven.

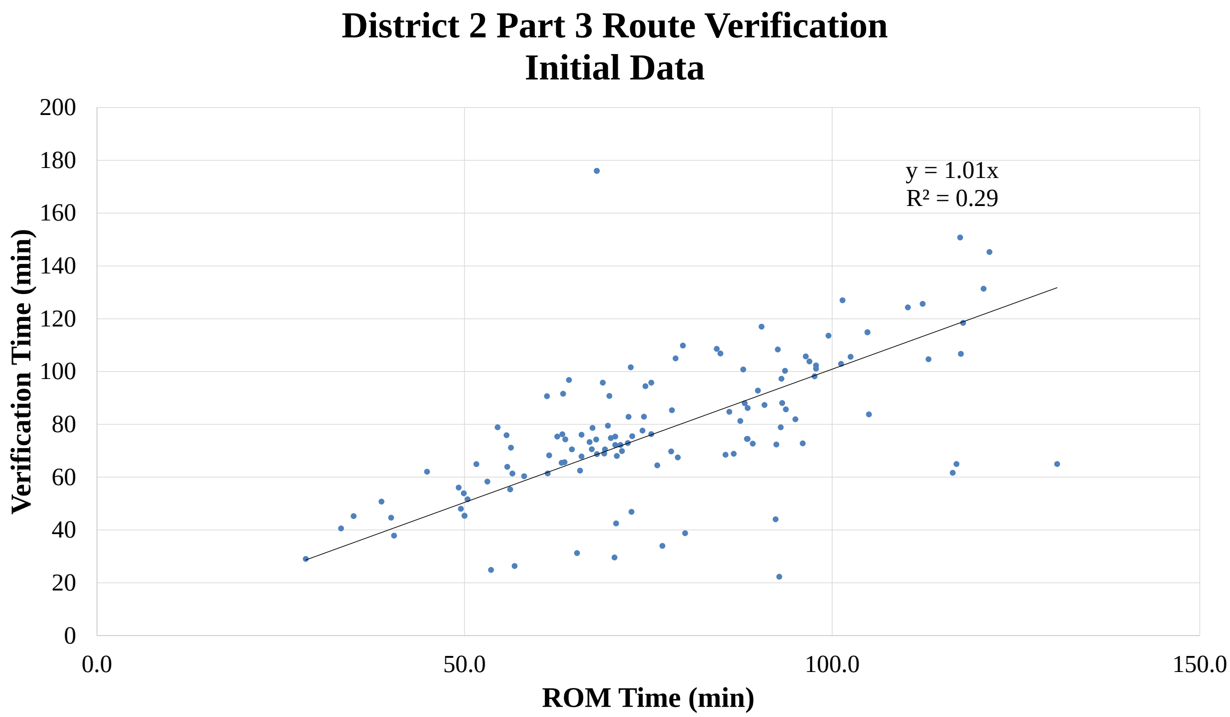


Figure 7.10: District 2 Part 3 Initial Route Verification Data.

Similar to the route verification results presented in District 2 Parts 1 and 2, the initial data obtained from driving the routes does not match the line of best fit, as shown by the coefficient of determination being 29%. The variance in the cycle times acquired from driving the routes and the cycle times from the ROM is that the operators drove at speeds significantly higher than the speeds utilized in the ROM due to safety concerns of driving at winter maintenance speeds during the summer months. The road construction projects being completed in District 2 also resulted in higher cycle times. To determine if the ROM was capable of determining accurate cycle times from the speed utilized within the model, the research team ran the ROM with the average speed acquired from driving the initial optimized routes. The results of reconfiguring the ROM to utilize the acquired speeds are shown in Figure 7.11.

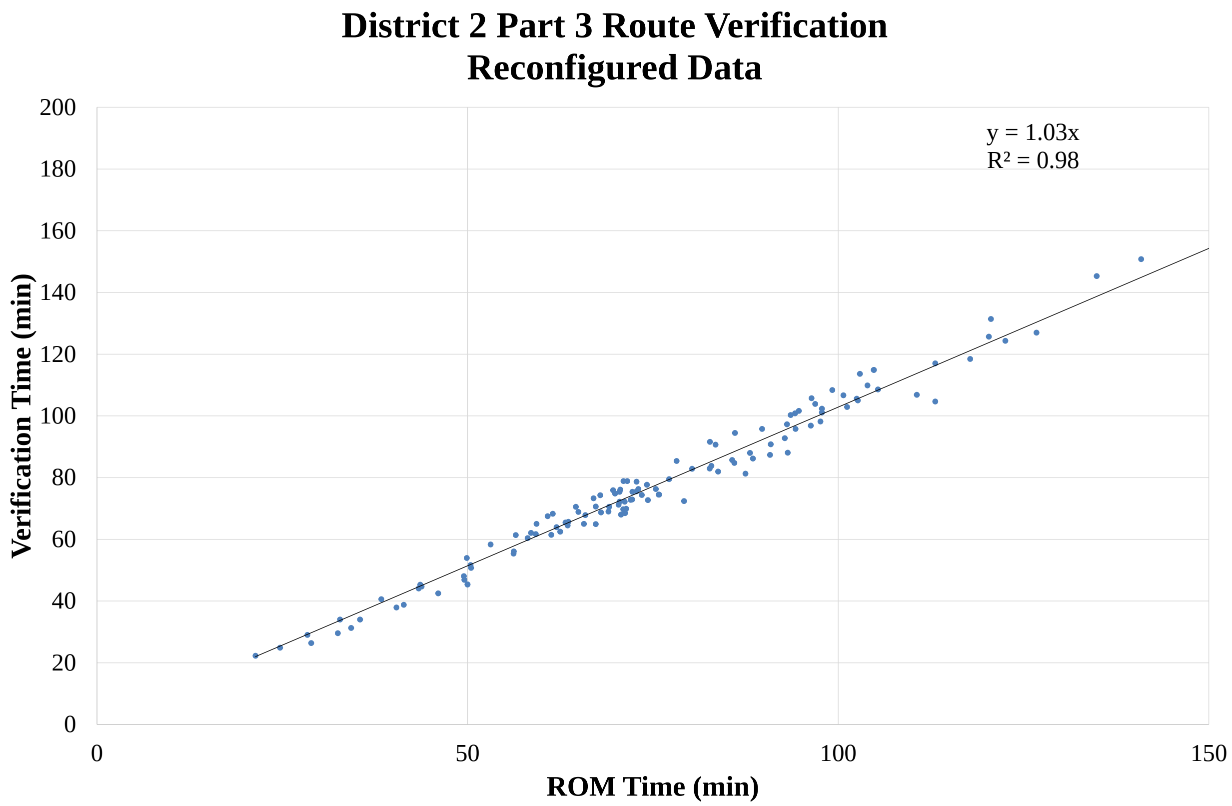


Figure 7.11: District 2 Part 3 Reconfigured Verification Data.

Implementing the speeds obtained from driving the routes into the ROM resulted in a 3% difference between the cycle times calculated from the ROM and the time acquired from driving the initial optimized routes. In addition, the coefficient of determination increased from the previous 29% to 98%, that is, 98% of the variance is now predictable when comparing the ROM cycle times to the acquired cycle times. The results of this analysis show that the speeds utilized in the ROM will accurately calculate the real world cycle times if the speeds used in the ROM are the same as those used for real world snow and ice events.

7.5 District 10 Route Verification Overview

In regards to the route verification plan for ODOT District 10, the research team worked closely with the District leadership and determined that because of the immense responsibilities of the garages during the time of the verification, it would be best to collect data for each county individually. The first county to drive the proposed routes was Gallia County located in the southernmost corner of the district. As each county finished driving the routes, a member of the research team drove to District 10 to collect the data and transport the GPS transponders to the next county. The GPS transponders were moved north until reaching Monroe County, at which point they were returned to The University of Akron. The movement of the GPS transponders from county to county is shown in Figure 7.12.

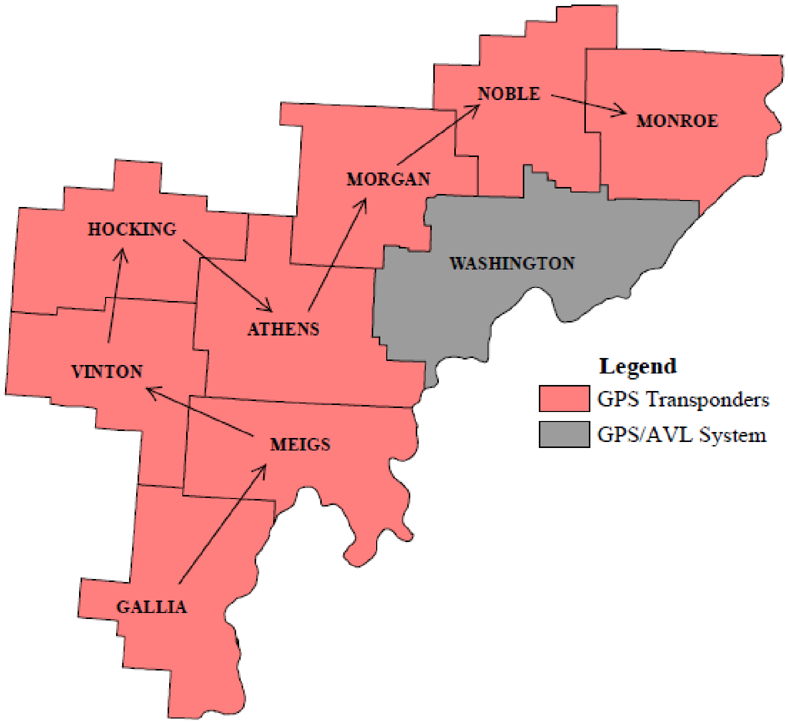
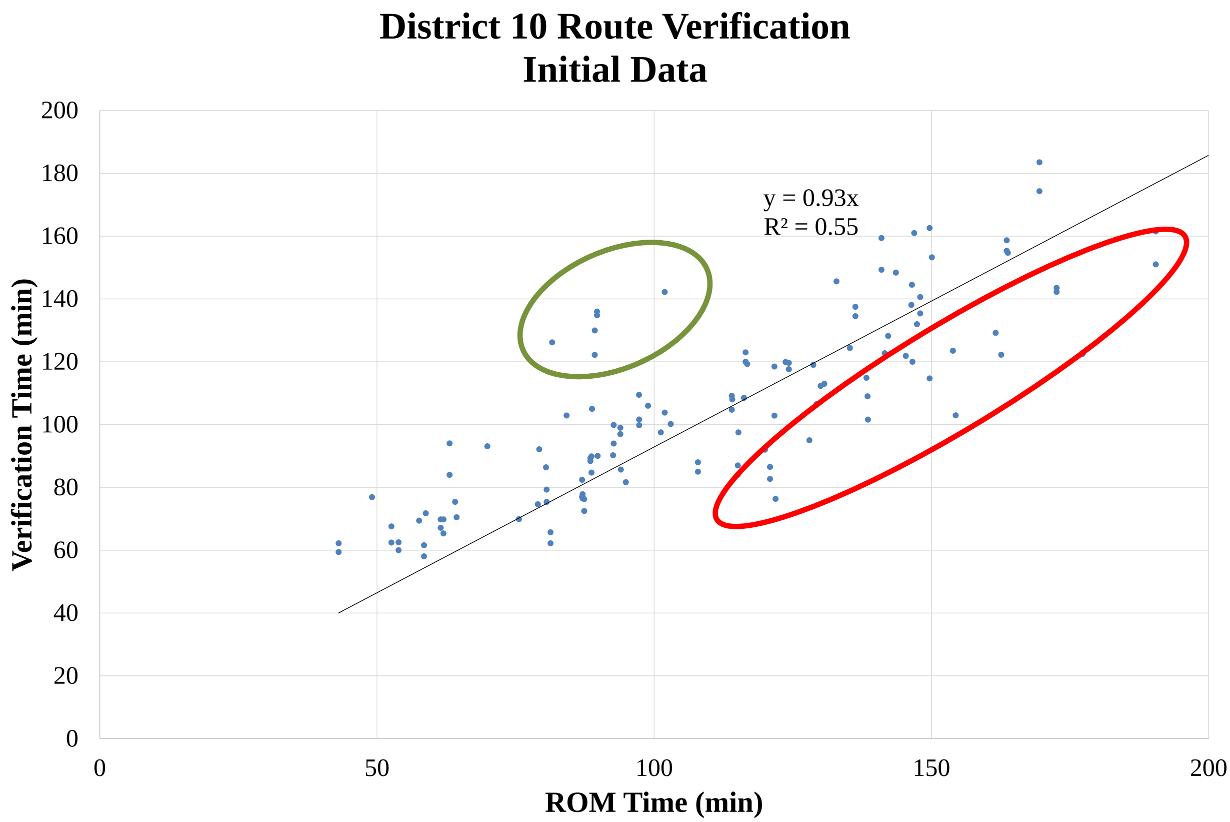


Figure 7.12: Map of Verification Plan for ODOT District 10.

As may be observed from Figure 7.12, Washington County did not receive the GPS units since the trucks there were already equipped with GPS/AVL systems (similar to Van Wert County in District 1). The routes in Washington County were not driven due to safety concerns out of respect for the operators who would have been driving slowly due to the traffic on the roads during the spring and summer months.

7.6 District 10 Route Verification Results

The results from the route verification process for District 10 showed that 90 of the 115 routes were driven, or approximately 78% of the initial optimized routes. The reason that not all of the routes were driven was the safety concerns for the operators who would not be able to safely travel the routes at typical treating speeds during the fall and summer seasons due to increased traffic volumes. Another reason that explains why 78% of the routes were driven was that the 90 routes that were driven were classified as Tier One after operating the ROM at the speeds acquired from driving the routes, in which case both the research team and ODOT leadership decided it was acceptable to validate the ROM-calculated cycle times. Figure 7.13 shows the data acquired before running the model at the average speeds driven.



Note: The points above the line of best fit as shown in the green oval represent the cycle times obtained from routes that were driven slower than the expected speeds as determined by District 10 leadership. In addition, the points within the red oval represent the routes that were driven at a higher average speed. These variations in speed may have occurred due to the routes being driven in the spring, causing the speeds to fluctuate due to a higher level of traffic than experienced during the snow and ice season.

Figure 7.13: District 10 Initial Route Verification Data.

Figure 7.13 above graphically shows the initial data collected that maintain a coefficient of determination of approximately 55%, which means that the ROM explains 55% of the variability of the data. The slope of the line shows that there is about a 7% difference between the time acquired from driving the routes and the calculated time from the ROM. The variance observed from the initial data was due to operators driving the routes at speeds that were different from the speeds used in the model. In order to analyze the ability of the ROM to produce accurate cycle times based on the inputted actual speed, the research team then ran the ROM with the average speeds acquired from driving the routes. The results after reconfiguring the model to use the acquired speeds are shown in Figure 7.14.

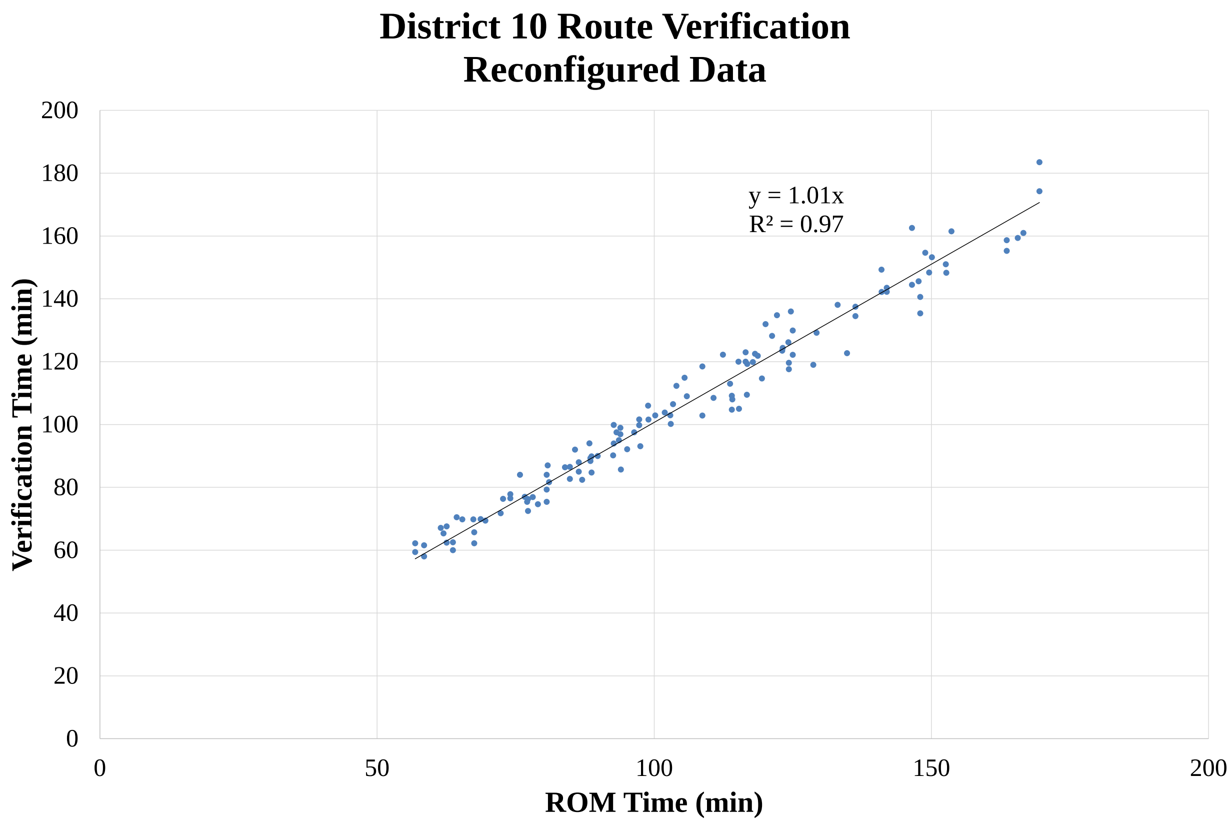


Figure 7.14: District 10 Reconfigured Verification Data.

The reconfigured results show that there is an approximate coefficient of determination value of 97%. That is, the ROM takes into account 97% of the variance between the cycle times acquired from driving the proposed routes and the cycle times produced from the model. In addition, the slope of the line shows that there is approximately a 1% difference between the cycle times acquired and the calculated cycle times when used the same speeds. The results from verifying the routes supported the concept that the ROM is capable of producing accurate cycle times when inputting the same speeds as would be traveled in real world applications.

The fleet optimization section summarizes the final results obtained regarding the optimized winter maintenance operations in Districts 1, 2, and 10. As mentioned in Chapter 4 of this report, the optimization of the fleets consisted of removing the least efficient trucks from the initial optimized routes in order to determine the minimum number needed at each facility to maintain the current LOS in each of the districts. This analysis was completed by using the LOS requirements for each district, the typical treating speeds, the removal of county borders, and utilizing an application rate of 400 lbs/ln mile. The 400 lbs/ln mile takes into account the worst-case scenario regarding the maximum application rate, thus allowing the ROM to determine an accurate amount of operational trucks needed to best treat the roads within each district. The flowchart below in Figure 8.1 describes the methodology to optimizing the fleet within the associated districts.

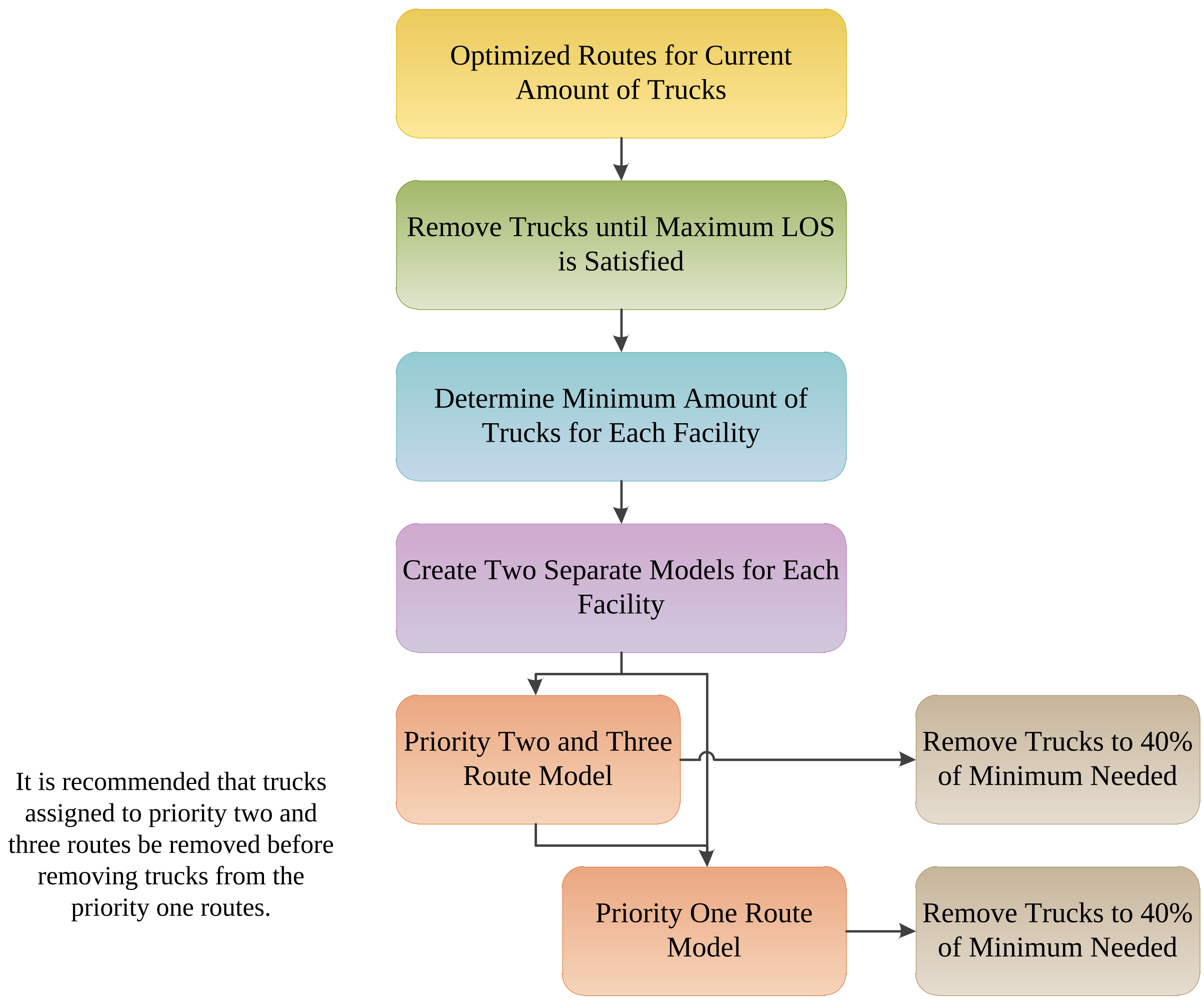


Figure 8.1: Fleet Optimization Methodology.

Figure 8.1 provides a visual representation of the fleet optimization process that was conducted in all districts associated with the project. Fleet optimization began by taking the ROM that utilized all trucks in a district and removing the trucks maintaining the least efficient routes at each facility. After removing the trucks, the ROM was run and new routes were created to accommodate the missing trucks. The process of removing trucks assigned to the least efficient routes and running the optimization model was repeated until the current LOS requirements were satisfied in the district. After hitting the threshold of the maximum number of trucks that could be removed within the scope of the LOS requirements, the research team was able to determine the minimum amount of routes needed within the district and each facility to maintain the desired LOS.

It is important to note that the efficiency for fleet-optimized trucks falls within a range of values and is not a fixed number. To account for this range, the research team took into account the number of cycles that may be completed for each truck at an application rate of 400 lbs/ ln mile and 250 lbs/ln mile. The lower end of the efficiency range was calculated at the number of cycles that may be completed at the higher application rate and the higher end of the efficiency utilized the lower application rate. Both efficiencies were calculated for the individual trucks with the equation shown in Equation 6.1 on page 41. The range of the potential efficiencies for each truck was then used to calculate the overall district efficiency range. The equation used to calculate the district efficiency is shown below in Equation 8.1;

$$District\ Efficiency = \frac{\Sigma\ IRE}{T} \qquad Equation\ 8.1$$

where,

IRE=Individual route efficiencies, and

T=Number of operational trucks.

After determining the minimum number of routes for the district, the research team continued to remove trucks from the ROM to conduct an analysis of the change in cycle times, deadhead times, and lane miles treated for each route. The research team decided to continue removing trucks from each facility until reaching approximately 40% of the minimum needed to satisfy the LOS requirements within the district. The research team believed that the removal of trucks until reaching 40% of the minimum amount needed would provide enough data to conduct an initial analysis of how the routes change to accommodate the missing truck and provide a valuable tool for county managers as they determine how to allocate their limited resources to best conduct winter maintenance operations. It is important to note that trucks assigned to the priority two and three routes were removed before the trucks assigned to the priority one routes. This was done to ensure that the priority one routes in the district is effectively maintained, regardless of the resources available at each facility at any given time. Figure 8.2 below shows an example of the fleet optimization process for Hardin County in District 1. After optimizing the district fleet, the ROM determined that the Hardin County Garage required a seven truck crew as the minimum number of trucks needed to best satisfy the LOS requirements of the district.

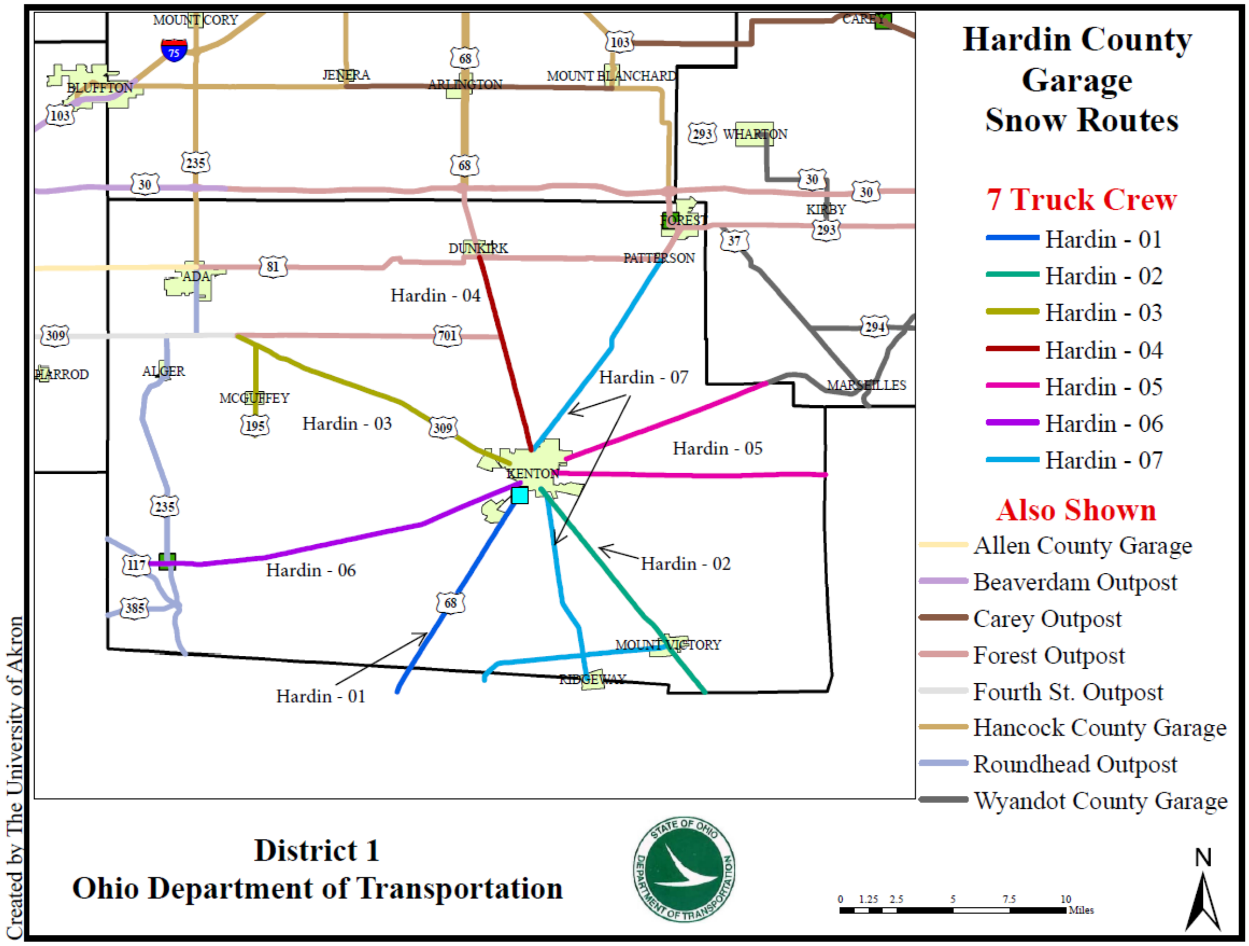


Figure 8.2: Example of the Minimum Truck Crew for Hardin County Garage.

The area that the Hardin County Garage maintains in Figure 8.2 is the same area that must be treated after trucks are removed from the ROM. This was done to prevent any confusion of where to treat amongst the different facilities in the district. Once the minimum number of trucks was determined for each facility, one truck that treated priority two and three routes was removed from the ROM and new routes were determined to accommodate the removed truck. Figure 8.3 provides an example of how the area treated by the Hardin County Garage remained the same as well as how the priority two and three routes changed to accommodate the removed truck.

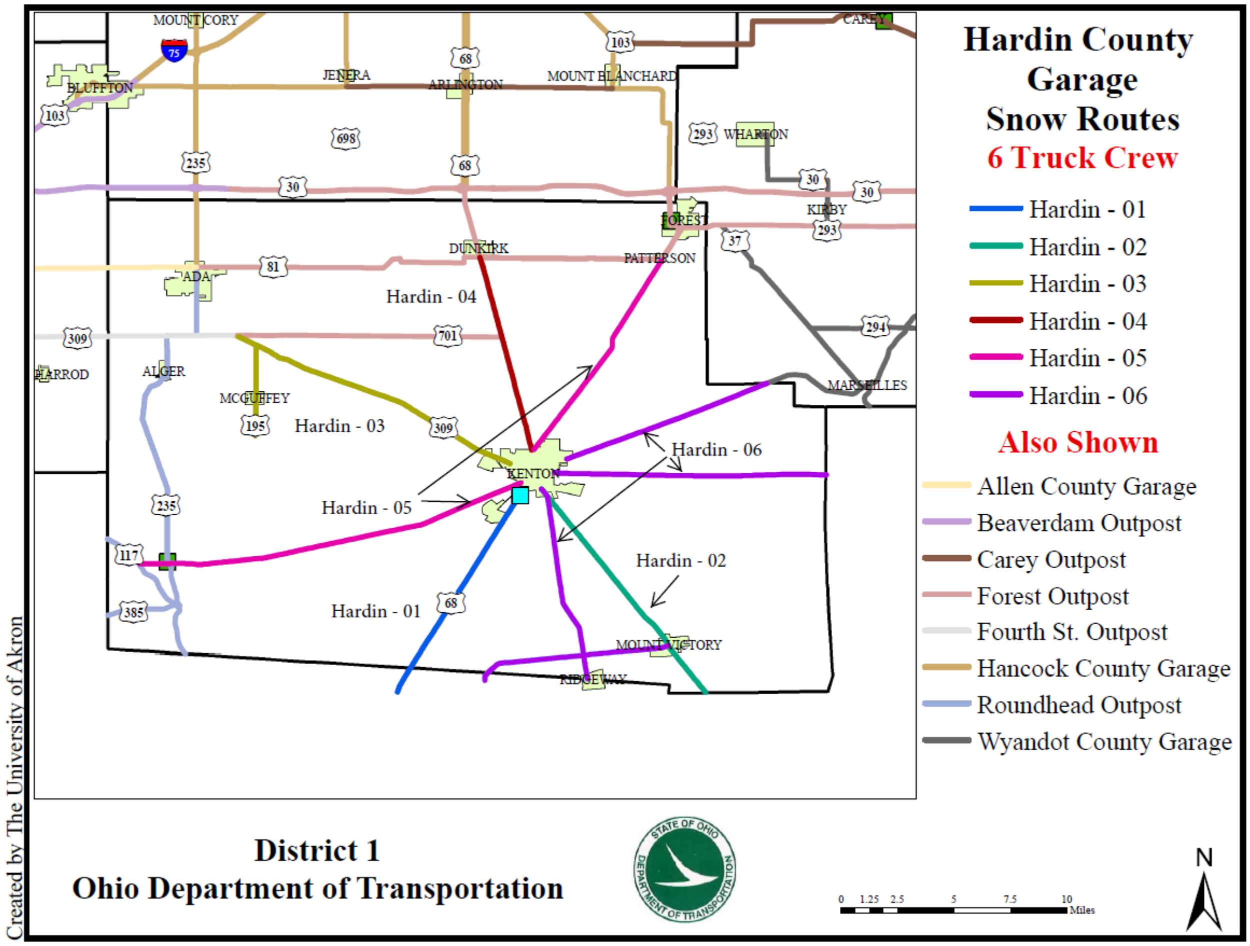


Figure 8.3: Example of Hardin County Garage Secondary Routes with One Truck Removed.

When comparing the routes between Figure 8.2 and Figure 8.3, the priority two and three routes changed to accommodate the removed truck, where Hardin – 07 in Figure 8.2 was absorbed by Hardin – 05 and Hardin – 06 in Figure 8.3. It may be observed that the priority one trucks (Trucks one through four) from Figure 8.2 remained unchanged in Figure 8.3. It goes to show that the priority one routes remain the same and only the priority two and three routes have changed to accommodate the removed truck. The research team continued to remove trucks from the priority two and three routes until reaching approximately 40% of the minimum number of trucks needed to satisfy the District's LOS requirements. This process was then completed for the priority one routes. The maps produced as a result of removing trucks from both the priority two and three routes before removing trucks from the priority one routes provide ODOT with a "playbook" of routes that offers flexible options for the end users to make informed decisions on winter maintenance operations.

The following sections of this chapter summarize the results for each district after conducting fleet optimization.

8.1 District 1 Fleet Optimization Results

Following the process described in the beginning of this chapter, the fleet optimization results in Table 8.1 below show a comparison in the number of trucks, the district total travel times to treat all roads for one iteration, the percent of trucks that satisfies the LOS requirements, and the district efficiency ranges for the trucks currently being driven and the optimized trucks.

Table 8.1: District 1 Route Optimization Summary of Results.

District 1 Fleet Optimization Analysis

		Current	**Fleet Optimized**	**Difference**
Operational Trucks		109	104	-5
Fleet Size		127	115	-12
Total Travel Time (Minutes)		7,651	7,443	-208
Percent LOS Maintained		53	53	0
District Efficiency Range	Low	77	81	4
	High	87	88	1

Note: The fleet size takes into account a 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all roads within the district for one iteration and allowing trucks to complete numerous cycles before returning to the garage for refilling.

The number of operational trucks shown in Table 8.1 above represents the number of trucks needed to conduct winter maintenance operations at the same LOS currently being maintained. This number does not take into account trucks that are unavailable for winter maintenance due to mechanical issues. The number shown in the Fleet Size row is the recommended fleet size after optimizing the district and adding the 10% safety factor to account for unavailable trucks at any given time. After optimizing District 1, the ROM suggests that the district requires 114 trucks to effectively treat all roadways within the district.

The total travel time represents the time required to treat each road within the district once with a 196 minute decrease in comparison with the current winter maintenance operations. The total travel time includes the deadhead time required to reach the treating area, the time required to treat the determined area, and the deadhead time to return to the facility from which the truck originated.

Upon applying the same parameters to the current winter operations as used in the optimized operations, the research team was able to determine that approximately 53% of the trucks currently used satisfy the

LOS requirements in District 1. After conducting route optimization for District 1, it was found that the same LOS could be satisfied with a fleet size of 114 trucks.

When calculating the district efficiency, it is important to note that the efficiency falls within a range of values and is not a fixed number. To account for this range, the research team took into account the number of cycles that may be completed for each truck at an application rate of 400 lbs/ ln mile and 250 lbs/ln mile. The lower end of the efficiency range was calculated at the number of cycles that may be completed at the higher application rate and the higher end of the efficiency utilized the lower application rate. Both efficiencies were calculated for the individual trucks with the equation shown previously in Equation 6.1 on page 41.

An additional aspect to be considered is the number of trucks that satisfy the LOS requirements within the district. The LOS requirements change by the priority of the road with priority one roads maintaining a lower time limit than priority three roads. The LOS requirements in District 1 are as follows:

- Priority One Routes - 60 minutes;
- Priority Two Routes - 90 minutes; and
- Priority Three Routes - 120 minutes.

The cycle times used to determine if the LOS requirements were satisfied for each truck within the district included the deadhead time to travel to and from the treated area, the time required to treat the determined section of road, and a refill time of ten minutes. The cycle times for the current, the initially optimized, and the fleet optimized trucks were calculated and the percent of trucks meeting the LOS requirements determined. The results of this analysis are shown in Figure 8.4.

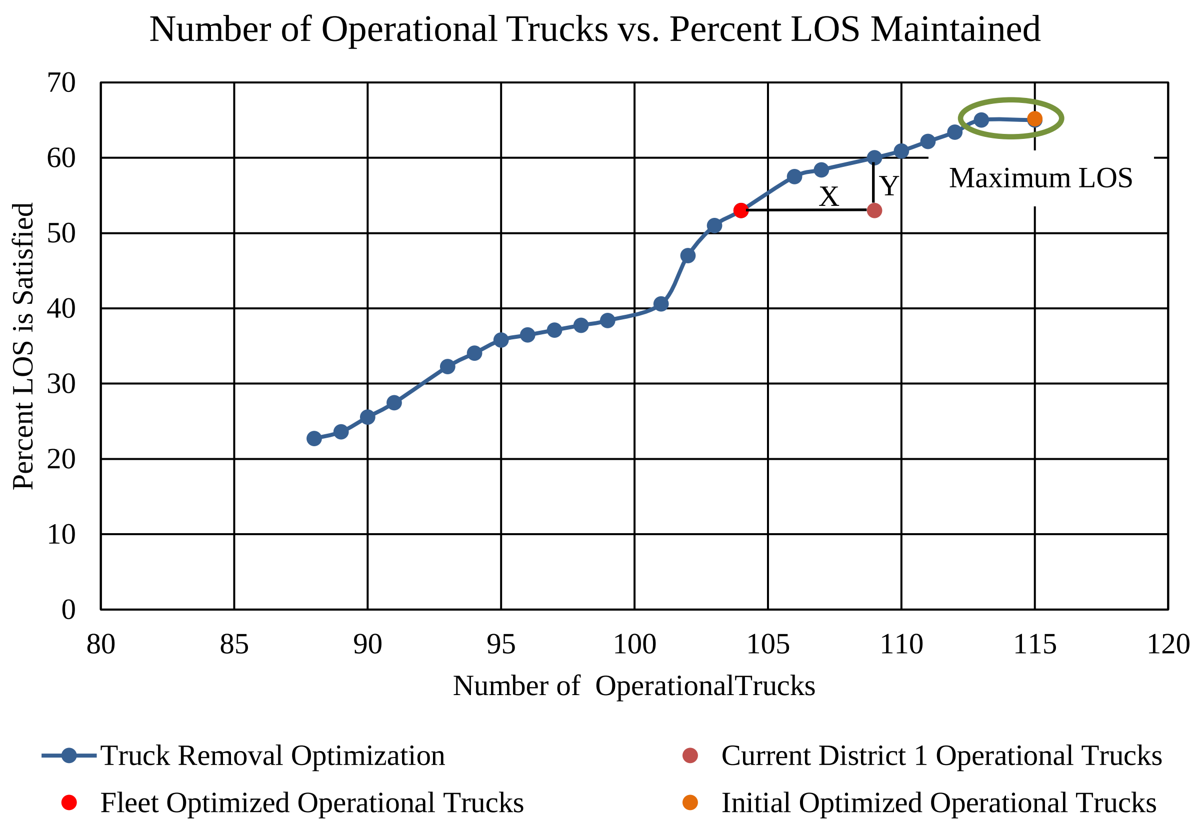


Figure 8.4: District 1 LOS Analysis.

As may be observed in Figure 8.4, District 1 currently operates 109 operational trucks with 53% of the trucks satisfying the LOS requirements within the district. After conducting Fleet Optimization, the research team determined that the same LOS may be obtained with 104 operational trucks. Line "X" in Figure 8.4 above provides a visual explanation of how the number of operational trucks may be decreased from 109 to 104 while maintaining the same LOS. It is important to note that if additional trucks are implemented, the maximum LOS that may be satisfied is approximately 65%, as shown by the green circle labeled "Maximum LOS" in Figure 8.4. This may be observed as the percent of trucks satisfying the LOS requirements within the district plateaus after additional trucks are added past 113. This plateau occurs after implementing operational constraints, such as safe turn-around locations and ensuring an acceptable amount of lane miles is maintained.

A summary of the recommended number amount of operational trucks at each facility may be found in Table 8.2.

Table 8.2: Recommended Operational Trucks at Each Facility within District 1.

Garage/Outpost	**Fleet Optimized Operational Truck Count**
Allen	6
Beaverdam	5
Delphos	4
Fourth Street	4
Defiance	9
Hicksville	2
Hancock	13
South Wood	4
Hardin	7
Forest	5
Roundhead	2
Paulding	10
Putnam	9
Van Wert	11
Wyandot	9
Carey	4
District Operational Trucks	104
With 10% Safety	115

Note: The district operational trucks are the sum of recommended operational trucks at each facility within the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

It is important to note that the recommended fleet size of 115 trucks takes into account a 10% safety factor to account for trucks that may be inoperable during snow and ice events due to mechanical or maintenance issues. A district overview of the District 1 optimized fleet may be found in Appendix B of this report.

8.1.1 District 1 Alternative Fleet Sizes

While conducting fleet optimization within District 1, the research team determined that District 1 may have options regarding their fleet size depending on its goals and intentions. The first option consists of maintaining the current number of operational trucks for winter maintenance operations. This is shown from line "Y" in Figure 8.4. Table 8.3 below summarizes the findings if the current number of operational trucks were optimized in District 1.

Table 8.3: Level of Service Increase if Current Operational Trucks are Optimized.

District 1 LOS Analysis Under Current Amount of Operational Trucks

		Current	**Optimized**	**Difference**
Operational Trucks		109	109	0
Fleet Size		127	120	-7
Total Travel Time (Minutes)		7,651	7,636	-15
Percent LOS Maintained		53	60	7
District Efficiency Range				
District Efficiency Range	Low	77	80	3
	High	87	88	1

Note: The optimized fleet size takes into account the number of operational trucks with an additional 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The percent LOS maintained is the percent of trucks that satisfy the LOS requirements in the district. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allowing routes to complete numerous cycles before returning to the garage for refilling.

As may be observed from Table 8.3 above, a fleet of 120 trucks with 109 operational trucks increases the percent of trucks satisfying the District LOS requirements by 7%. This increases the current percent of trucks satisfying the LOS requirements from 53% to 60%.

The second option would allow District 1 to reach the maximum level of service attainable under the current facility locations and safe turn-around locations. This analysis summarizes the findings shown in Figure 8.4 that related the percent of trucks satisfying the LOS requirements in the district to the number of operational trucks implemented. Table 8.4 summarizes the findings to reach the maximum percent of trucks satisfying the LOS requirements in District 1.

Table 8.4: District 1 Maximum Level of Service Attainment.

District 1 Maximum LOS Attainment

		Current	Optimized	Difference
Operational Trucks		109	113	4
Fleet Size		127	125	-2
Total Travel Time (Minutes)		7,651	7,692	41
Percent LOS Maintained		53	65	12
District Efficiency Range	Low	77	79	2
	High	87	88	1

Note: The optimized fleet size takes into account the number of operational trucks with an additional 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The percent LOS maintained is the percent of trucks that satisfy the LOS requirements within the district. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allowing routes to complete numerous cycles before returning to the garage for refilling.

Table 8.4 above shows that a fleet of 125 trucks with 113 operational trucks is needed to reach the maximum amount of trucks satisfying the LOS requirements. The LOS increases from 53% of the trucks satisfying the LOS to 65%.

8.1.2 District 1 Fleet Optimization Results Summary

The results previously presented after conducting fleet optimization within District 1 provide an analysis under three scenarios. A visual representation of the three scenarios is shown below in Figure 8.5.

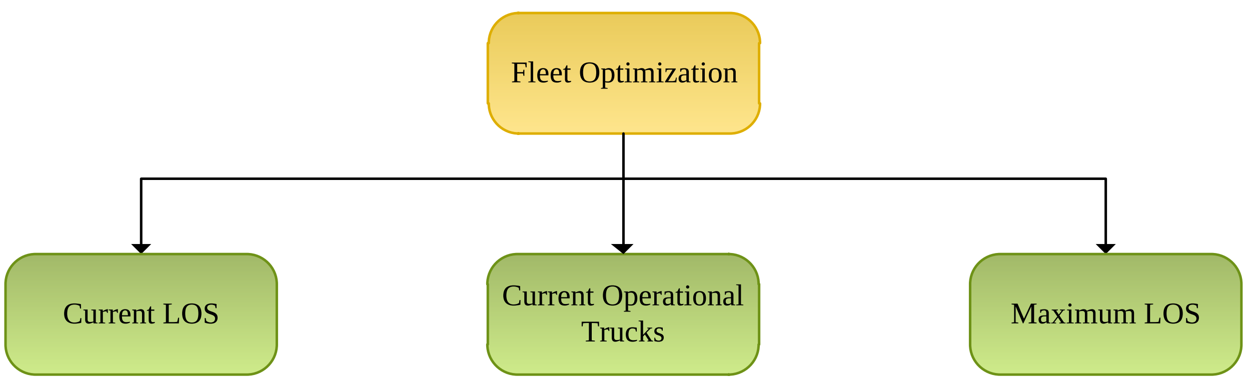


Figure 8.5: Fleet Optimized Scenarios.

The first scenario consisting of the optimal fleet size to maintain the LOS that is currently maintained, the second being the attainable LOS if the current fleet remains unchanged, and the third consisting of the fleet size to attain the highest LOS within the district. A summary of the assignment of operational trucks throughout the district is shown in Table 8.5.

Table 8.5: District 1 Operational Truck Assignments for Desired Outcomes.

Garage/Outpost	**Current LOS**	**Current Operational Trucks**	**Maximum LOS**
Allen	6	6	6
Beaverdam	5	5	5
Delphos	4	4	5
Fourth Street	4	4	4
Defiance	9	9	9
Hicksville	2	3	3
Hancock	13	13	14
South Wood	4	4	4
Hardin	7	7	7
Forest	5	5	5
Roundhead	2	2	2
Paulding	10	11	12
Putnam	9	10	11
Van Wert	11	12	12
Wyandot	9	10	10
Carey	4	4	4
District Operational Trucks	104	109	113
With 10% Safety	115	120	125

Note: The district operational trucks are the sum of recommended operational trucks at each facility within the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

As may be observed from Table 8.5, many of the facility truck assignments in District 1 remain unchanged when increasing the LOS. Facilities such as the Putnam and Paulding County Garages increase, resulting in greater LOS attainment throughout the district.

8.2 District 2 Fleet Optimization Results

As previously mentioned in the Chapter 3 of this report, the fleet optimization analysis was conducted under three difference scenarios within District 2 that utilize potential facility relocations and construction. The results in this section provide the optimal fleet sizes to maintain a similar LOS that is currently maintained in the District, the LOS that could be obtained from the implementation of new facilities with the current fleet, and the fleet size to achieve the maximum LOS attainable in the district after implementing winter maintenance constraints. This methodology is similar to District 1 as shown in Figure 8.5 on page 68. The following subsections of this report provide the results for each part in District 2.

8.2.1 District 2 Part 1 Fleet Optimization Results

The fleet optimization results in Table 8.6 show a comparison in the number of trucks, the district total travel times to treat all roads for one iteration, the percent of trucks that satisfies the LOS requirements, and the district efficiency ranges for the trucks currently being driven and the optimized trucks.

Table 8.6: District 2 Part 1 Fleet Optimization Results.

District 2 Part 1 Fleet Optimization Analysis

		Current LOS	**Current Operational Trucks**	**Maximum LOS**
Operational Trucks		106	114	123
Fleet Size		117	126	136
Difference From Current Fleet Size		-9	0	10
Total Travel Time (Minutes)		8,724	8,864	9100
Percent LOS Maintained		27	38	50
District Efficiency Range	Low	78	77	75
	High	87	87	87

Note: The fleet size takes into account a 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all roads within the district for one iteration and allowing trucks to complete numerous cycles before returning to the garage for refilling.

When considering the facility locations in Part 1, the research team has determined that the fleet may be diminished by 9 trucks to maintain a similar LOS that is currently maintained. In addition, the LOS may be increased to 38% of the trucks satisfying the District requirements by maintaining the current fleet size. Lastly, a maximum of approximately 50% of the routes satisfying the LOS requirements may be observed if increasing the current fleet size by 10 trucks. Figure 8.6 provides a visual representation of Table 8.6.

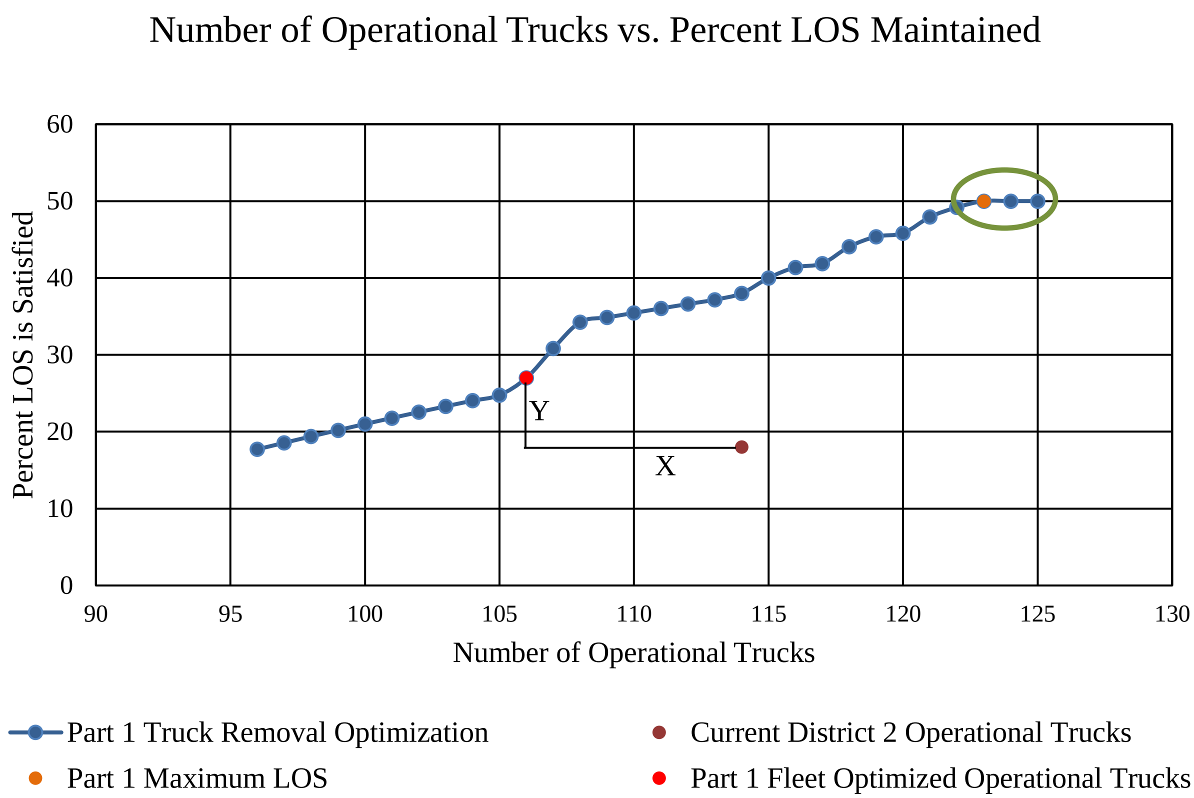


Figure 8.6: District 2 Part 1 LOS Analysis.

Figure 8.6 shows the percent of operational trucks that satisfy the district LOS requirements as trucks are removed. The line denoted with an "X" represents the decrease in the current fleet to maintain a similar LOS that is currently maintained. The line denoted with a "Y" represents the increase in trucks satisfying the LOS requirements. The green oval represents the LOS plateau, showing that there is a limit to the percent of trucks satisfying the LOS requirements after implementing operational constraints.

Table 8.7 has been provided to show the operational truck facility assignment for each desired outcome in District 2 Part 1.

Table 8.7: District 2 Part 1 Operational Truck Assignments.

Garage/Outpost	Current LOS	Current Operational Trucks	Maximum LOS
Fulton	8	9	8
Henry	10	13	13
Lucas	10	10	14
Ottawa	6	6	6
Edison	4	6	6
Sandusky	12	12	14
Seneca	10	10	14
Williams	9	9	11
Wood	20	22	22
Northwood	17	17	15
Southwood	0	0	0
District Operational Trucks	106	114	123
With 10% Safety	117	126	136

Note: The district operational trucks are the sum of recommended operational trucks at each facility within the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

8.2.2 District 2 Part 2 Fleet Optimization Results

Similar to Part 1, the fleet optimization results in Table 8.8 show a comparison in the number of trucks, the district total travel times to treat all roads for one iteration, the percent of trucks that satisfies the LOS requirements, and the district efficiency ranges for the trucks currently being driven and the optimized trucks under the Part 2 parameters described in Chapter 3 of this report.

Table 8.8: District 2 Part 2 Fleet Optimization Results.

District 2 Part 2 Fleet Optimization Analysis

		Current LOS	**Current Operational Trucks**	**Maximum LOS**
Operational Trucks		102	114	119
Fleet Size		113	126	131
Difference From Current Fleet Size		-13	0	5
Total Travel Time (Minutes)		8,422	8,756	8,846
Percent LOS Maintained		28	41	47
District Efficiency Range	Low	79	77	75
	High	88	87	87

Note: The fleet size takes into account a 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all roads within the district for one iteration and the best case scenario of allowing trucks to complete numerous cycles before returning to the garage for refilling.

Table 8.8 above shows that the additional outpost in southern Wood County allow for 13 trucks to be removed from the current fleet to maintain a similar LOS that is currently maintained. In comparison to the Part 1 results, the additional outpost allows for an additional four trucks to be removed. This is primarily due to the outpost's location allowing for trucks to more efficiently treat priority roads with less deadhead time. A LOS of 41% may be obtained if the current fleet size is maintained and a LOS of 47% may be observed if the current fleet is increased by five trucks. A visual representation of the percent of routes satisfying the LOS requirements based on various operational truck amounts may be observed in Figure 8.7.

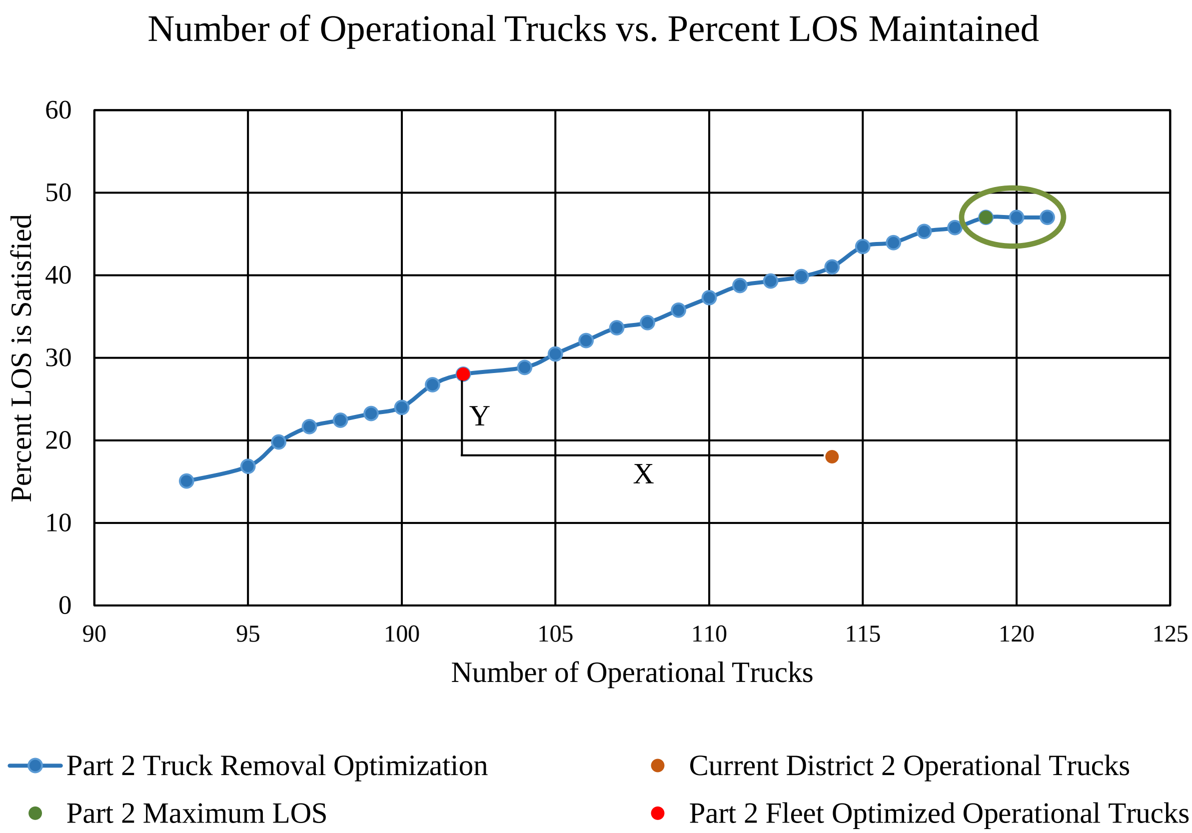


Figure 8.7: District 2 Part 2 LOS Analysis.

Similar to the Part 1 LOS analysis, Figure 8.7 shows the percent of operational trucks that satisfy the district LOS requirements as trucks are removed. The line denoted with an "X" represents the decrease in the current fleet to maintain a similar LOS that is currently maintained. The line denoted with a "Y" represents the increase in trucks satisfying the LOS requirements. The green oval represents the LOS plateau, showing that there is a limit to the percent of trucks satisfying the LOS requirements after implementing operational constraints.

Table 8.9 has been provided to show the operational truck facility assignment for each desired outcome in District 2 Part 2.

Table 8.9: District 2 Part 2 Operational Truck Assignments.

Garage/Outpost	Current LOS	Current Operational Trucks	Maximum LOS
Fulton	8	9	8
Henry	10	10	12
Lucas	9	12	12
Ottawa	6	5	6
Edison	4	6	6
Sandusky	12	14	14
Seneca	10	13	14
Williams	9	11	11
Wood	13	13	14
Northwood	15	15	15
Southwood	6	6	7
District Operational Trucks	102	114	119
With 10% Safety	113	126	131

Note: The district operational trucks are the sum of recommended operational trucks at each facility within the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

8.2.3 District 2 Part 3 Fleet Optimization Results

Similar to the previously described Parts 1 and 2, the fleet optimization results in Table 8.10 show a comparison in the number of trucks, the district total travel times to treat all roads for one iteration, the percent of trucks that satisfies the LOS requirements, and the district efficiency ranges for the trucks currently being driven and the optimized trucks under the Part 3 parameters described in Chapter 3 of this report.

Table 8.10: District 2 Part 3 Fleet Optimization Results.

District 2 Part 3 Fleet Optimization Analysis

		Current LOS	Current Operational Trucks	Maximum LOS
Operational Trucks		101	114	123
Fleet Size		112	126	136
Difference From Current Fleet Size		-14	0	10
Total Travel Time (Minutes)		8,507	8,617	8,894
Percent LOS Maintained		30	42	51
District Efficiency Range	Low	79	77	75
	High	86	87	87

Note: The fleet size takes into account a 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The district efficiency takes into account the worst-case scenario of treating all roads within the district for one iteration and the best case scenario of allowing trucks to complete numerous cycles before returning to the garage for refilling.

Table 8.10 above shows that the additional outpost in southern Wood County and the relocation of the Wood County Garage allow for 14 trucks to be removed from the current fleet to maintain a similar LOS that is currently maintained. In comparison to the Part 2 results, the additional outpost allows for an additional truck to be removed. This is primarily due to the outpost and county garage's locations allowing for trucks to more efficiently treat priority roads with less deadhead time. A LOS of 42% may be attained if the current fleet size is maintained and a LOS of 51% may be observed if the current fleet is increased by 10 trucks. It is important to note that the Part 3 results show the largest decrease in fleet size to maintain the current LOS maintained and also supports the greatest LOS that may be obtained by increasing the fleet size. A visual representation of the percent of routes satisfying the LOS requirements based on various operational truck amounts may be observed in Figure 8.8.

Number of Operational Trucks vs. Percent LOS Maintained

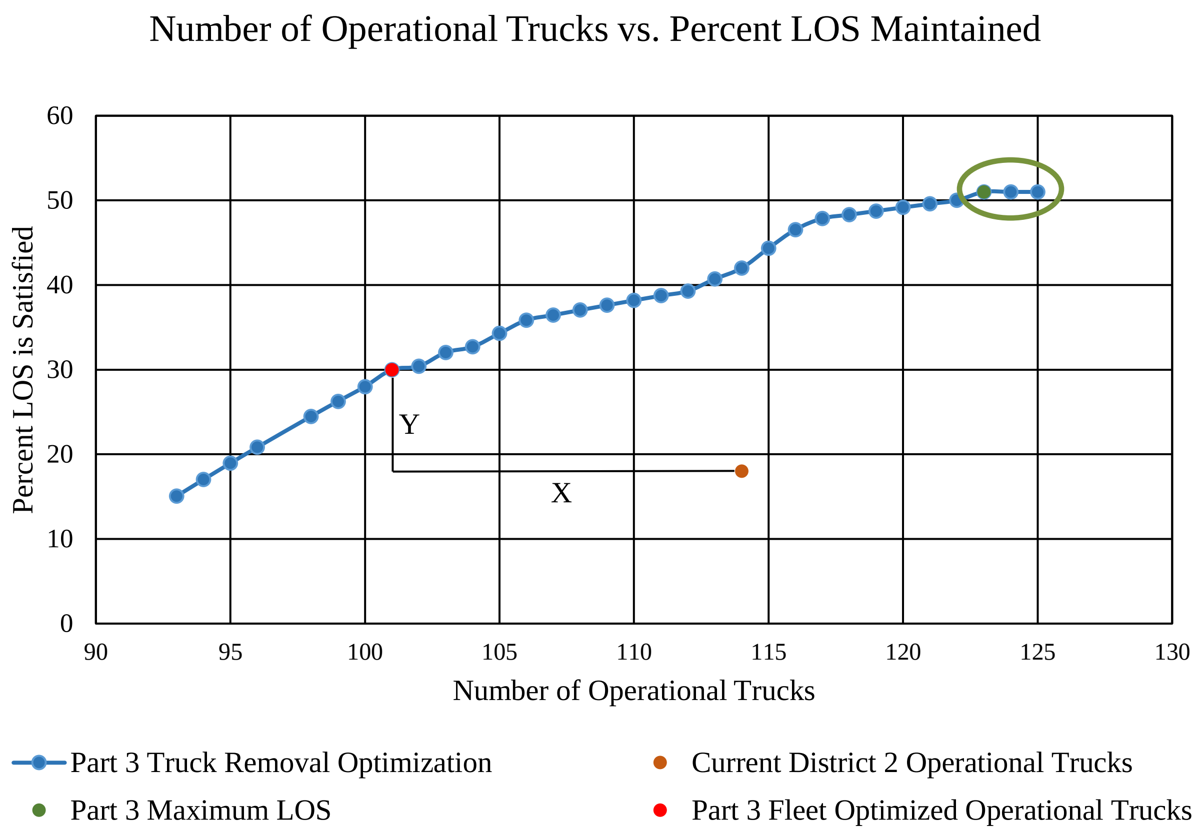


Figure 8.8: District 2 Part 3 LOS Analysis.

Similar to the LOS analysis for Parts 1 and 2, Figure 8.8 shows the percent of operational trucks that satisfy the district LOS requirements as trucks are removed. The line denoted with an “X” represents the decrease in the current fleet to maintain a similar LOS that is currently maintained. The line denoted with a “Y” represents the increase in trucks satisfying the LOS requirements while maintaining the current fleet size. The green oval represents the LOS plateau, showing that there is a limit to the percent of trucks satisfying the LOS requirements after implementing operational constraints.

Table 8.11 has been provided to show the operational truck facility assignment for each desired outcome in District 2 Part 1.

Table 8.11: District 2 Part 3 Operational Truck Assignments.

Garage/Outpost	Current LOS	Current Operational Trucks	Maximum LOS
Fulton	8	9	8
Henry	10	12	13
Lucas	9	10	12
Ottawa	5	5	6
Edison	4	6	6
Sandusky	11	13	14
Seneca	11	12	14
Williams	9	9	11
Wood	12	14	15
Northwood	14	14	14
Southwood	8	10	10
District Operational Trucks	101	114	123
With 10% Safety	112	126	136

Note: The district operational trucks are the sum of recommended operational trucks at each facility within the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

8.3 District 10 Fleet Optimization Results

By following the same process previously described in this chapter, the research team was able to determine the optimal fleet size to maintain the current LOS with fewer operational trucks. Table 8.12 shows a comparison in the number of trucks, the district total travel times to treat all routes once, and the district efficiency ranges for the routes currently being driven and the optimized routes.

Table 8.12: District 10 Route Optimization Summary of Results.

District 10 Route Optimization Analysis				
		Current	**Fleet Optimized**	**Difference**
Operational Trucks		116	109	-7
Fleet Size		128	120	-8
Total Travel Time (Minutes)		12,650	11,813	-837
Percent LOS Maintained		60	61	1
District Efficiency Range	Low	81	83	2
	High	86	87	1

Note: The optimized fleet size takes into account the number of operational trucks with an additional 10% safety factor due to approximately 10% of the fleet being unavailable for winter maintenance operations at any given time. The total travel time is the expected time required to treat all roadways within the district once. The percent LOS maintained is the percent of trucks that satisfy the LOS requirements in the district. The district efficiency takes into account the worst-case scenario of treating all routes within the district for one iteration and allowing routes to complete numerous cycles before returning to the garage for refilling.

As may be observed in Table 8.12, the ROM has determined that the optimal number of operational trucks in District 10 to be 109. The optimization resulted in a decrease of 7 trucks from the current number of operational trucks in the district. It is important to note that the number of operational trucks is not the same as the recommended fleet size in the district since approximately 10% of a district's fleet may be inoperable at any given time. Taking the inoperable trucks into account, the research team added 10% to the 109 to show that a truck inventory of 120 trucks is necessary for the district.

The total travel time represents that time required to treat each route once within the district with an 838 minute decrease when comparing the current routes to the optimized routes. The total travel time includes the deadhead time required to reach the treating area, the time required to treat the determined area, and the deadhead time to return to the facility where the truck originated. From an operational point of view, these data are valuable in predicting the amount of time required to treat the entire district but also in predicting the expected labor costs at a district level.

An additional aspect to be considered is the amount of routes that satisfy the LOS requirements in the district. The LOS requirements change by the priority of the road with priority one routes maintaining a lower time limit than priority three roads. The LOS requirements within District 10 are as follows:

- Priority One Routes - 90 minutes;
- Priority Two Routes - 120 minutes; and
- Priority Three Routes - 150 minutes.

The cycle times used to determine if the LOS requirements were satisfied for each route within the district included the deadhead time to travel to and from the treated area for each route, the time required to treat the determined route, and a refill time of 10 minutes. The cycle times for the current routes, the initial optimized routes, the minimum number of routes, and the fleet optimized routes (removing trucks beyond the minimum recommended total) were calculated and the percent of routes meeting the LOS requirements determined. The results of this analysis are shown in Figure 8.9.

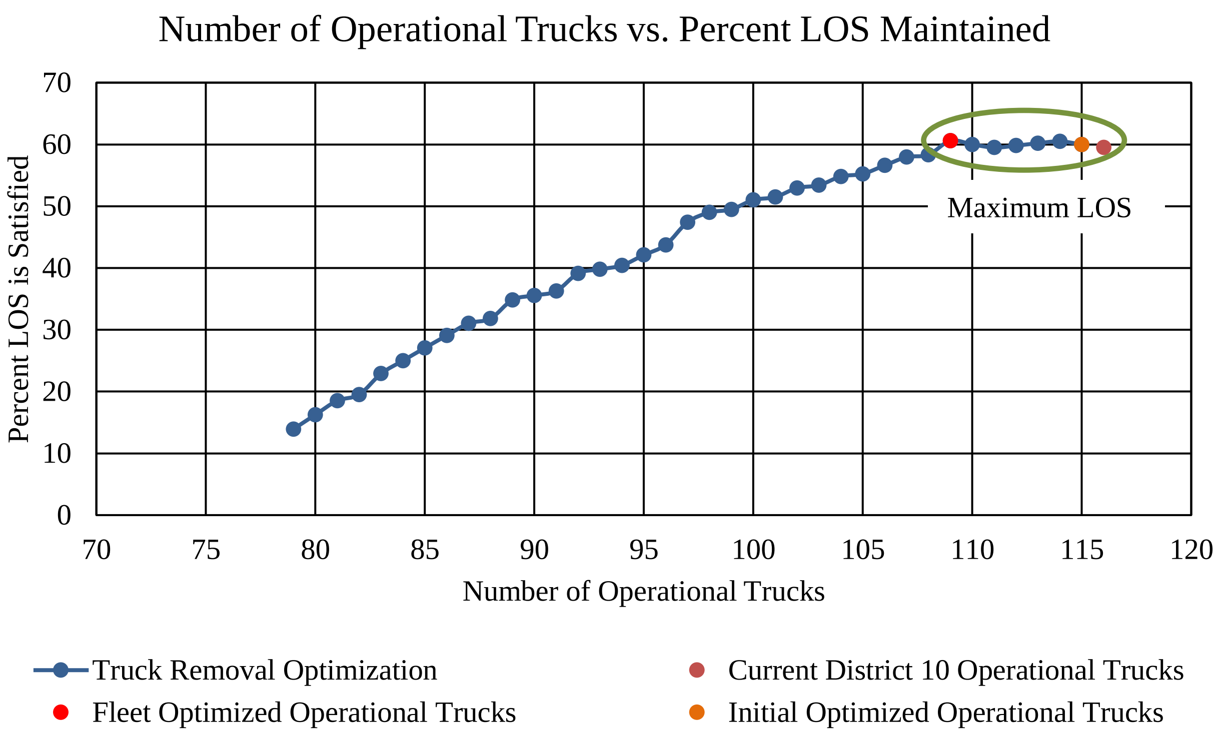


Figure 8.9: District 10 LOS Analysis.

The results shown in Figure 8.9 show that approximately 60% of the routes in the district will satisfy the LOS requirements when trucks travel at typical winter maintenance operations speeds. The point where the percentage of the LOS satisfied begins to decrease occurs after the number of routes is diminished to below 109. In order to increase the percentage of routes satisfying the LOS in the district, facilities should be constructed in the regions that are currently difficult to maintain. The concept of the district operating at the maximum LOS attainable is shown in the green oval in Figure 8.9, which highlights the plateau of the percent of operational trucks that satisfy the LOS in the district. This plateau occurs after implementing operational constraints, such as safe turn-around locations and ensuring an acceptable amount of lane miles is maintained.

A summary of the number of operational trucks per facility is provided in Table 8.13.

Table 8.13: Recommended Operational Trucks at Each Facility in District 10.

Garage/Outpost	**Fleet Optimized Operational Truck Count**
Athens	9
Hollister	3
Gallia	11
Hocking	8
Laurelville	2
Meigs	8
Tuppers Plains	5
Monroe	8
Duffy	4
Morgan	10
Noble	14
Vinton	6
Wilkesville	3
Washington	8
Bartlett	2
Belpre	4
Macksburg	4
District Operational Trucks	109
With 10% Safety	120

Note: The district operational trucks are the sum of recommended operational trucks at each facility in the district. Through discussions with ODOT leadership, it is recommended that the fleet size be determined after adding an additional 10% to the recommended total of operational trucks. This additional 10% takes into account trucks that may be inoperable during snow and ice events.

Similar to Districts 1 and 2 previously discussed in this chapter, the recommended fleet size of 120 trucks takes into account an additional 10% to the recommended number of operational trucks. This addition ensures there are a sufficient number of trucks to effectively conduct winter maintenance operations as some trucks may be inoperable during snow and ice events for various reasons, including mechanical issues. A district overview of the District 10 optimized fleet may be found in Appendix B of this report.

CHAPTER IX ROUTE VULNERABILITY

While the Fleet Optimization determined the optimal fleet size to maintain the current LOS within Districts 1, 2, and 10, the research team was able to identify possible strategies to improve the percent of routes satisfying the district LOS requirements. These recommendations are the result of recognizing limitations on the number of operational trucks used to conduct winter maintenance operations from the available facility locations.

When considering the number of operational trucks satisfying the LOS requirements, there is a pivotal point when the number of operational trucks will yield the highest LOS satisfaction possible in the district. This occurs after implementing operational constraints relating to turnaround locations and lane mile requirements for individual routes. The maximum LOS obtained is limited to the facility locations within a district due to the remote roadways that may not be treated under the LOS requirements due to the typical speeds traveled during snow and ice events.

To prove this point, the research team assigned 60 trucks to each facility in Districts 1, 2, and 10 and utilized the ROM under the average treating speeds each district determined. The results of this analysis are used to determine the challenging areas in each district where construction of future facilities may increase the amount of operational trucks that satisfy the LOS.

9.1 District 1 Route Vulnerability

In order to show the areas that would benefit from additional facilities, the research team ran the ROM that utilized the current facility locations with 60 available trucks at each facility to conduct winter maintenance operations. By limiting each truck to strictly adhere to District 1 LOS requirements previously mentioned in this report, the research team was able to determine the challenging areas due to facility locations as shown in Figure 9.1.

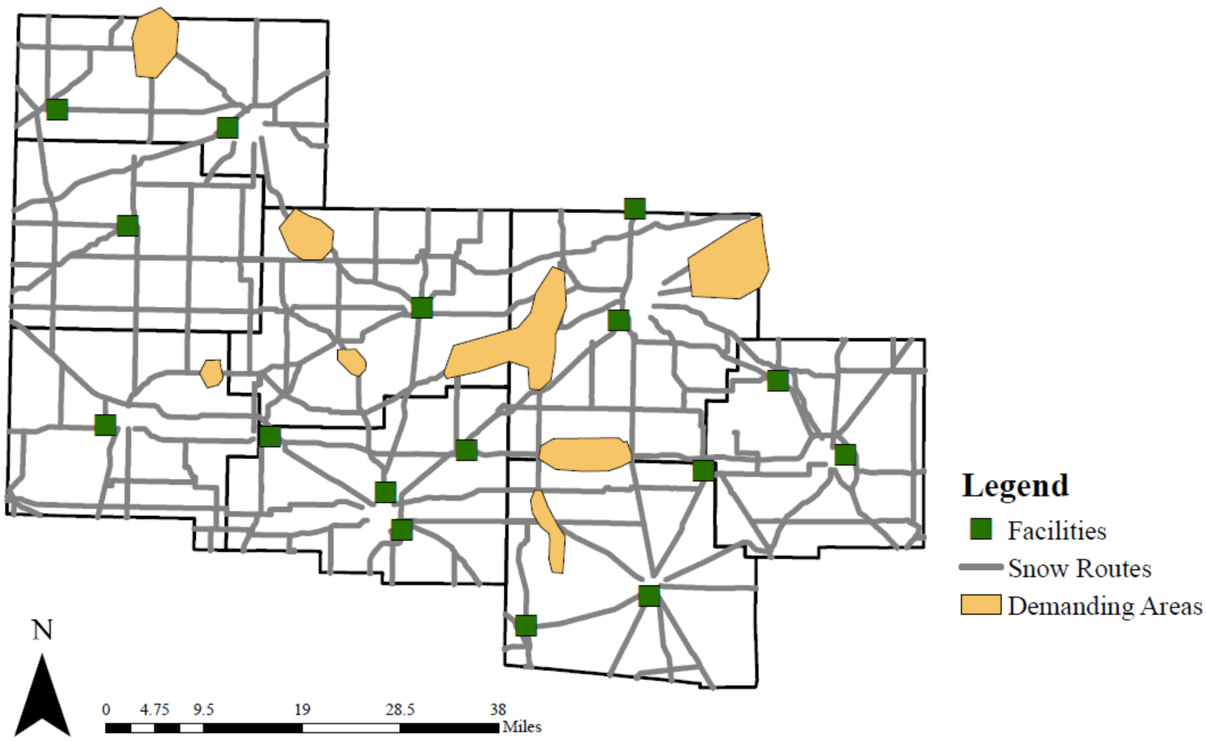


Figure 9.1: District 1 Demanding Areas.

The areas labeled as "Demanding Areas" were classified as such due to the greatest potential to increase the number of trucks that would satisfy the LOS requirements if facilities were constructed in these areas. The challenging areas are difficult to maintain from the current facility locations due to the inability of trucks to complete the cycles under the LOS requirements.

9.2 District 2 Route Vulnerability

In order to best determine the vulnerability in District 2, this section is divided into three subsections. Each subsection represents the different scenarios that were analyzed for District 2, relating to the previously mentioned Parts 1, 2, and 3. Similar to District 1, each scenario in District 2 consisted of assigning 60 trucks to each facility and allowing the ROM to optimize the routes. The locations not treated for each scenario were highlighted and presented as an overlay to the district map.

9.2.1 District 2 Part 1 Vulnerability

Upon operating the ROM under the conditions previously described, the research team was able to identify areas that are difficult to maintain due to the trucks traveling at typical treating speeds during snow and ice events. Figure 9.2 is a map of the demanding areas that the district currently experiences.

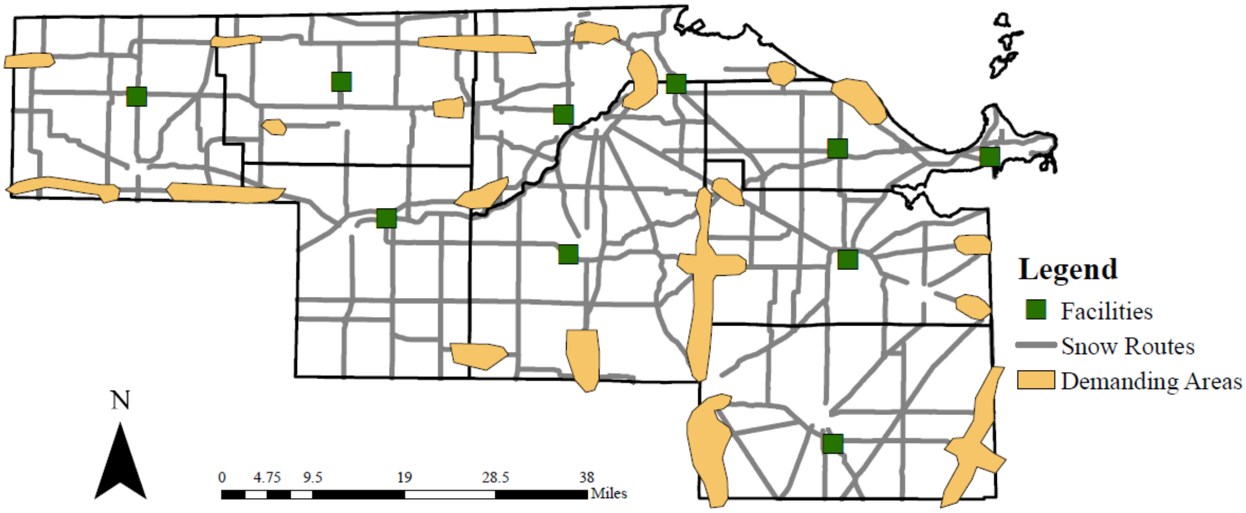


Figure 9.2: District 2 Part 1 Demanding Areas.

As may be observed from Figure 9.2, there are numerous areas that are difficult to maintain under the current facility locations. These areas are typically on county borders where no outposts are available to station trucks, creating deadhead and longer cycle times to treat the roads in the district.

9.2.2 District 2 Part 2 Vulnerability

Under the scenario for District 2 Part 2, which includes the addition of an outpost in southern Wood County and the relocation of the Sandusky County Garage, it may be observed that that challenging areas are resolved in the southern area of Wood County and the south eastern area of Henry County. This observation was determined as a result of comparing the demanding areas from Part 1 to Part 2.

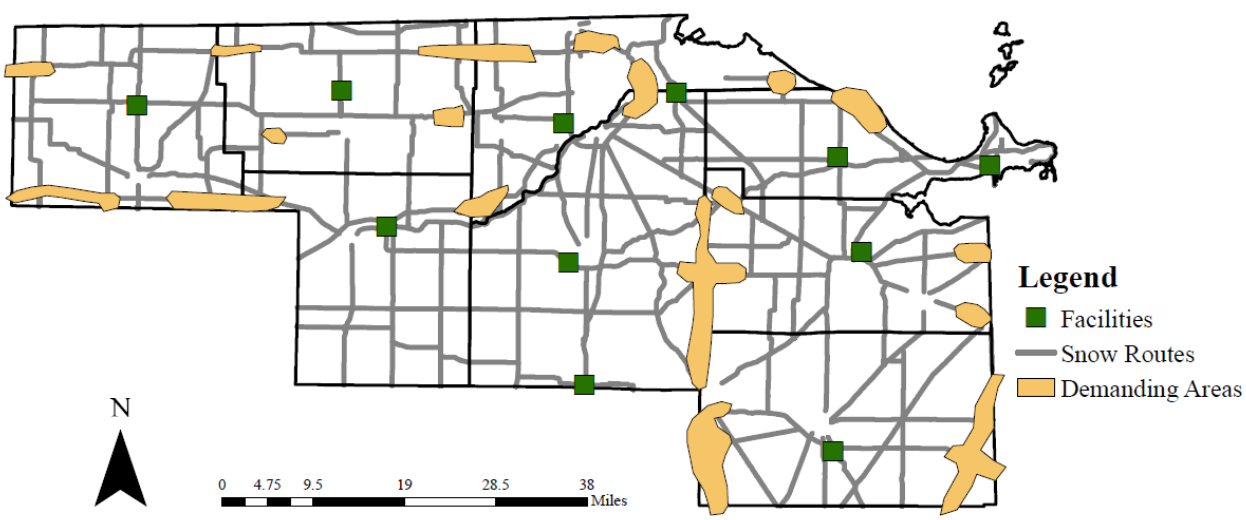


Figure 9.3: District 2 Part 2 Demanding Areas.

The implementation and construction of the Southwood Outpost resolves some challenging areas but the majority of the challenging areas in the district remained the same.

9.2.3 District 2 Part 3 Vulnerability

The challenging areas in District 2 under the Part 3 scenario, consisting of moving the Wood County Garage from its location in Part 2 to a new location in Part 3, may be observed in Figure 9.4. The same process of deploying 60 trucks at each facility under strict LOS requirements with trucks traveling at expected speeds during snow events was used to determine these vulnerable areas.

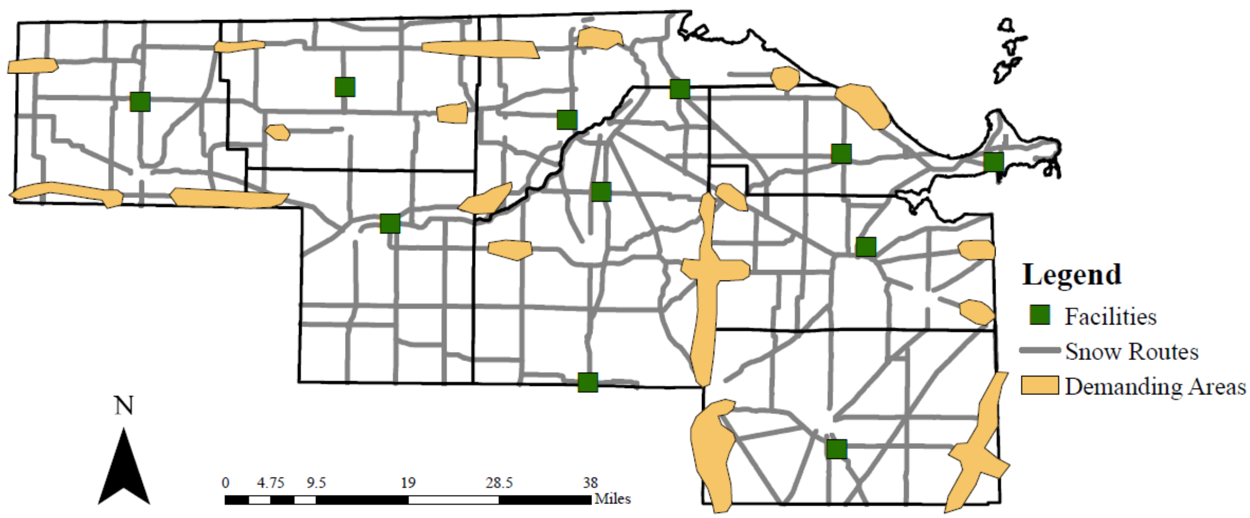


Figure 9.4: District 2 Part 3 Demanding Areas.

Figure 9.4 above shows that the challenging areas along I-75 west of the Northwood Outpost are removed after implementing the new Wood County Garage location. While this allows for a higher LOS satisfaction for priority one roads in the district, an additional challenging area arises along US 6 west of SR 235.

9.3 District 10 Route Vulnerability

As previously mentioned, the research team operated the ROM with 60 trucks in each facility that may be used to conduct winter maintenance operations. By providing the ROM with excess trucks, the research team was able to determine the areas that are difficult to maintain due to facility and traveling speed constraints. The results of this analysis are shown on in Figure 9.5.

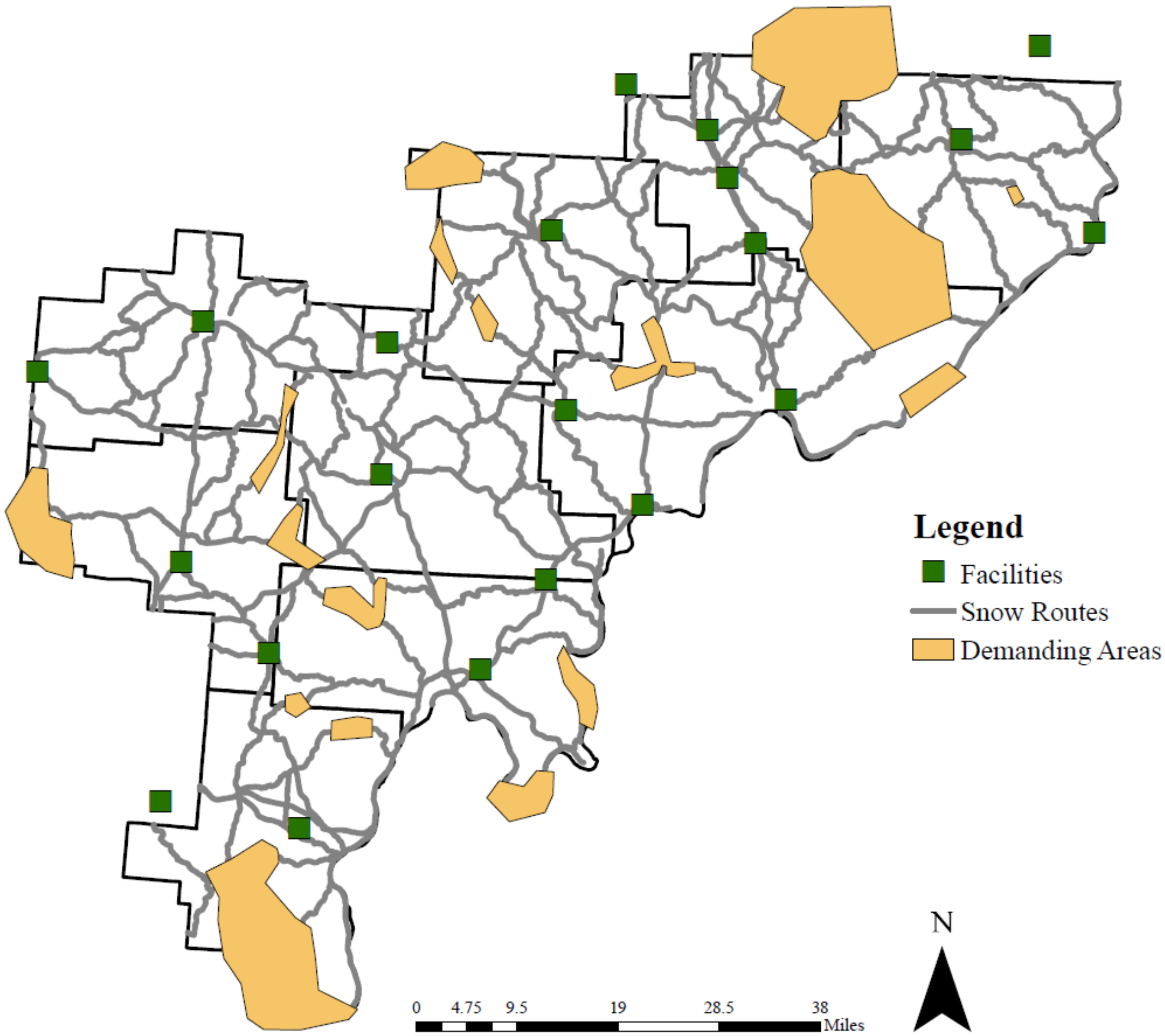


Figure 9.5: District 10 Demanding Areas.

As may be observed from Figure 9.5, there are large demanding areas in District 10. The largest demanding areas may be found in southern Gallia County, northeastern Washington County, and northeastern Noble County. Due to the LOS being limited by facility locations rather than the fleet size, additional facilities in these areas would increase the amount of routes that satisfy the requirements in the district.

CHAPTER X IMPLEMENTATION

This chapter presents the implementation of the optimized routes generated during this study. This implementation plan was created to assist in successfully implementing the previously discussed results from this report. This chapter is divided into eight sections:

- Section One – Recommendations for implementation of the optimized routes;
- Section Two – Steps needed to implement the findings from this study;
- Section Three – Suggested time frame for implementation;
- Section Four – Expected benefits from implementation;
- Section Five – Potential risks and obstacles to implementation;
- Section Six – Strategies to overcome potential risks and obstacles;
- Section Seven – Potential users and other organizations that may be affected; and
- Section Eight – Estimated cost of implementation.

10.1 Recommendations for the Implementation of the Optimized Routes

The implementation of the optimized routes is a decision that must first be made at the district level, then the county level.

10.2 Steps Needed to Implement Findings

The steps needed to implement the findings primarily pertain to the training of personnel, preparations to station trucks at the optimal facilities, and guidance on future construction of facilities in the demanding areas outlined in Chapter 9 of this report.

The first step that must be taken to successfully implement the findings of this project is to train county managers and operators on how to use the optimized routes as a tool to continue providing quality service during snow and ice events. Care must be taken to show how the optimized routes not only determine the optimal fleet size in the district involved but also determine the minimum number of operational trucks at each facility to ensure that an acceptable LOS is maintained.

A concern from many county managers is that they often operate with fewer personnel than called for by the recommended minimum number of operational trucks. The results of this project have provided optimized routes that are below the recommended minimum for each facility. This opens the more flexibility for county managers to decide how to best allocate their limited resources for conducting snow and ice operations in their areas of responsibility.

The next step for implementing the findings from this project consists of reallocating trucks to the optimal facilities as determine through the ROM. A district level plan may be necessary to ensure that all outposts and county garages have the necessary trucks to adequately treat roads in their areas of responsibility.

The final step consists of using the data presented in Chapter 9 of this report to assist in the future construction of facilities in each of the district's challenging areas to increase the LOS maintained.

10.3 Suggested Time Frame for Implementation

The implementation of the optimized routes may begin immediately. The primary time constraint is on ensuring that the county managers are adequately trained on the utilization of the optimized routes and those preliminary questions and concerns are addressed prior to the winter season.

10.4 Benefits Expected from Implementation

The expected benefits from the implementation of the findings from this project include cost savings from a reduced fleet size and a decrease in the amount of time required to treat all roads in Districts 1, 2, and 10. While the question of cost savings is important, it is also worthy of considering the potential increase in safety for the drivers who travel during snow and ice events. By treating the roads in a shorter amount of time, the safety for local traffic increases while the risk of accidents related to poor weather conditions decreases. In addition, the optimization of each facility for a variety of operational trucks available will enable ODOT to continuing providing outstanding service during snow and ice events, regardless of the amount of resources available at any given time.

Another benefit that may be gained from the implementation of the findings is the validation of the challenging areas in each facility. By collecting data from the routes that treat these challenging areas, ODOT should be able to verify the challenging areas determined by the ROM. The validation of the challenging areas in the districts involved with the Route Optimization project may justify and guide the future construction of facilities.

10.5 Potential Risks and Obstacles to Implementation

One of the potential risks of and obstacles to the implementation of the optimized routes is confusion of the areas each facility is responsible to maintain. The current routes used for winter maintenance have been used for years and there is a familiarity with the routes that may be difficult to change. This familiarity with the current routes may guide operators to revert to the routes they are familiar with and dismiss the findings of the Route Optimization project.

10.6 Strategies to Overcome Potential Risks and Obstacles

A change in operations is a challenge that all organizations must overcome in their own way, such as developing a solution that is tailored to the culture and ethos of each organization. The best solution to overcoming the potential resistance from implementing the findings of this project is to conduct adequate personnel training before the winter season. This training must include addressing the comments and concerns regarding the new treating areas for each facility and any questions regarding the treating areas for the individual routes within the district.

10.7 Potential Users and Other Organizations

The Route Optimization of Districts 1, 2, and 10 may provide information to other organizations that have access to ArcGIS and conduct winter maintenance operations. These organizations may include municipalities and state DOTs. In addition, the results of this project may be used to facilitate the automation of the route optimization process within ArcGIS. By automating the process described in this report, an organization may experience significant cost savings with minimal manual input upon successful completion of the automation.

10.8 Estimated Cost of Implementation

ODOT currently has the resources to implement the recommendations from this project at little to no additional cost.

REFERENCES

The Ohio Department of Transportation. (2011). *Snow and Ice Practices.* The Ohio Department of Transportation Division of Operations.

Assad, A., & Golden, B. (1995). Chapter 5 - Arc Routing Methods and Applications. In M. B. al, *Handbooks in OR & MS* (p. Vol 8).

Bodin, L., & Kursh, S. (1979). A Detailed Description of a Computer System for the Routing and Scheduling of Street Sweepers. *Compur. & Ops Res Vol 6*, 131-138.

Dowds, J., Novak, D., Scott, D., & Sullivan, J. (2013). *Optimization of Snow Removal in Vermont.* Vermont Agency of Transportation.

Esri. (2016). *An Overview of the Network Analyst Toolbox*. Retrieved from ArcGIS Pro: http://pro.arcgis.com/en/pro-app/tool-reference/network-analyst/an-overview-of-the-network-analyst-toolbox.htm

Fu, L., Trudel, M., & Kim, V. (2009). Optimizing Winter Road Maintenance Operations Under Real-Time Information. *European Journal of Operational Research 196*, 332-341.

Gudac, I., Hanak, T., & Marovic, I. (2014). *Optimization of Winter Road Maintenance Services Under Real Time Information.* University of Rijeka.

Gupta, D. (2010). *Optimal Workforce Planning and Shift Scheduling fo Snow and Ice Removal.* Missouri Department of Transportation.

Haber, D., & Limage, U. (1990). *Benefit Cost Analysis of Winter Maintenance Levels of the Idaho Transportation Department.* Boise: Idaho Transportation Department.

Haghani, A., & Hamedi, M. (2002). *Calvert County Snow Emergency Decision Support System Phase II.* University of Maryland.

Jaung, W. (2011). *Optimizing Winter/Snow Removal Operations in MoDOT St. Louis District - Includes Outcome Based Evaluation of Operations Final Report.* Missouri Department of Transportation.

Mandloi, D., & Thill, J.-C. (2010, March 15). Object-Oriented Data Modeling of an Indoor/Outdoor Urban Transportation Network and Route Planning Analysis. *Geospatial Analysis and Modelling of Urban Structure and Dynamics*, pp. 197-220.

Qstarz. (2013). Retrieved from Qstarz: Beyond Navigation: http://www.qstarz.com/about_Qstarz.html

Salazar-Aguilar, A., Langevin, A., & Laporte, G. (2012). *Synchronized Arc Routing for Snow Plowing Operations.* Computer & Operations Research, Volume 39, issue 7.

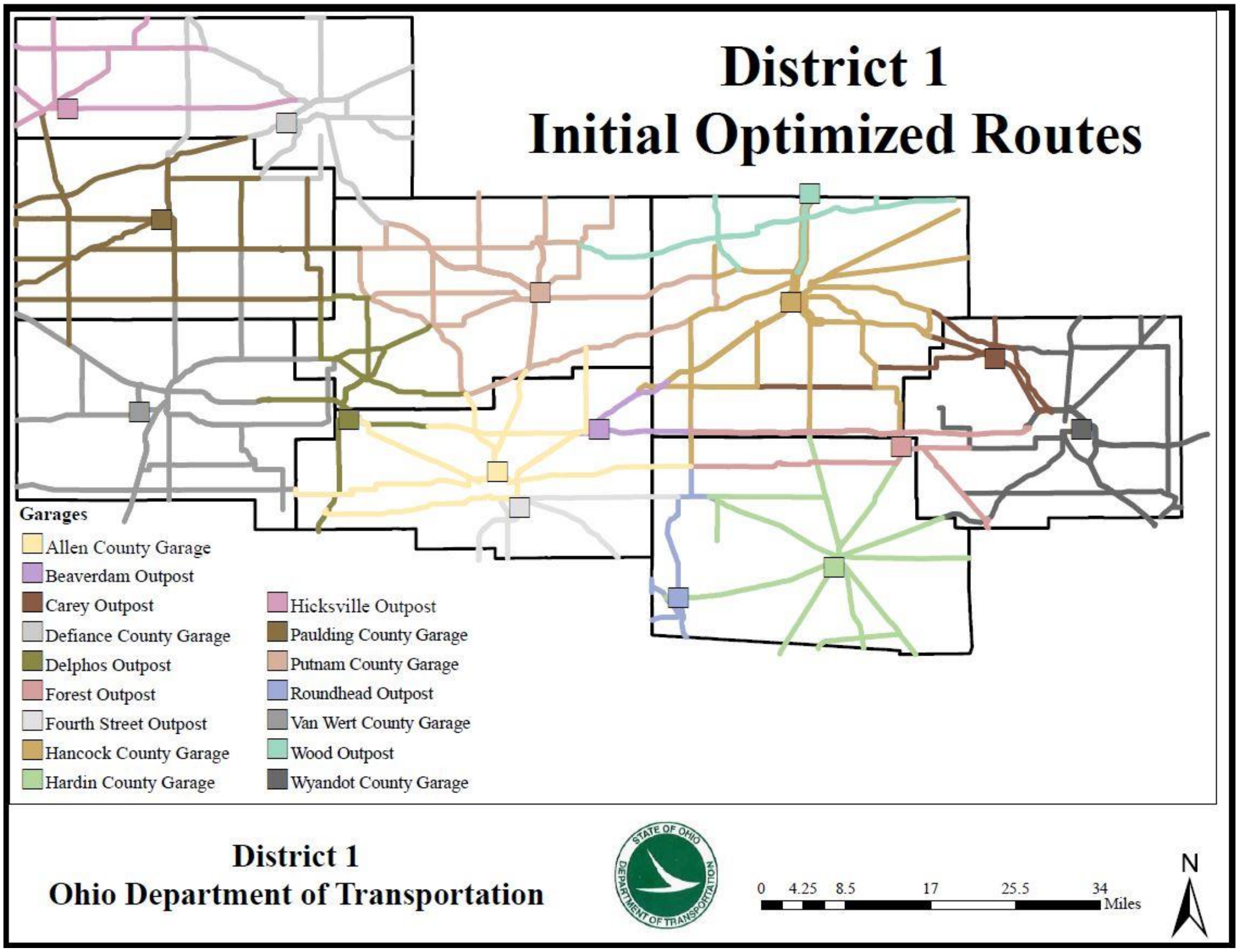
The Ohio Department of Transportation. (2016). *Department of Transportation District 1*. Retrieved from http://www.dot.state.oh.us/districts/d01/Pages/default.aspx

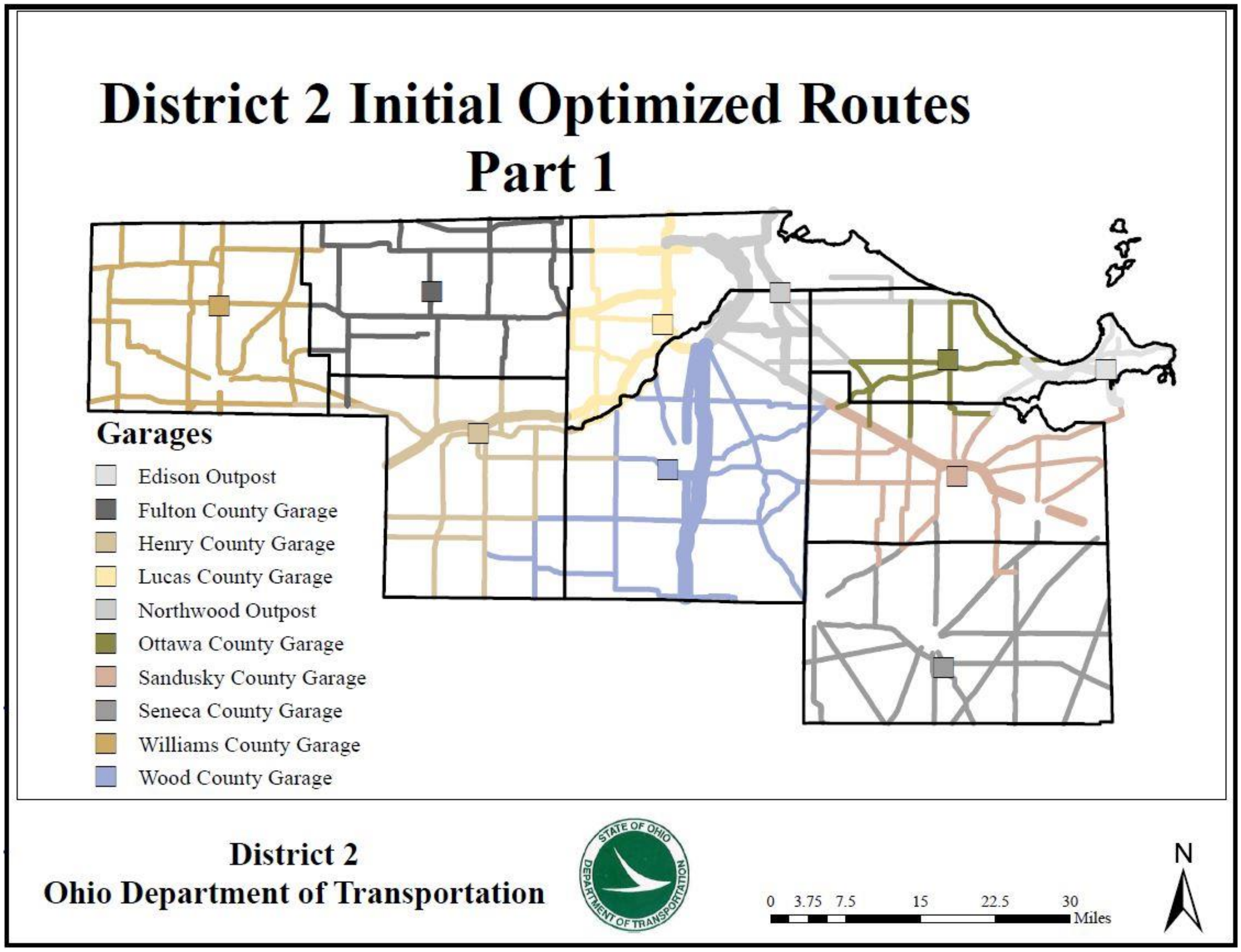
The Ohio Department of Transportation. (2016). *Department of Transportation District 10*. Retrieved from http://www.dot.state.oh.us/districts/d10/Pages/default.aspx

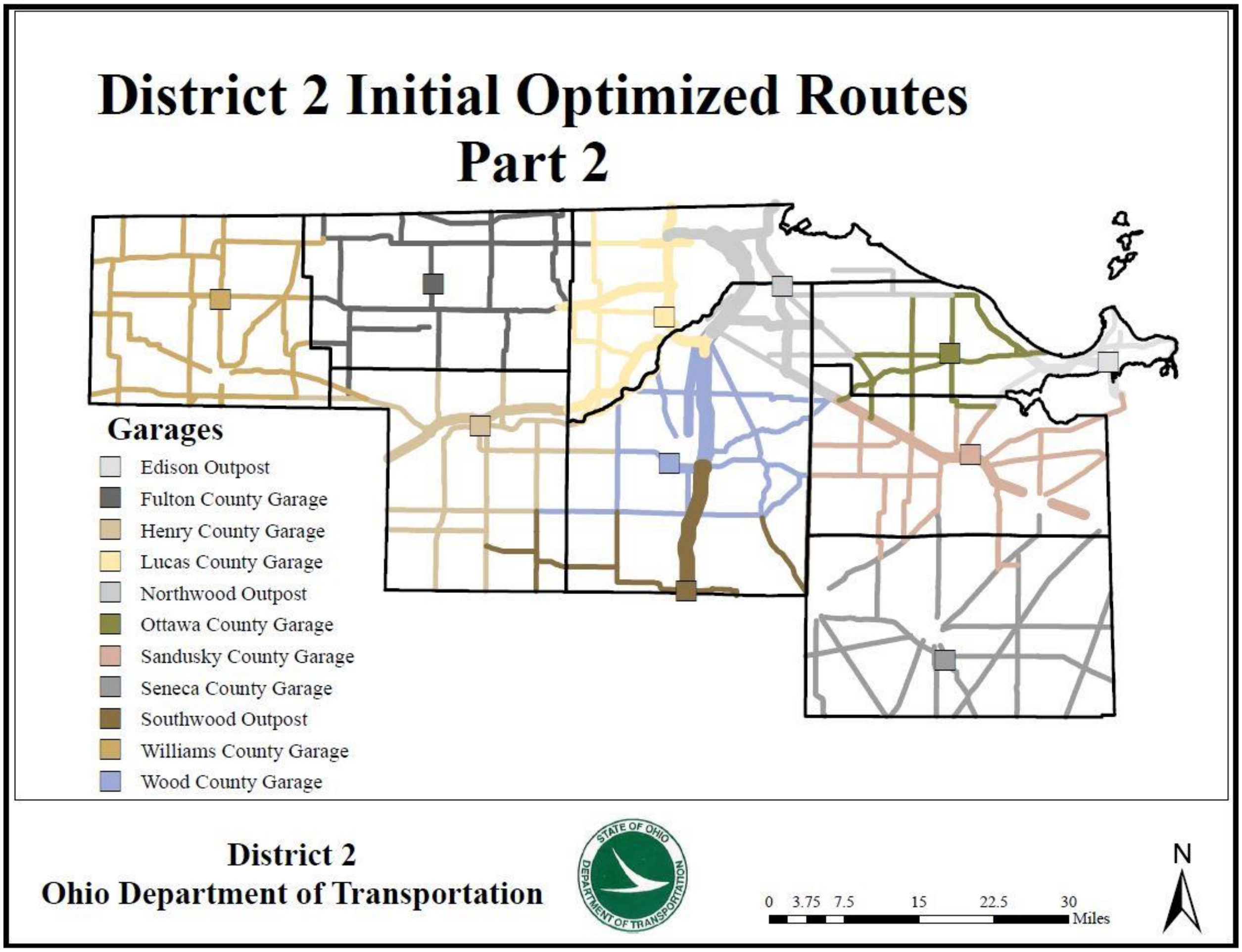
The Ohio Department of Transportation. (2016). *Ohio Department of Transportation District 2*. Retrieved from http://www.dot.state.oh.us/districts/d02/Pages/default.aspx

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D.,Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354

APPENDIX A: INITIAL OPTIMIZED DISTRICT MAPS




District 2 Initial Optimized Routes
Part 1
Garages
Edison Outpost
Fulton County Garage
Henry County Garage
Lucas County Garage
Northwood Outpost
Ottawa County Garage
Sandusky County Garage
Seneca County Garage
Williams County Garage
Wood County Garage
District 2
Ohio Department of Transportation
0 3.75 7.5 15 22.5 30
Miles
N


District 2 Initial Optimized Routes
Part 2
Garages
Edison Outpost
Fulton County Garage
Henry County Garage
Lucas County Garage
Northwood Outpost
Ottawa County Garage
Sandusky County Garage
Seneca County Garage
Southwood Outpost
Williams County Garage
Wood County Garage
District 2
Ohio Department of Transportation
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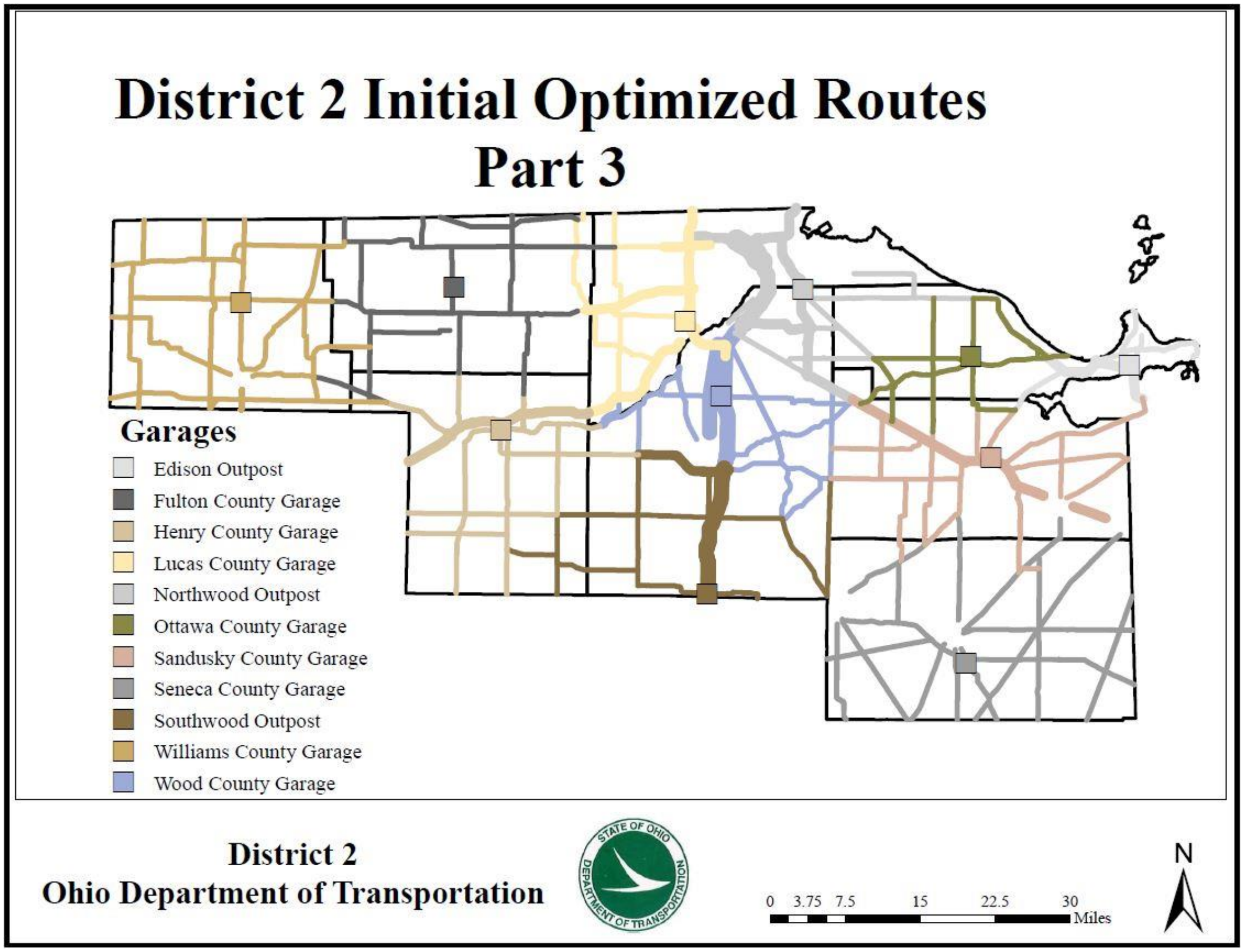

District 2 Initial Optimized Routes
Part 3
Garages
Edison Outpost
Fulton County Garage
Henry County Garage
Lucas County Garage
Northwood Outpost
Ottawa County Garage
Sandusky County Garage
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Miles
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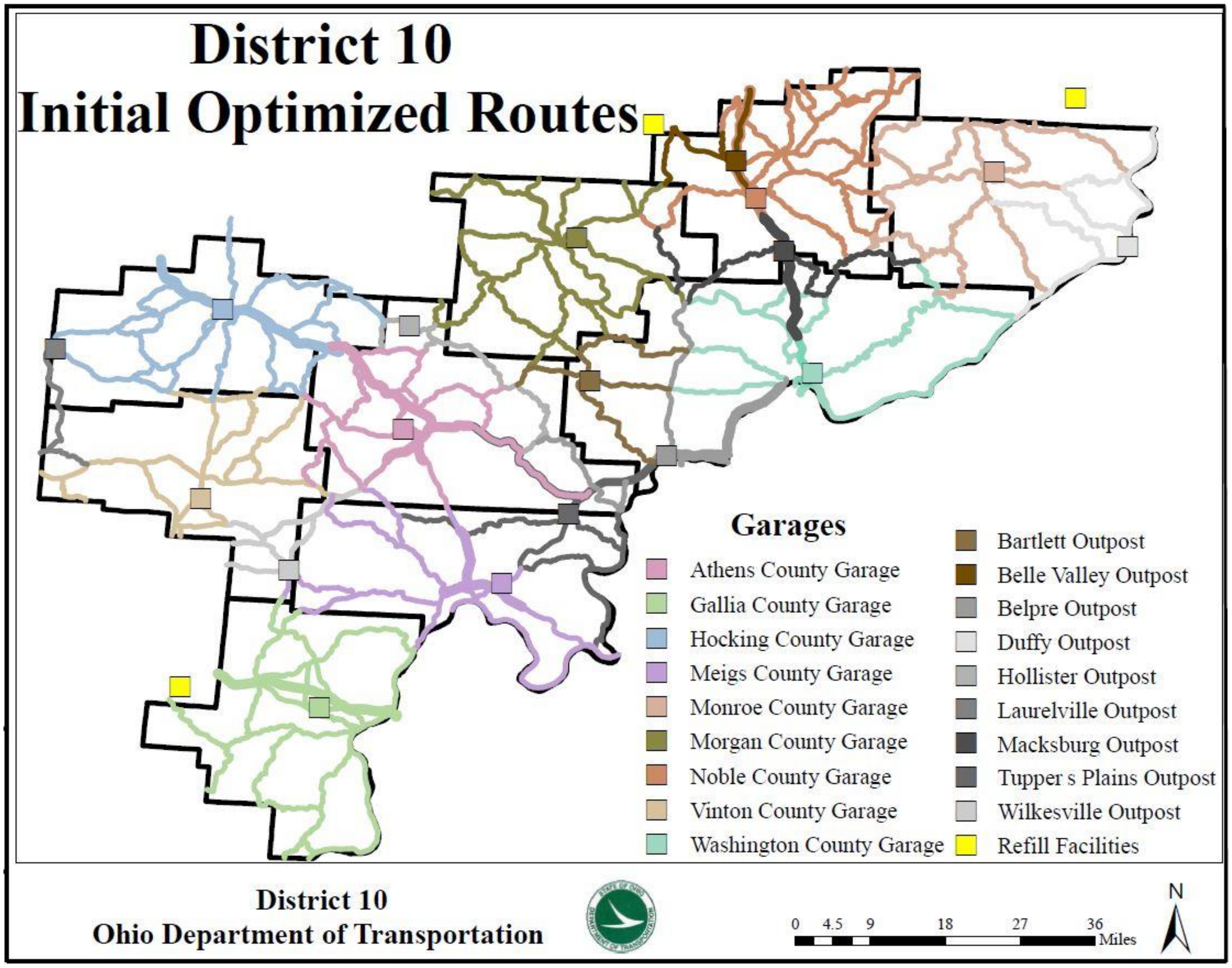
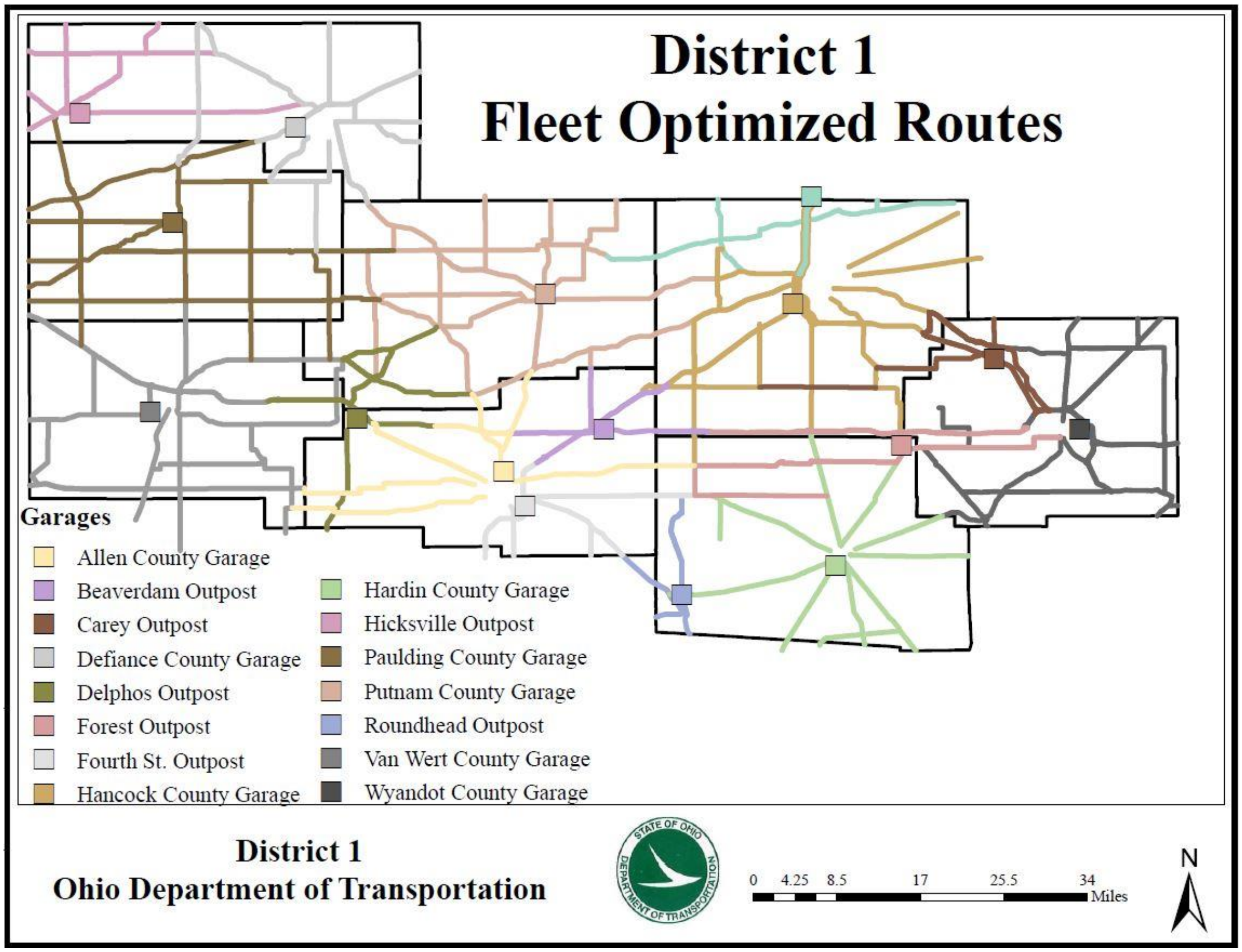
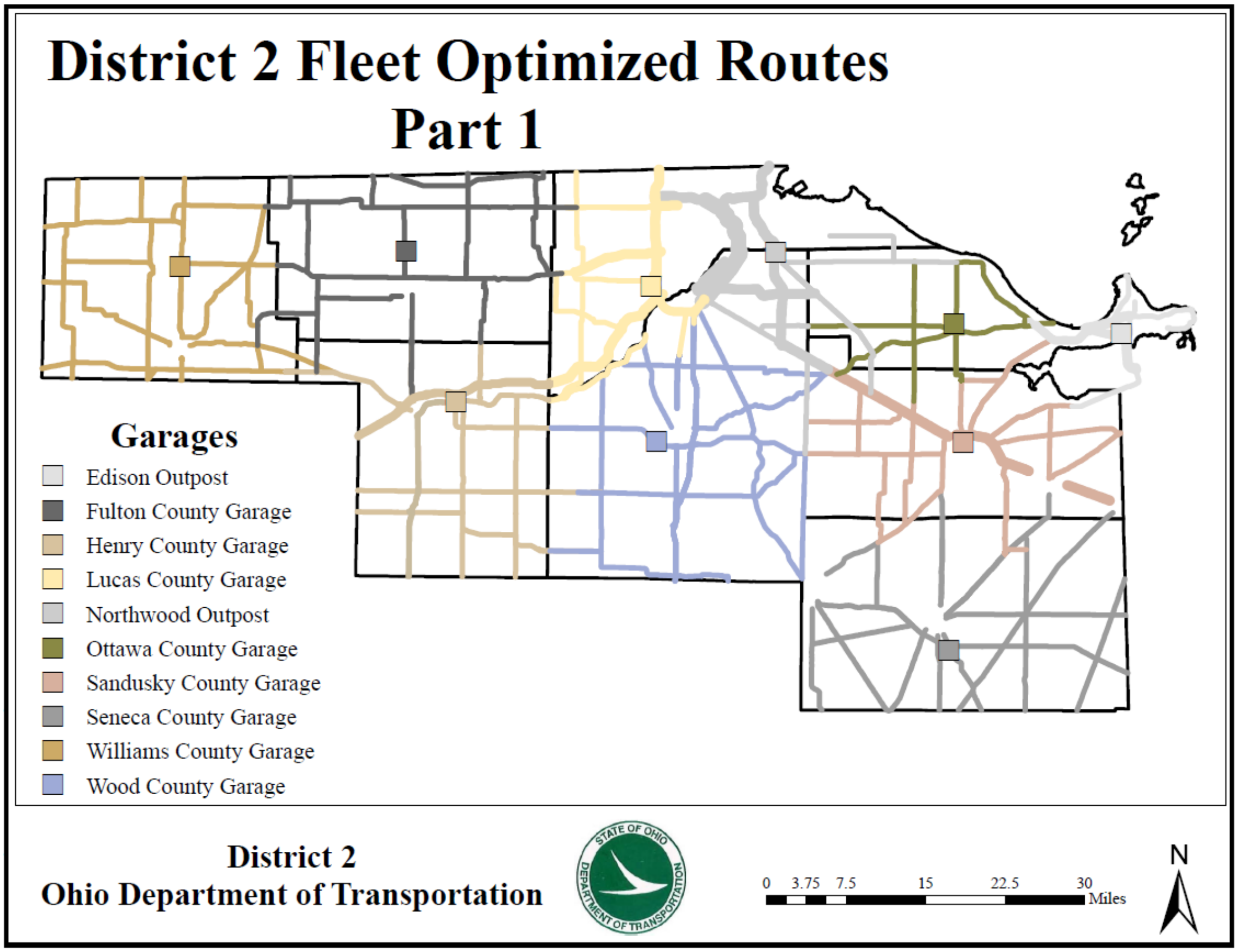


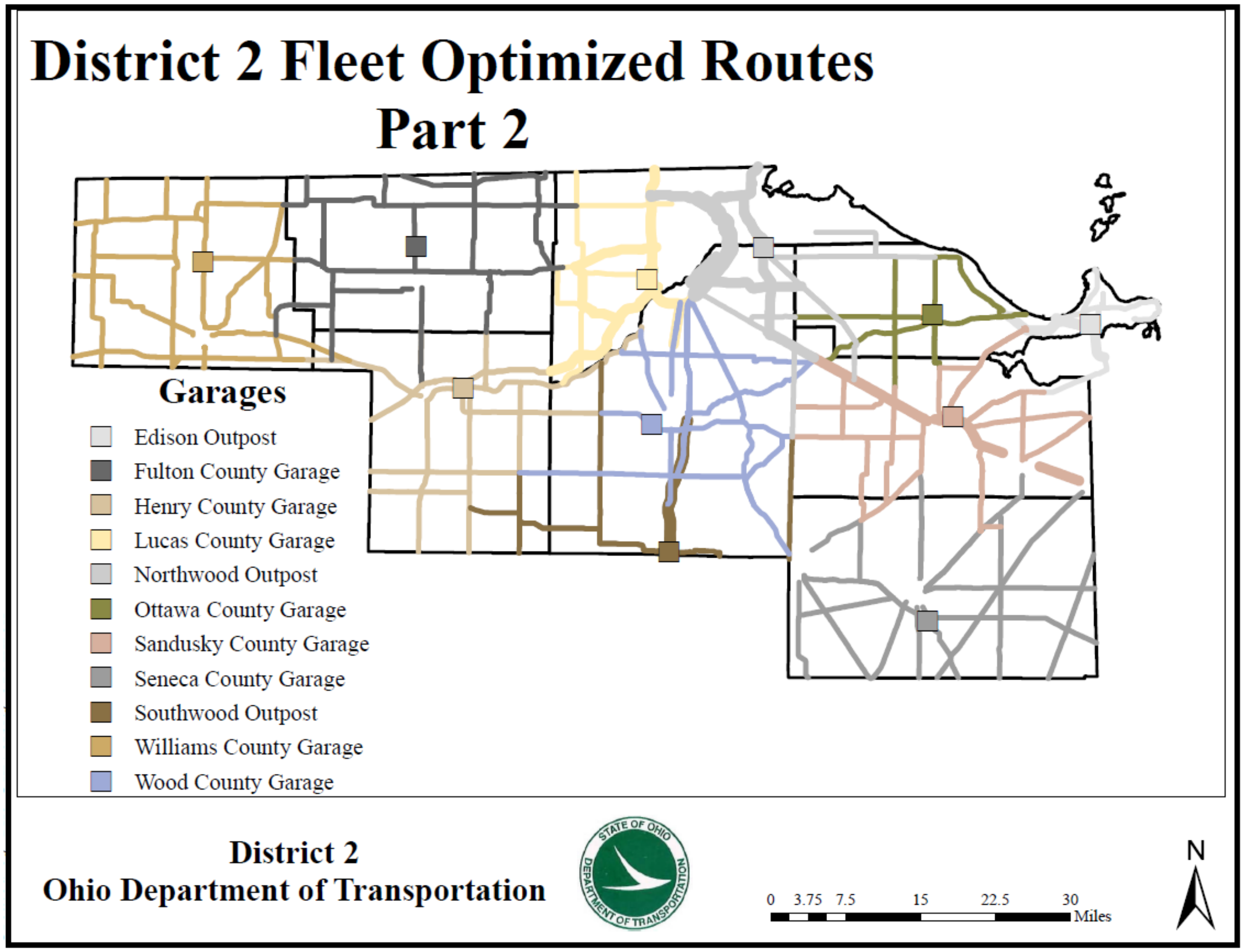
District 10
Initial Optimized Routes
Garages
Athens County Garage
Gallia County Garage
Hocking County Garage
Meigs County Garage
Monroe County Garage
Morgan County Garage
Noble County Garage
Vinton County Garage
Washington County Garage
Bartlett Outpost
Belle Valley Outpost
Belpre Outpost
Duffy Outpost
Hollister Outpost
Laurelville Outpost
Macksburg Outpost
Tupper s Plains Outpost
Wilkesville Outpost
Refill Facilities
District 10
Ohio Department of Transportation
0 4.5 9 18 27 36
Miles
N



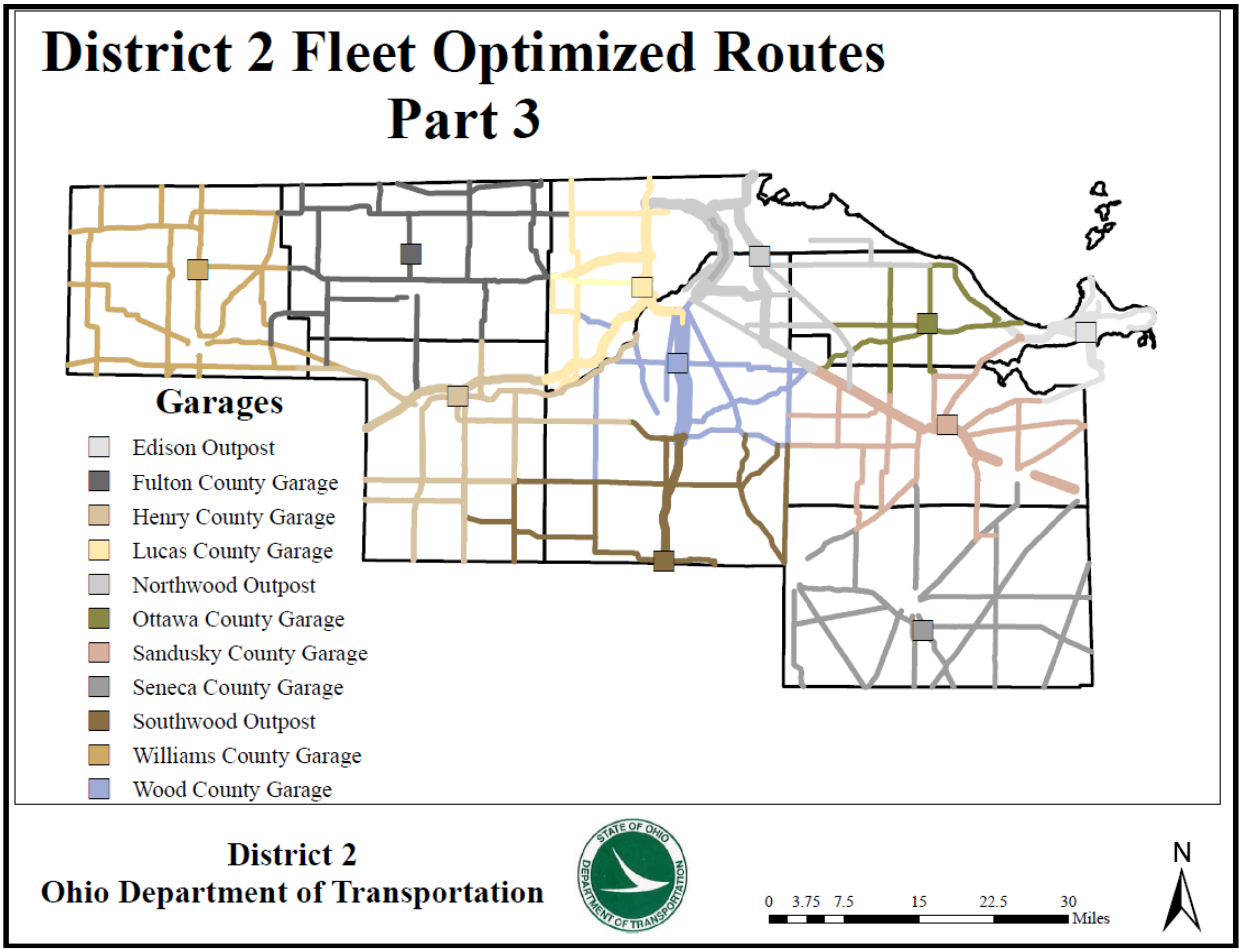
The individual routes for each facility in District 1 will be provided to the District Highway Maintenance Administrators in a separate document.



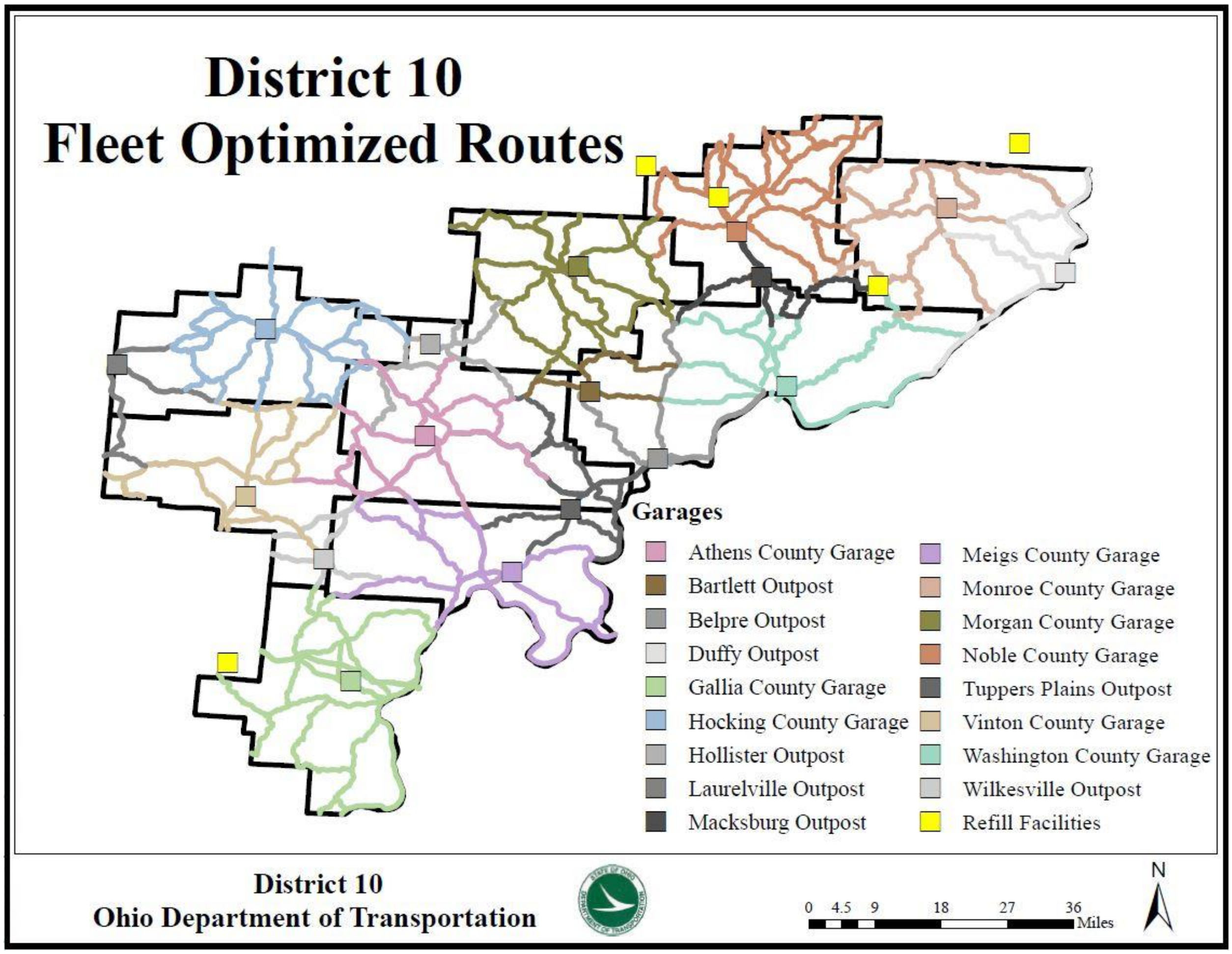
The individual routes for each facility in District 2 Part 1 will be provided to the District Highway Maintenance Administrators in a separate document.



The individual routes for each facility in District 2 Part 2 will be provided to the District Highway Maintenance Administrators in a separate document.



The individual routes for each facility in District 2 Part 3 will be provided to the District Highway Maintenance Administrators in a separate document.



The individual routes for each facility in District 10 will be provided to the District Highway Maintenance Administrators in a separate document.