MOUNTAIN-PLAINS CONSORTIUM

MPC 22-487 | C. Liu and N. Marković

ASSESSING AND IMPROVING EFFICIENCY OF SNOWPLOWING OPERATIONS VIA DATA AND ANALYTICS

MOUNTAIN-PLAINS CONSORTIUM REGION 8

A University Transportation Center sponsored by the U.S. Department of Transportation serving the Mountain-Plains Region. Consortium members:

Colorado State University
North Dakota State University
South Dakota State University
University of Colorado Denver
University of Denver
University of Utah
Utah State University
University of Wyoming

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
MPC-637		

4. Title and Subtitle	5. Report Date
Assessing and Improving Efficiency of Snowplowing Operations via Data and Analytics	November 2022
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Cathy Liu and Nikola Marković	MPC 22-487

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Department of Civil & Environmental Engineering University of Utah 110 Central Campus Drive, Suite 2000 Salt Lake City, UT 84112	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Mountain-Plains Consortium North Dakota State University PO Box 6050, Fargo, ND 58108	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Supported by a grant from the US DOT, University Transportation Centers Program

16. Abstract

This project presents a comprehensive study on enhancing snowplowing routes in 12 regions in northern Utah. The research employs both exact and approximate methods to identify snowplowing routes that lead to reductions in total travel time, turnaround time, and deadhead miles by an average of 4.87%, 15.38%, and 13.85%, respectively, across all the regions. These improvements can significantly enhance the efficiency of snow removal operations and contribute to the overall social welfare. The study's models also examine the tradeoffs between various operational policies, such as echelon vs. non-echelon routing and fleet extension. These insightful analyses empower local management teams to determine the most suitable strategies for their respective regions. Apart from optimization modeling, a pivotal aspect of this work involves data visualization. The team utilizes data visualization techniques to effectively demonstrate the efficacy of the new snowplowing routes, comparing them to current practices, and presenting the findings to the Utah Department of Transportation. This visualization aids in conveying the significance and impact of the proposed improvements, further supporting decision-making processes.

17. Key Word	18. Distribution Statement
deicing chemicals, geographic information systems, global positioning system, location, optimization, routes, snowplows, snow removal, software, storage facilities	Public distribution

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	59	n/a

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Assessing and Improving Efficiency of Snowplowing Operations via Data and Analytics

Cathy Liu, Ph.D., P.E.

Nikola Marković, Ph.D.

Department of Civil & Environmental Engineering
University of Utah
110 Central Campus Drive, Suite 2000
Salt Lake City, UT 84112

November 2022

Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

ABSTRACT

This project presents a comprehensive study on enhancing snowplowing routes in 12 regions in northern Utah. The research employs both exact and approximate methods to identify snowplowing routes that lead to reductions in total travel time, turnaround time, and deadhead miles by an average of 4.87%, 15.38%, and 13.85%, respectively, across all the regions. These improvements can significantly enhance the efficiency of snow removal operations and contribute to the overall social welfare. The study's models also examine the tradeoffs between various operational policies, such as echelon vs. non-echelon routing and fleet extension. These insightful analyses empower local management teams to determine the most suitable strategies for their respective regions. Apart from optimization modeling, a pivotal aspect of this work involves data visualization. The team utilizes data visualization techniques to effectively demonstrate the efficacy of the new snowplowing routes, comparing them to current practices, and presenting the findings to the Utah Department of Transportation. This visualization aids in conveying the significance and impact of the proposed improvements, further supporting decision-making processes.

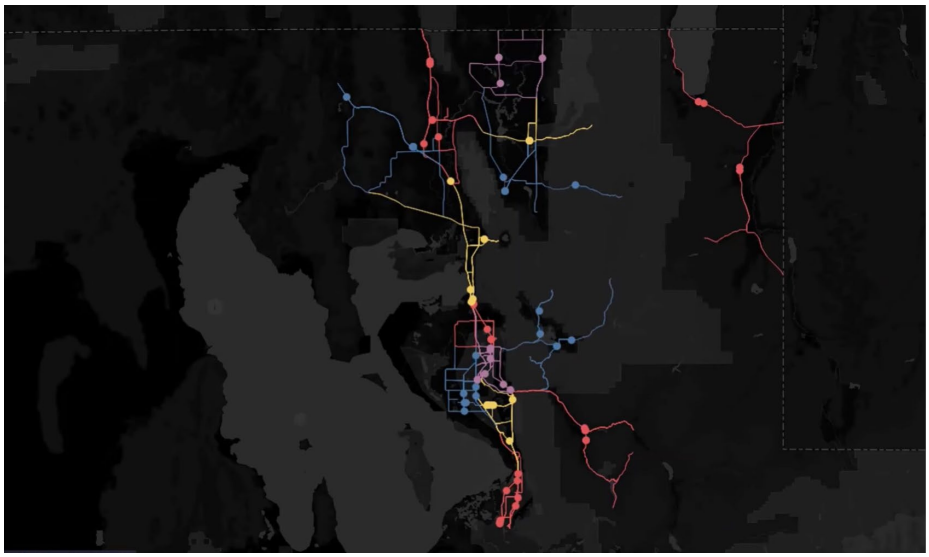
Contents

List of Figures

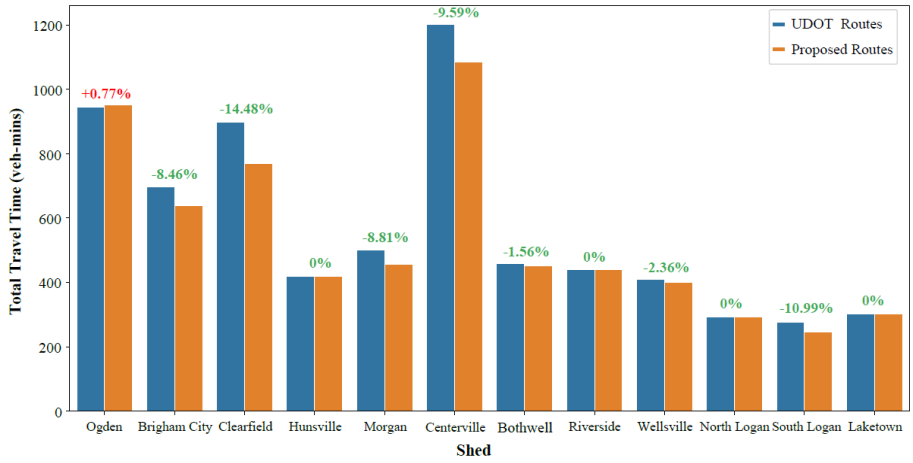
EXECUTIVE SUMMARY

In this project, we optimize plowing operations of 12 cities in northern Utah. First, we evaluate current UDOT plowing operations by leveraging AVL data. Next, we optimize plow routes for the 12 cities with the primary objective of minimizing the total vehicle hours driven. On average, vehicle-hours, turnaround times, and deadhead miles are reduced by 4.87%, 15.38%, and 13.85%, respectively. The high-level route animation over all regions and the improvements or performance measurements as well as detailed route animations for each region are reported in following context.

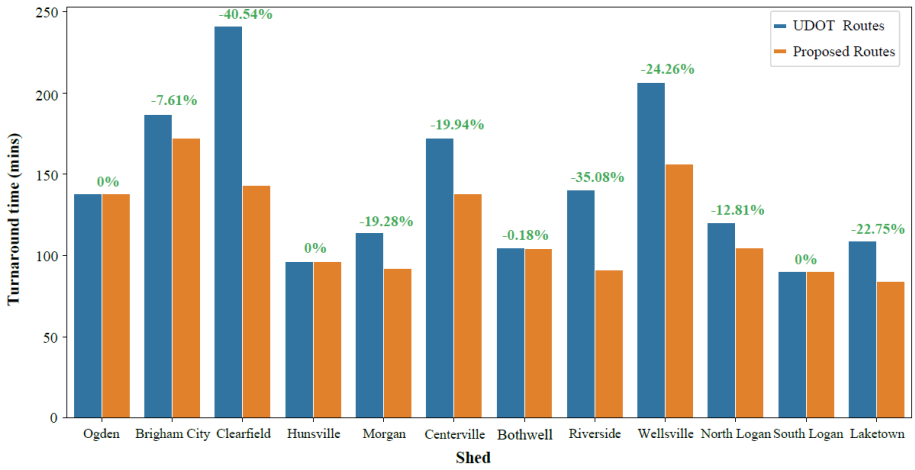
UDOT Plowing Routes (animation: https://youtu.be/Z1n-aXYtS18)



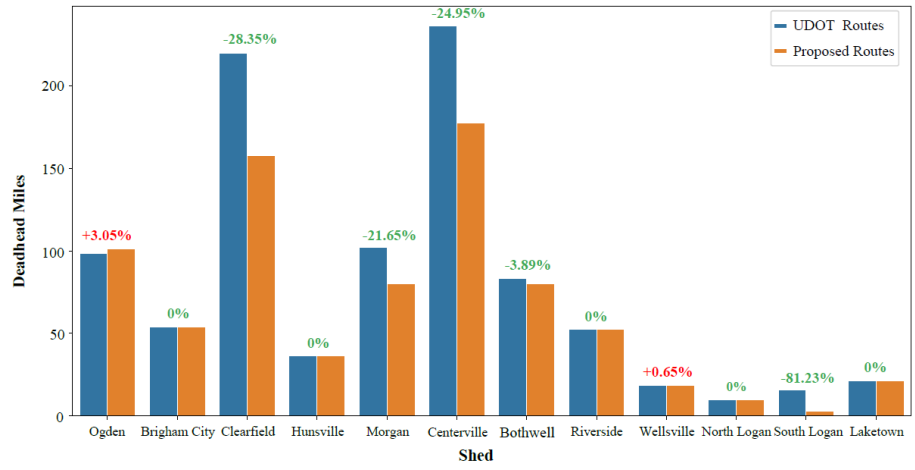
Proposed Plowing Routes (animation: https://youtu.be/_up1UDmRqLg)



Improvement in total travel time



Improvement in turnaround time



Improvement in deadhead miles

1. INTRODUCTION

Snow removal is essential to ensuring public mobility and safety, especially in the areas suffering frequent snow storms. According to the Federal Highway Administration, more than 70% of the nation's roads are located in snowy regions. As a result, road maintenance operations concerned with snow removal and ice control cost more than $2.3 billion each year. To meet the rising expectations of road users and limit these investments, it is important to maximize the efficiency of snow-removal operations. This requires examining the current level of service, equipment type and allocation, staffing levels, assessing the network-wide performance, and determining whether and how potential changes in operations could be made to improve the overall efficiency. In this project, we first reconstruct the UDOT's current snow plowing routes by leveraging their automatic vehicle location (AVL) data. Then, we optimize snow plowing routes in 12 regions in northern Utah by applying vehicle routing heuristics. Finally, we evaluate the performance of current UDOT routes and proposed routes based on four metrics including total travel times, turnaround times and deadhead miles.

The described efforts included two to five meetings with each region's foreman to validate both sets of routes. The discussions typically involved the following items:

- Road network: In addition to network partition, we had to validate the required number of passes along each road link, which depends on the number of lanes as well as existence of wide shoulders. The vehicle speed was commonly set to 60% of the speed limit, but was occasionally modified (e.g., for the roads where higher truck speeds would knock out mailboxes when pushing the snow, or for icy canyon roads). Also, each road would have its designated priority.
- Operational policies: Because different regions have different operational policies, we had to ensure that they are accounted for in the proposed routes. For example, some foremen would have their trucks open the right-most lane throughout the region before having the trucks clear any remaining lanes. A counter example is preference of some foremen for running trucks in echelons to simultaneously clean more than one lane. In fact, this is mandatory for all (multi-lane) interstates to avoid snow piling up on the road. Another example is the preference of some foremen for keeping current the sub-partition of their regional networks.
- Fleet composition: Because snow removal operations may involve trucks of different types and capabilities, we had to validate fleet composition for each region. The UDOT fleet involves: regular (or general purpose) trucks that clean one lane at a time, double-wing trucks that clean one and a half lanes at a time (e.g., right-most lane and a shoulder), and tow-plow trucks that simultaneously clean two lanes. The latter two groups account for less than 20% of the overall fleet and their assignments are generally fixed and limited to major roads and highways. For example, two tow-plow trucks in Centerville are only allowed on Interstate 15, where they operate in echelons, thereby ensuring simultaneous snow removal across all the lanes.
- Capacity constraints: Salt capacity is a common constraint in snow removal operations. The considered trucks typically have a 7-ton capacity and apply 250 lbs. of salt per lane mile. This allows truckers to clean 56 lane-miles before having to return to their depots to refill. Because salt capacity was more constraining than fuel, the latter was not considered explicitly.
- Performance measures: All the regions were interested in four performance measures: vehicle miles, vehicle minutes, deadhead miles that measure excessive passes (e.g., when a three-lane road is traversed five times), and the turnaround time that denotes duration of the longest route (i.e., the time the last truck returns to the depot). For each region, total vehicle minutes were set as the objective function, while the maximum route duration constraint was iteratively reduced to explore the trade-off between the efficiency (i.e., vehicle minutes) and turnaround time.

2. IMPLEMENT PROCEDURES FOR ROUTING OPTIMIZATION

2.1 Network Processing

The objective of this step is to obtain the roadway information (i.e., the number of lanes, length and travel time of each road segment), which will be crucial for the subsequent step. To describe the procedure, we consider the Wellsville region as an example.

First, we need the base map of the roadways assigned to the Wellsville shed (see left panel of Figure 2.1). Based on the road segments shown in the base map, we edit the road network in ArcGIS pro, a GIS software. The right panel of Figure 2.1 presents the network in which nodes represent intersections, while each line between two adjacent nodes represents a road segment.

Figure 2.1 The planned roadways (left) and resulting network edited in ArcGIS pro (right). The green box represents the maintenance station (also referred to as the depot).

Next, we extract infrastructure information for each road segment in the GIS software. For example, consider the road segment indicated with the red arrow in Figure 2.1). It has a length of 7.99 miles, with head node ID and tail node 1 and 2, and it takes a truck 12.25 minutes to traverse this segment. (Note that the travel time is computed assuming the speed of 70% of the speed limit.) Detailed road information for remaining road links is presented in Table 2.1, which can be stored in an EXCEL or CSV file. Note that each direction is considered separately. For example, rows 1 and 2 provide the data for the two directions of the same road segment.

Table 2.1 Plow Lane Information

Node ID	Node ID	Duration (min)	Length (mile)	# Lane	Priority
1	2	11.99	7.99	1	3
2	1	11.99	7.99	1	3
2	3	17.10	8.55	1	3
3	2	17.10	8.55	1	3
3	4	3.84	1.6	1	3
4	3	3.84	1.6	1	3
3	5	2.44	1.22	1	3
5	3	2.44	1.22	1	3
4	5	3.36	2.24	2	1
5	4	3.36	2.24	2	1
5	6	4.35	2.54	1	3
6	5	4.35	2.54	1	3
6	7	0.96	0.4	1	3
7	6	0.96	0.4	1	3
7	8	4.22	1.76	1	3
8	7	4.22	1.76	1	3
8	10	3.84	1.6	2	3
10	8	3.84	1.6	2	3
8	16	9.26	5.4	1	3
16	8	9.26	5.4	1	3
8	14	10.05	5.86	2	3
14	8	10.05	5.86	2	3
10	11	34.08	14.2	1	3
11	10	34.08	14.2	1	3
14	15	2.98	1.24	2	1
15	14	2.98	1.24	2	1
14	12	3.29	1.92	2	1
12	14	3.29	1.92	2	1
12	13	4.49	2.62	2	2
13	12	4.49	2.62	2	2
12	5	6.86	4.57	2	1
5	12	6.86	4.57	2	1

2.2 Network Transformation

We describe transformation of the snowplow routing problem into a "node routing problem." The motivation for this transformation is availability of various algorithms and libraries for node routing. Figure 2.2 illustrates the transformation for a single road segment with four lanes in both directions. The black nodes represent upstream and downstream intersections, while the four lanes are represented with four blue arrows. In snowplow routing each lane must be traversed, while in node routing each "delivery node" must be visited. Thus, we insert a red "delivery" node in the middle of each blue arrow. Now, if trucks visit all the red nodes and return to their depot, all the lanes will be traversed.

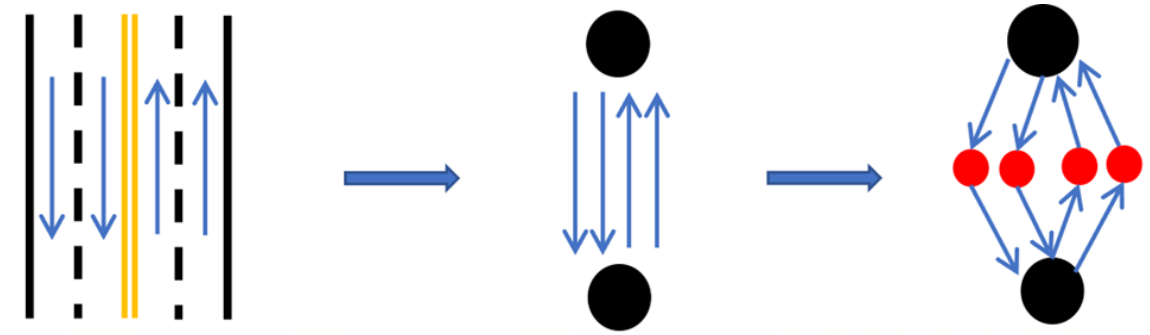


Figure 2.2 An illustrative example of routing problem transformation

After inserting the red nodes, the travel costs between the nodes need to be adjusted. For example, consider Figure 2.3, where the travel time from node 1 to the inserted node 4 is simply one half of the travel time between the intersection nodes 1 and 2.

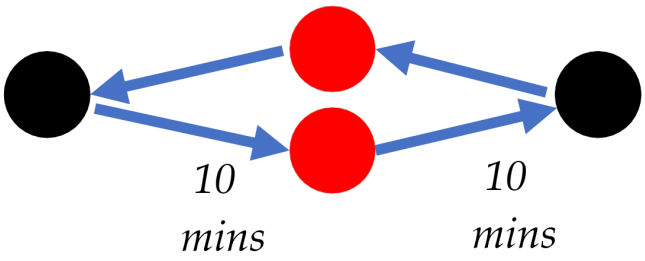


Figure 2.3 An illustrative example of link cost after transformation

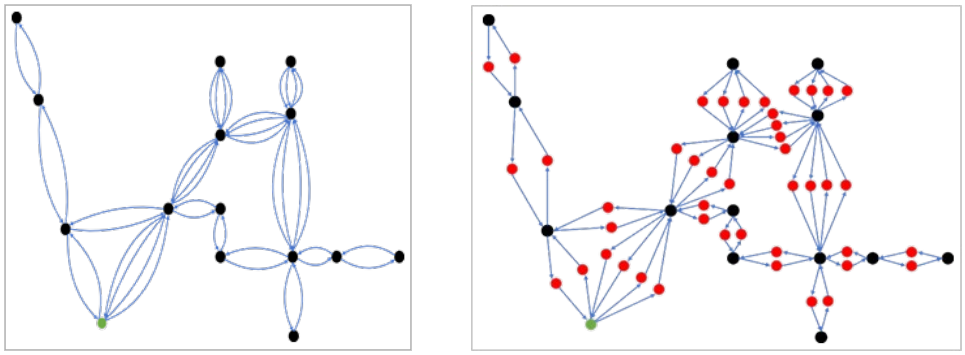
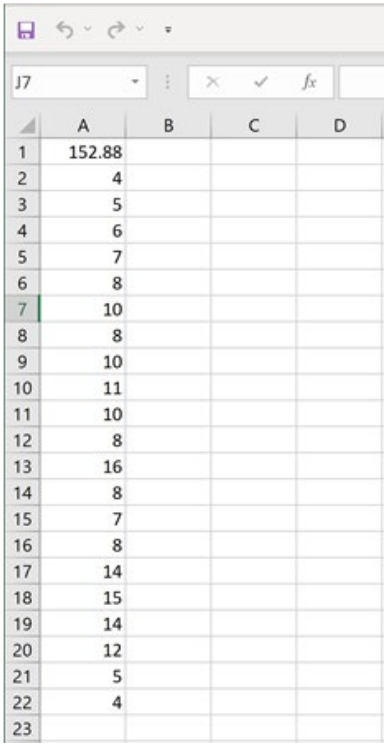


Figure 2.4 Graph transformation: the original network in which the black nodes represent intersections while the blue arrows represent the lanes between two adjacent intersections. Right: The transformed network in which all curved blue arrows are replaced with red nodes.

2.3 Node Routing Problem Optimization

Here we use algorithms (the cheapest insertion for route construction and crossover and exchange operations for route improvement) provided in a MATLAB toolbox to tackle the node routing problem and obtain the route for each snowplow truck. The first input is the road segment information obtained in the previous section. The second input is the number of plows that can be dispatched for snow removal. With these data, we apply the MATLAB code to design routes that minimize total travel time while cleaning all the lanes.



	A	B	C	D
1	152.88			
2	4			
3	5			
4	6			
5	7			
6	8			
7	10			
8	8			
9	10			
10	11			
11	10			
12	8			
13	16			
14	8			
15	7			
16	8			
17	14			
18	15			
19	14			
20	12			
21	5			
22	4			
23				

Figure 2.5 A presentation of one plowing route

We enter the file name to load roadway information and also define the number of trucks at line 12. After running the code, each route will be saved in a single CSV file.

Here we consider one file and describe the stored route. From Figure 2.5, the first row tells us the travel time for this route. The following rows show that the truck starts its trip at node 4, which is the depot, and then proceeds by visiting nodes 5, 6, 7, 8, 10, etc. Its final destination is node 4, which means that the truck returns to the depot. If needed, the resulting routes can be manually adjusted.

```
clear
clc

%% load roadways data
fileName = 'roadInfo.xlsx';
readData = readmatrix(fileName);
roadInfo = readData (:,[1,2,3,5]) ;
depotNodeID = 4;
%%


%% the number of trucks avaiable for service
numTruck = 4;


% ......


%% save routes to excel  file
for  routeID = 1:size(loc,2)
    curRoute = optimizedRouteSet{1,routeID};
    filename = ['route_' num2str(routeID) '.xlsx'];
    xlswrite(filename,curRoute);
end
%%
```

Figure 2.6 MATLAB code for importing data and exporting results

3. RESULTS

3.1 Brigham City Shed

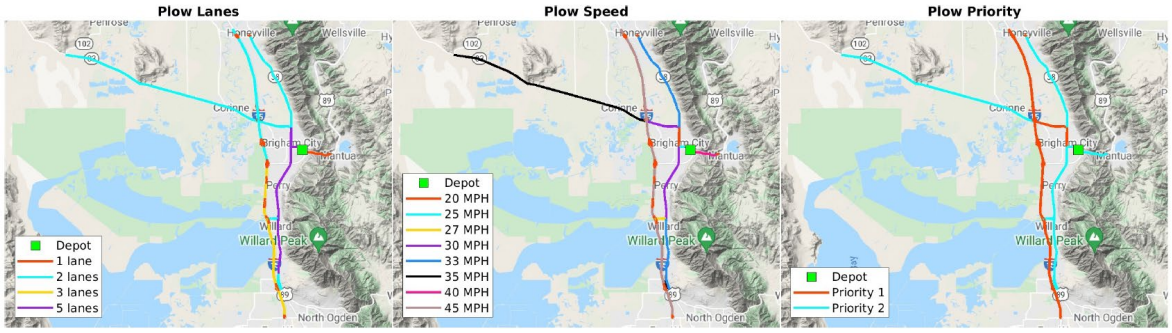


Figure 3.1 Plowing lanes, travel speed and road priorities in Brigham City

For this shed, UDOT assigned one tow plow and one double-wing truck as well as a single-wing truck to I-15, and the resulting plowing routes are presented below.

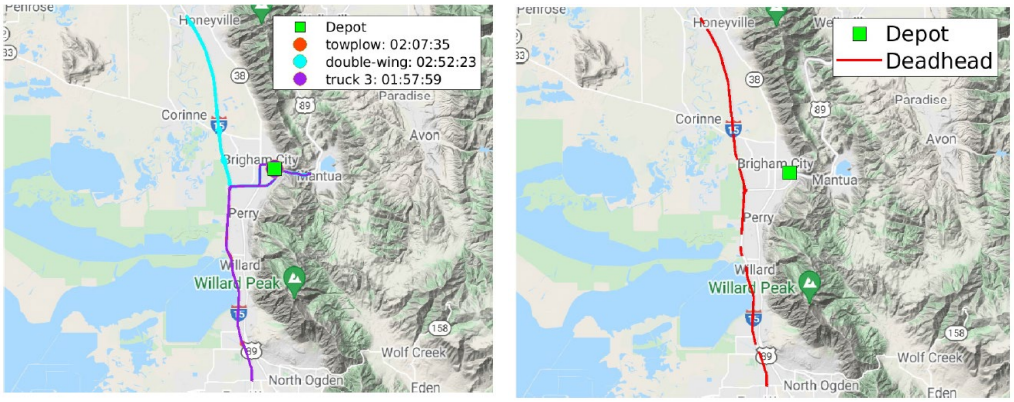


Figure 3.2 UDOT plowing routes along I-15 (animation: https://youtu.be/BuW6gpehHto)

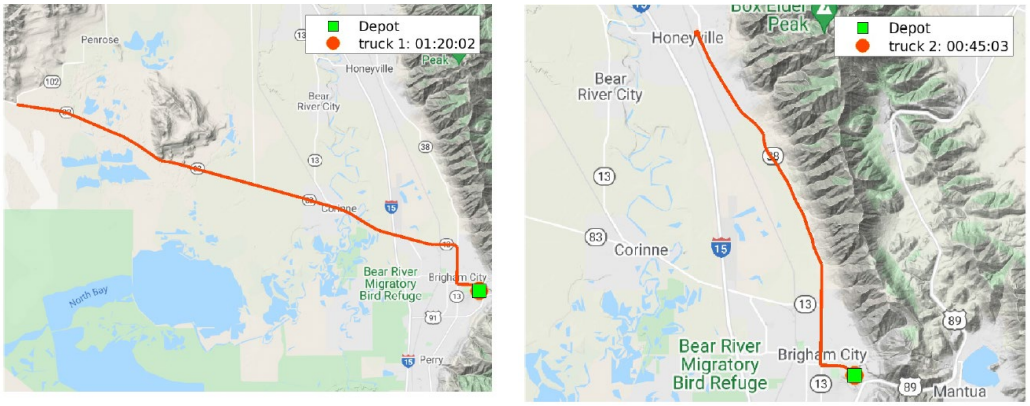


Figure 3.3 UDOT plowing routes along SR-83 and SR-38 (animation: https://youtu.be/a3dRAPnQKbU; https://youtu.be/kFUTUyMdeeY)

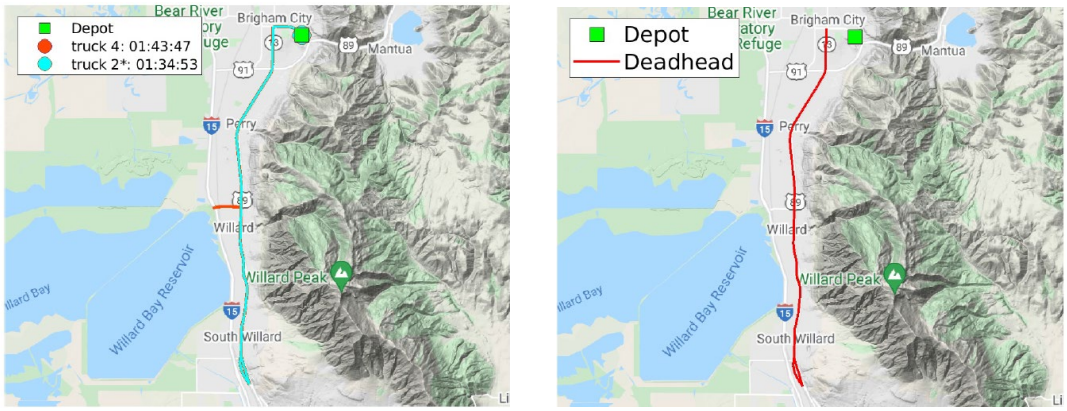


Figure 3.4 UDOT plowing routes along US-89 (animation: https://youtu.be/cvT8WgiMXII)

To further improve the efficiency of snow removal operations, we assign only one tow-plow and one double-wing truck to I-15. The single-wing truck previously assigned to I-15 will be employed to remove snow on US-89. remain. The plowing routes for SR-38 and SR-83 keep unchanged and the proposed routes for I-15 and US-89 are presented as follows.

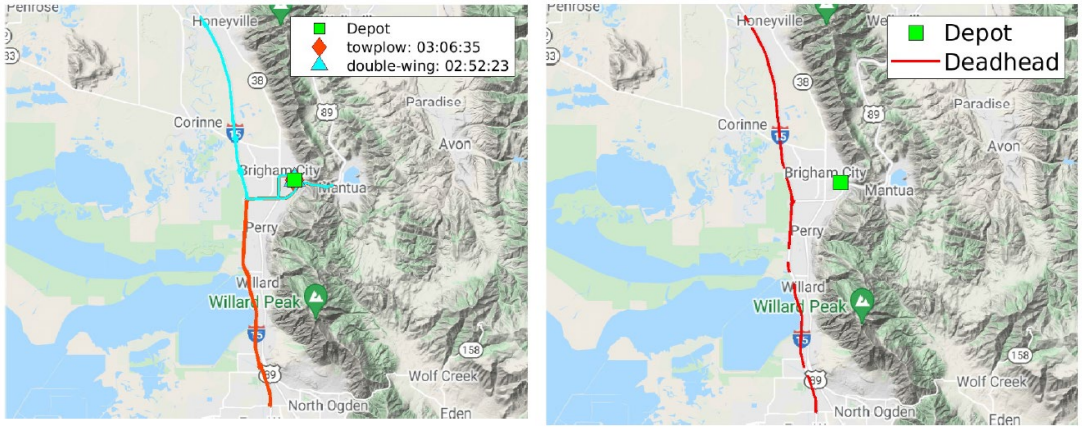


Figure 3.5 Proposed plowing routes along I-15 with a tow plow and a double-wing truck (animation: https://youtu.be/uHBb08CnjVA)

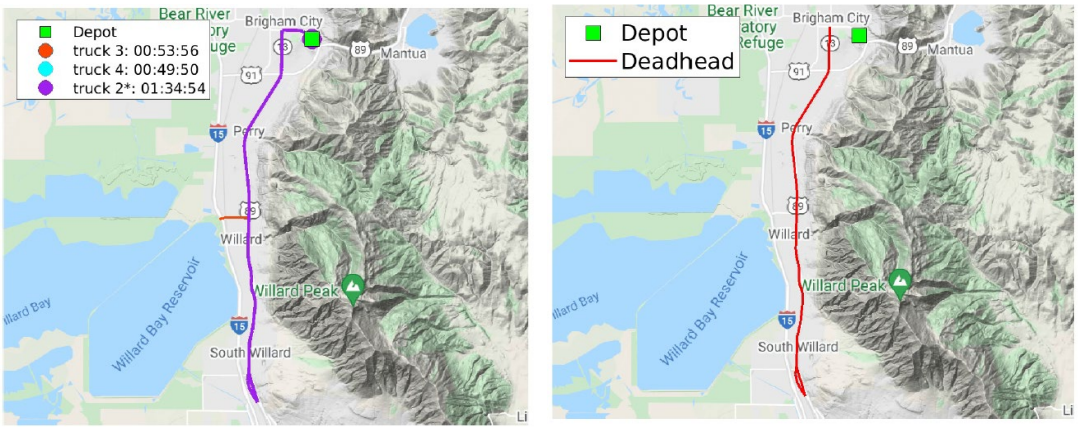


Figure 3.6 Proposed plowing routes along US-89 with three single-wing trucks (animation: https://youtu.be/B3M-3EB8l0w)

The detail performance of UDOT plowing routes and our proposed routes is shown Figure 3.7. The total travel time of the proposed routes is 8.46% less than that of UDOT routes. Although the turnaround time is increased by 8%, the workload on US-89 is more balanced.

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	(miles)	Salt (tons)
I-15					
towplow	186.58	113.88	30.39	20.85	23.26
double-wing	172.38	106.37	28.01	19.71	16.25
SR-83					
1	80.03	43.82	0.00	0.00	5.48
SR-38					
2	45.05	22.11	0.00	0.00	2.76
US-89					
2'	49.84	25.85	25.06	13.26	1.57
3	53.94	27.69	0.00	0.00	3.46
4	49.84	25.85	0.00	0.00	3.23
Total	637.66	365.57	83.46	53.82	56.01
Max	186.58	113.88	30.39	20.85	23.26

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	(miles)	Salt (tons)
I-15					
towplow	127.58	76.09	30.39	20.85	13.81
double-wing	172.38	106.37	28.01	19.71	16.25
3	117.98	75.58	0.00	0.00	9.45
SR-83					
1	80.03	43.82	0.00	0.00	5.48
SR-38					
2	45.05	22.11	0.00	0.00	2.76
US-89					
2'	49.84	25.85	0.00	0.00	1.57
4	103.78	53.54	25.06	13.26	5.04
Total	696.64	403.36	83.46	53.82	56.01
Max	172.38	106.37	30.39	20.85	16.25

Figure 3.7 Performance comparison of proposed routes (left) and UDOT routes (right) for Brigham City

3.2 Clearfield Shed

The responsible roadways are divided into four groups and the detailed plowing information for each group is provided in Figures 3.8-3.11.

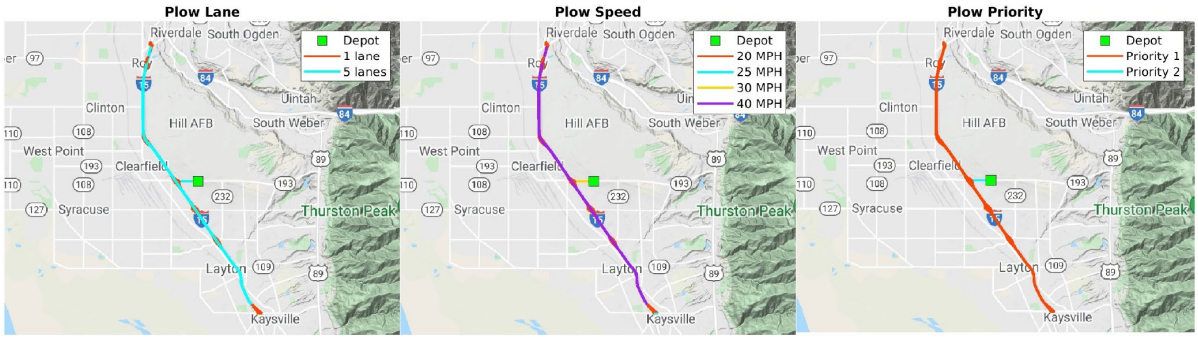


Figure 3.8 Plowing lanes, travel speed and road priorities along I-15 in group 1 within Clearfield

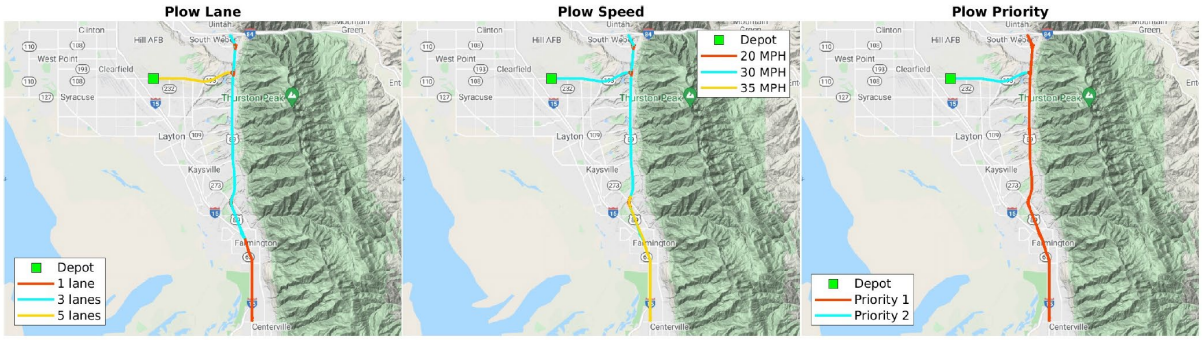


Figure 3.9 Plowing lanes, travel speed and road priorities along US-89 in group 2 within Clearfield

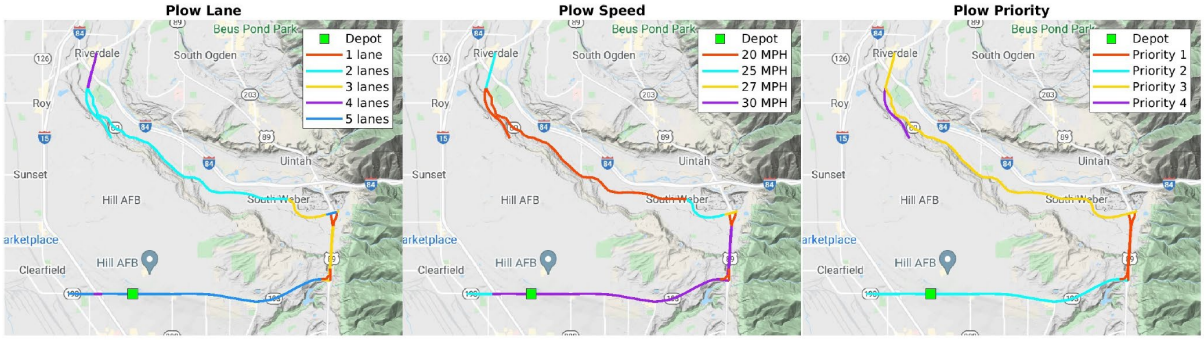


Figure 3.10 Plowing lanes, travel speed and road priorities along SR-193, SR-60 and SR-168 in group 3 within Clearfield

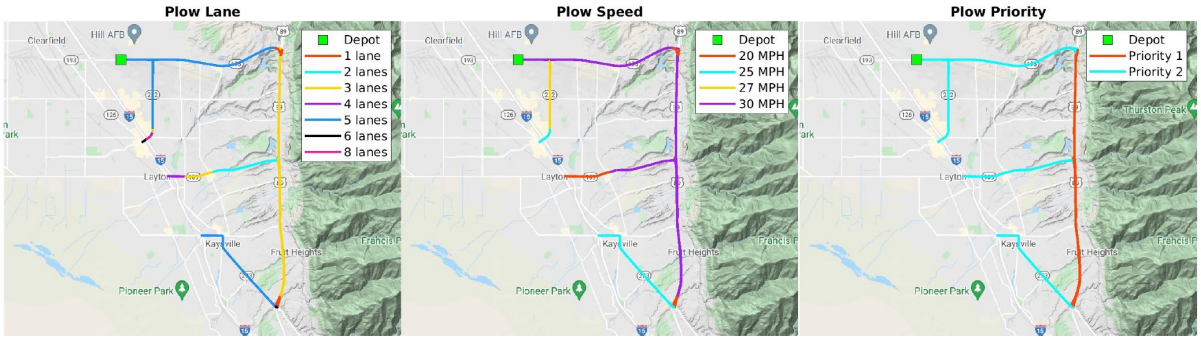


Figure 3.11 Plowing lanes, travel speed and road priorities along SR-109, SR-232 and SR-273 in group 4 within Clearfield

The visualization of UDOT routes and proposed routes are presented below:

(1) Group 1: I-15: the proposed routes are identical to UDOT routes

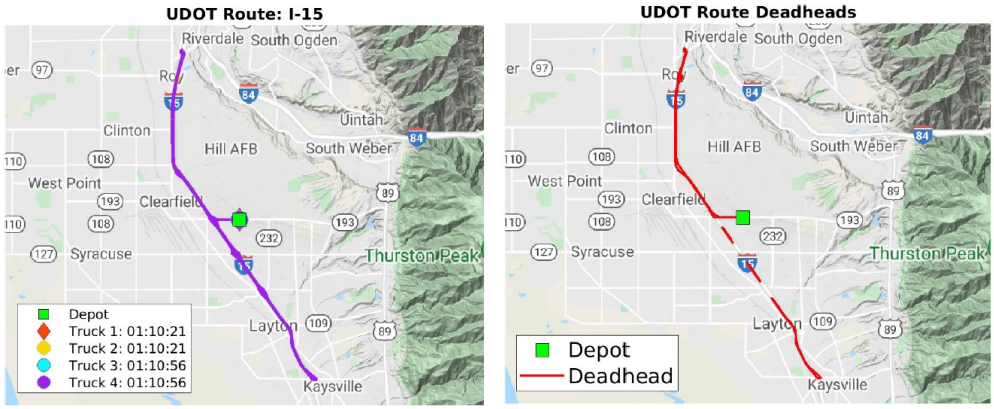


Figure 3.12 UDOT plowing routes along I-15 within Clearfield (animation: https://youtu.be/dKeFHa8uyuI)

(2) Group 2: US-89

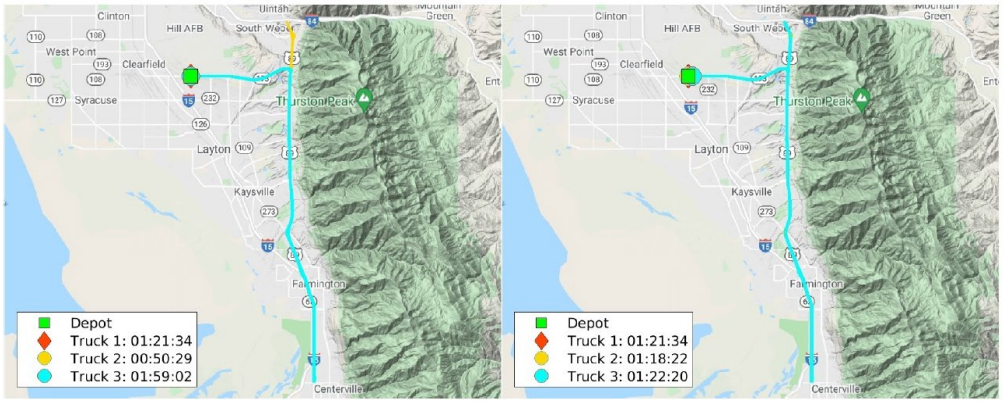


Figure 3.13 Left: UDOT plowing routes. Right: Proposed plowing routes (animation: https://youtu.be/_eh2czrACAY)

(3) Group 3: SR-193 & SR-60 & SR-168

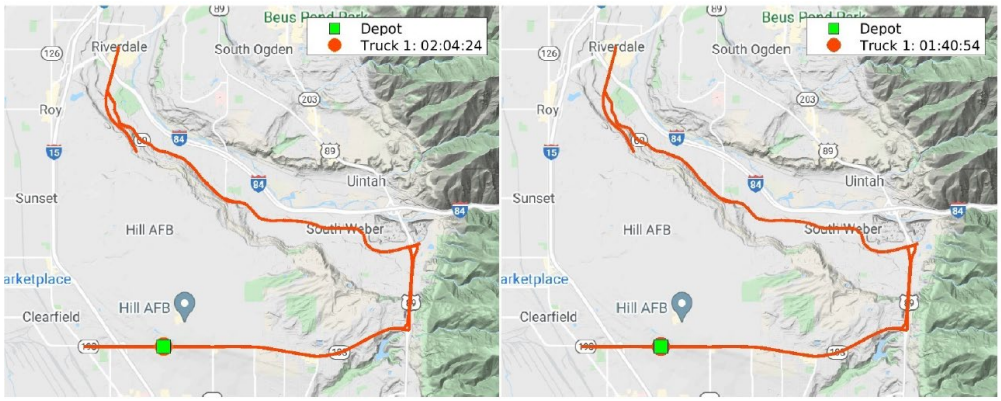


Figure 3.14 Left: UDOT plowing routes. Right: Proposed plowing routes (animation: https://youtu.be/56gfsnpAbjE)

(4) Group 4: SR-109 & SR-232 & SR-273

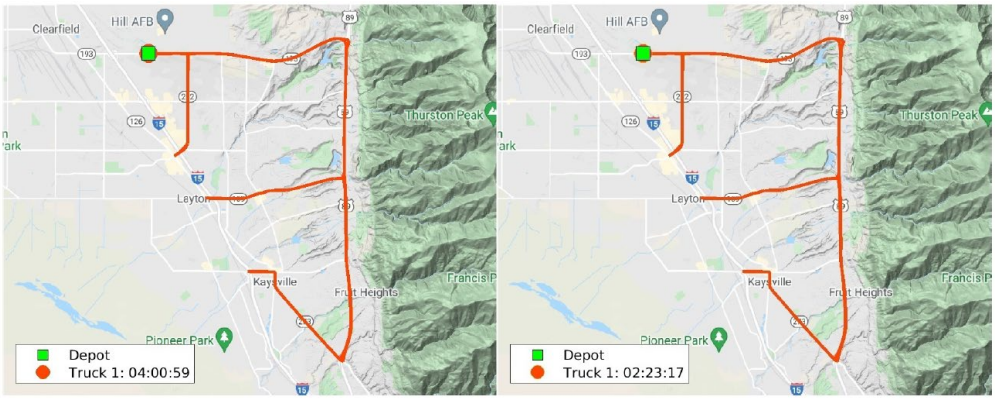


Figure 3.15 Left: UDOT plowing routes. Right: Proposed plowing routes (animation: https://youtu.be/3PvJvtHgdVg)

Figure 3.15 compares UDOT's existing routes with the proposed routes, and their respective performance improvements are summarized as follows:

Group 1: No change in the proposed route compared to UDOT's route.

Group 2: Total vehicle minutes reduced by 3.60% (from 251.09 minutes to 242.04 minutes), turnaround time reduced by 31.03% (from 119.03 minutes to 82.10 minutes), and deadhead miles reduced by 8.29% (from 44.61 miles to 40.91 miles).

Group 3: Total vehicle minutes reduced by 18.89% (from 124.40 minutes to 100.90 minutes), turnaround time reduced by 18.89% (from 124.40 minutes to 100.90 minutes), and deadhead miles reduced by 44.68% (from 25.18 miles to 13.93 miles).

Group 4: Total vehicle minutes reduced by 40.54% (from 240.98 minutes to 143.28 minutes), turnaround time reduced by 40.54% (from 240.98 minutes to 143.28 minutes), and deadhead miles reduced by 63.49% (from 74.74 miles to 27.29 miles).

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
Group 1: I-15					
1 (tow-plow)	70.35	38.99	23.02	25.55	6.55
2	70.35	38.99	39.23	18.45	2.57
3	70.93	39.13	30.76	15.76	2.92
4	70.93	39.13	30.76	15.76	2.92
Total	282.56	156.24	123.77	75.52	14.96
Max	70.93	39.13	39.23	25.55	6.55
Group 2: US-89					
1 (tow-plow)	81.57	41.84	12.49	11.58	9.01
2	50.49	23.78	18.35	8.34	1.93
3	119.03	61.34	49.52	24.69	4.58
Total	251.09	126.96	80.36	44.61	15.52
Max	119.03	61.34	49.52	24.69	9.01
Group 3: SR-193 & SR-60 & SR-168					
1	124.40	52.39	52.79	25.18	3.40
Total	124.40	52.39	52.79	25.18	3.40
Max	124.40	52.39	52.79	25.18	3.40
Group 4: SR-109 & SR-232 & SR-273					
1	240.98	110.46	155.24	74.74	4.47
Total	240.98	110.46	155.24	74.74	4.47
Max	240.98	110.46	155.24	74.74	4.47

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
Group 1: I-15					
1 (tow-plow)	70.35	38.99	23.02	25.55	6.55
2	70.35	38.99	39.23	18.45	2.57
3	70.93	39.13	30.76	15.76	2.92
4	70.93	39.13	30.76	15.76	2.92
Total	282.56	156.24	123.77	75.52	14.96
Max	70.93	39.13	39.23	25.55	6.55
Group 2: US-89					
1 (tow-plow)	81.57	41.84	26.38	25.72	7.25
2	78.37	38.99	6.82	3.28	4.46
3	82.10	42.42	24.23	11.91	3.81
Total	242.04	123.25	57.43	40.91	15.52
Max	82.10	42.42	26.38	25.72	7.25
Group 3: SR-193 & SR-60 & SR-168					
1	100.90	41.14	28.98	13.93	3.40
Total	100.90	41.14	28.98	13.93	3.40
Max	100.90	41.14	28.98	13.93	3.40
Group 4: SR-109 & SR-232 & SR-273					
1	143.28	63.01	57.54	27.29	4.47
Total	143.28	63.01	57.54	27.29	4.47
Max	143.28	63.01	57.54	27.29	4.47

Figure 3.16 Performance comparison of UDOT plowing routes (left) and proposed plowing routes (right) for Clearfield

3.3 Huntsville Shed

The detailed plowing information for Huntsville is provided in Figures 3.8-3.11.

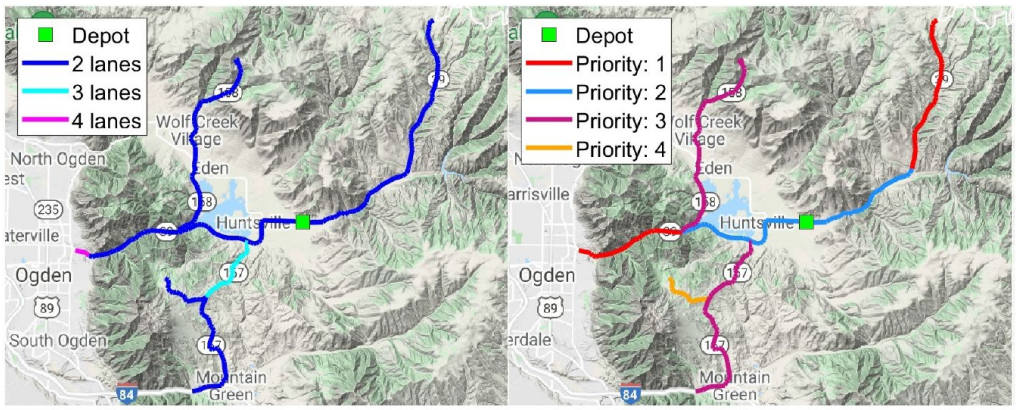


Figure 3.17 Plowing lanes, travel speed and road priorities within Huntsville

Because the road network in Huntsville is simple and we found that the plowing routes are already optimal after applying optimization methods on this case. The UDOT routes and the performance are presented in Figure 3.18 and 3.19.

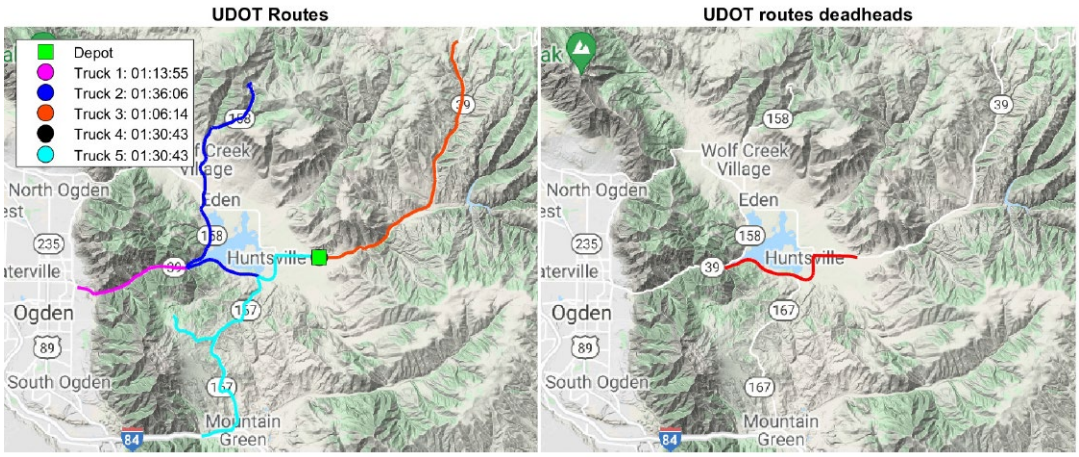


Figure 3.18 UDOT plowing routes (animation: https://youtu.be/_FlHTFecRbI)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	73.92	30.80	0	0	3.85
# 2	96.10	40.04	40.80	17.00	2.88
# 3	66.24	27.60	0	0	3.45
# 4	90.72	37.80	23.04	9.60	3.53
# 5	90.72	37.80	23.04	9.60	3.53
Total	417.70	174.04	86.88	36.20	17.24
Max	96.10	40.04	40.80	17.00	3.85

Figure 3.19 The Performance of UDOT plowing routes for Huntsville

3.4 Morgan Shed

The detailed plowing information for Huntsville is provided in Figure 3.20.

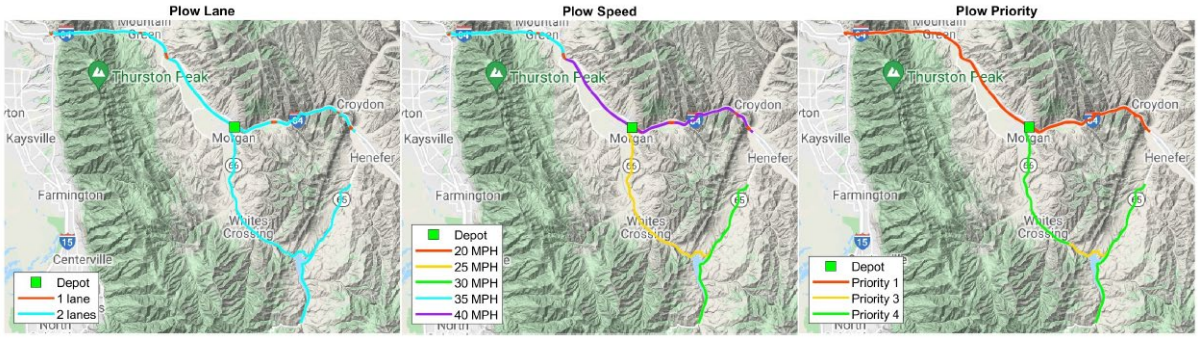


Figure 3.20 Plowing lanes, travel speed and road priority within Morgan

The visualization of UDOT routes and proposed routes are presented below:

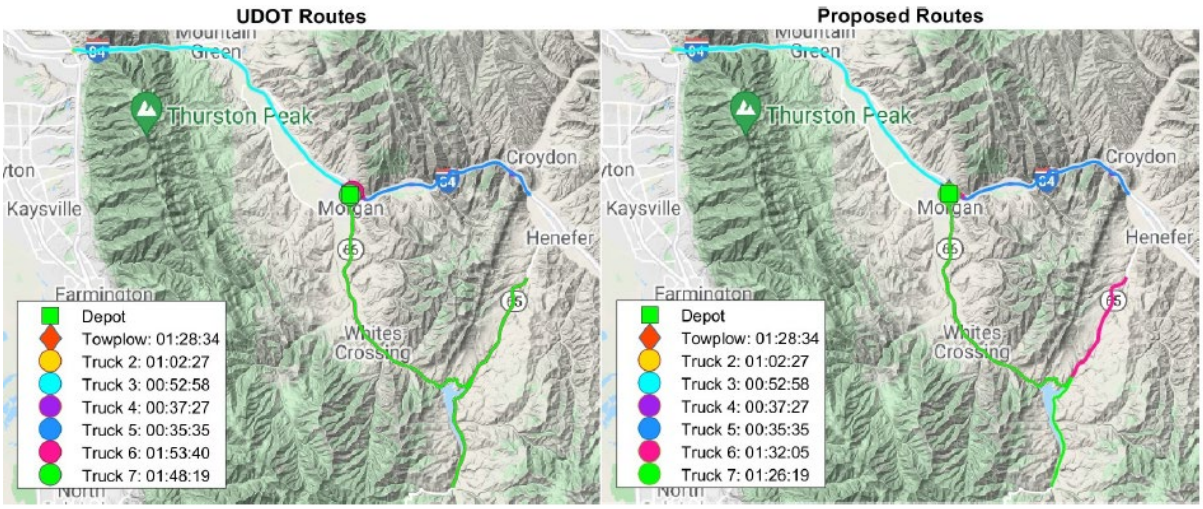


Figure 3.21 UDOT plowing routes (left) and proposed plowing routes (right) for Morgan (animation: https://youtu.be/46JCgNc3YAQ)

As shown in Figure 3.22, the proposed routes exhibit substantial improvements when compared to UDOT routes:

- Total vehicle minutes is reduced by 8.81% (from 499.42 minutes to 455.42 minutes).
- Turnaround time is reduced by 19.28% (from 114.08 minutes to 92.08 minutes).
- Deadhead miles are reduced by 21.72% (from 102.07 miles to 79.97 miles).

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
1 (tow-plow)	88.56	53.87	29.41	17.95	11.22
2	62.45	35.34	54.65	32.74	0.33
3	52.97	31.81	3.00	1.00	3.85
4	37.45	20.02	1.26	0.42	2.45
5	35.59	22.06	6.76	2.86	2.40
6	114.08	50.72	52.86	23.74	3.37
7	108.32	48.80	51.42	23.36	3.18
Total	499.42	262.62	199.36	102.07	20.25
Max	114.08	53.87	54.65	32.74	11.22

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
1 (tow-plow)	88.56	53.87	29.41	17.95	11.22
2	62.45	35.34	54.65	32.74	0.33
3	52.97	31.81	3.00	1.00	3.85
4	37.45	20.02	1.26	0.42	2.45
5	35.59	22.06	6.76	2.86	2.40
6	92.08	39.73	30.86	12.74	3.37
7	86.32	37.80	29.42	12.26	3.19
Total	455.42	240.63	155.36	79.97	20.25
Max	92.08	53.87	54.65	32.74	11.22

Figure 3.22 Performance comparison of UDOT routes (left) and proposed routes (right) for Morgan

3.5 Centerville Shed

The detailed plowing information for Centerville is provided in Figure 3.23.

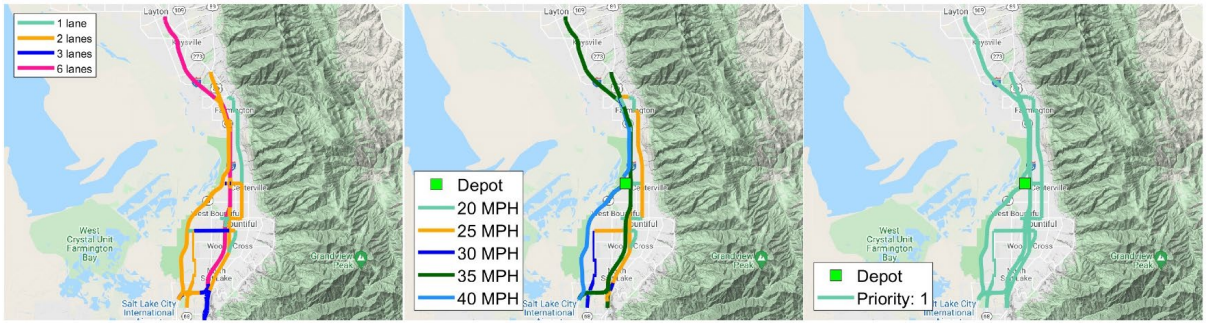


Figure 3.23 Plowing lanes, travel speed and road priorities within Centerville

For this shed, we first applied optimization approached to optimize plowing routes based on current fleet configuration. The resulting plowing routes are presented below.

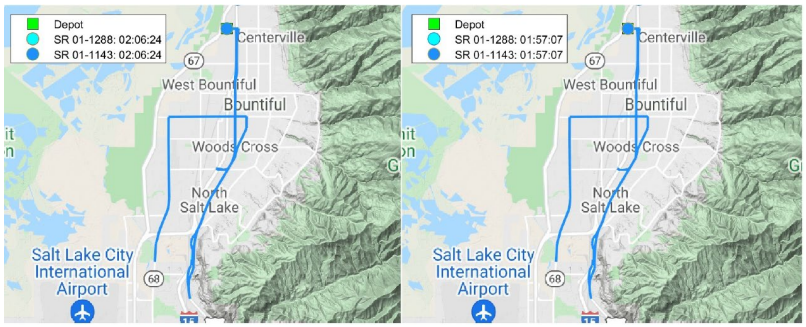


Figure 3.24 UDOT plowing routes (left) and proposed plowing routes (right) along SR-89 and SR-68 in group 1 (animation: https://youtu.be/Wl_KH-KaXlY)

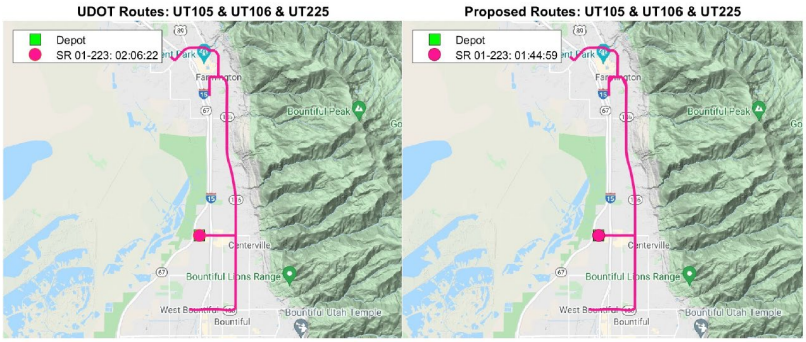


Figure 3.25 UDOT plowing routes (left) and proposed plowing routes (right) along SR-105, SR-106 and SR-225 (animation: https://youtu.be/Q_VMc4W-6GQ)

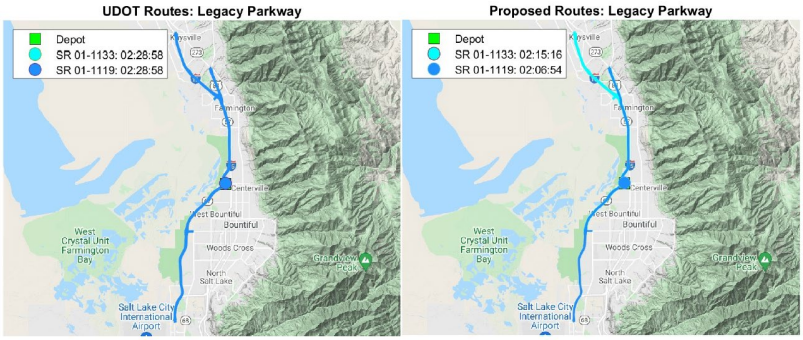


Figure 3.26 UDOT plowing routes (left) and proposed plowing routes (right) along Legacy Parkway in group 3 (animation: https://youtu.be/FruUKOu_k2A)

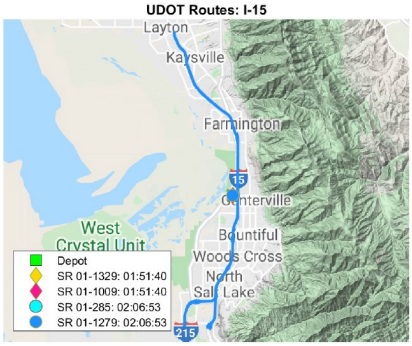


Figure 3.27 The visualization of UDOT plowing routes (left) and proposed plowing routes (right) along I-15 in group 4 (animation: https://youtu.be/xwMGOk3cEF4)

Truck Label	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
SR01-223	126.36	50.72	34.27	13.67	4.63
SR01-1288	126.40	56.70	30.16	13.76	5.37
SR01-1143	126.40	56.70	52.23	23.85	4.11
SR01-1133	172.30	96.33	82.92	49.24	5.89
SR01-1119	172.30	96.33	94.25	53.19	5.39
SR01-1329	111.67	60.46	25.98	14.23	13.34
SR01-1009	111.67	60.46	43.69	21.38	12.44
SR01-285	126.89	66.11	49.82	24.49	5.20
SR01-1279	126.89	66.11	44.27	22.65	5.43
Total	1200.88	609.92	457.58	236.45	61.80
Max	172.30	96.33	94.25	53.19	13.34

Truck Label	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
SR01-223	104.99	42.33	12.90	5.28	4.63
SR01-1288	117.11	52.10	18.77	8.46	5.46
SR01-1143	117.11	52.10	42.95	19.25	4.11
SR01-1133	131.38	71.31	66.40	34.52	4.60
SR01-1119	137.94	79.91	39.98	27.19	6.59
SR01-1329	111.67	60.46	25.98	14.23	13.34
SR01-1009	111.67	60.46	43.69	21.38	12.44
SR01-285	126.89	66.11	49.82	24.49	5.20
SR01-1279	126.89	66.11	44.27	22.65	5.43
Total	1085.65	550.89	344.76	177.45	61.80
Max	137.94	79.91	66.40	34.52	13.34

Figure 3.28 Performance of UDOT routes (left) and proposed routes (right) for Centerville

Based on the current fleet configuration, the proposed changes lead to impressive improvements:

- Total vehicle minutes is reduced by 9.59%, from 1200.88 minutes to 1085.65 minutes.
- Turnaround time is reduced by 19.94%, from 172.30 minutes to 137.94 minutes.
- Deadhead miles are reduced by 24.95%, from 236.45 miles to 177.45 miles.

In addition to optimizing routes with the current fleet configuration, we received information from the local manager that Legacy Parkway will be serviced with a double-wing truck and a single-wing truck in the future. Taking this into account, we have also conducted route optimization based on the future fleet composition for Legacy Parkway.

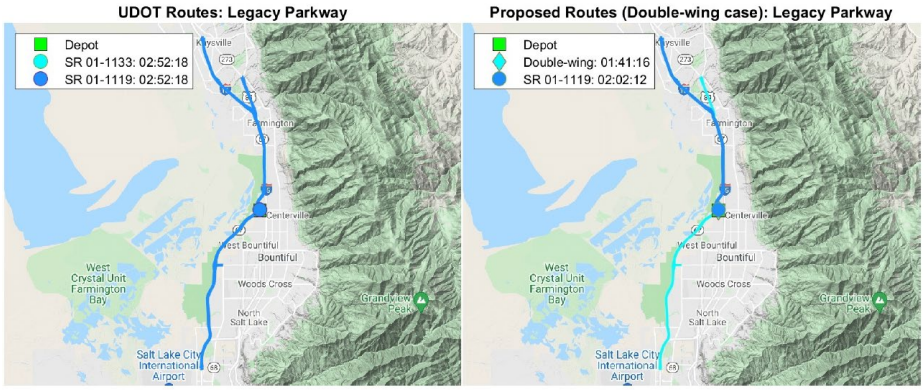


Figure 3.29 The route comparison of UDOT routes with current configuration (left) and proposed routes with new fleet composition (right) along Legacy Parkway (animation: https://youtu.be/wq2HSxgTiDI)

Truck Label	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
SR01-223	126.36	50.72	34.27	13.67	4.63
SR01-1288	126.40	56.70	30.16	13.76	5.37
SR01-1143	126.40	56.70	52.23	23.85	4.11
SR01-1133	172.30	96.33	82.92	49.24	5.89
SR01-1119	172.30	96.33	94.25	53.19	5.39
SR01-1329	111.67	60.46	25.98	14.23	13.34
SR01-1009	111.67	60.46	43.69	21.38	12.44
SR01-285	126.89	66.11	49.82	24.49	5.20
SR01-1279	126.89	66.11	44.27	22.65	5.43
Total	1200.88	609.92	457.58	236.45	61.80
Max	172.30	96.33	94.25	53.19	13.34

Truck Label	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
SR01-223	104.99	42.33	12.90	5.28	4.63
SR01-1288	117.11	52.10	18.77	8.46	5.46
SR01-1143	117.11	52.10	42.95	19.25	4.11
DoubleWing	101.26	58.63	84.55	50.72	8.94
SR01-1119	122.20	64.94	72.53	41.98	2.54
SR01-1329	111.67	60.46	25.98	14.23	13.34
SR01-1009	111.67	60.46	43.69	21.38	12.44
SR01-285	126.89	66.11	49.82	24.49	5.20
SR01-1279	126.89	66.11	44.27	22.65	5.43
Total	1039.79	523.24	395.46	208.44	61.80
Max	126.89	66.11	84.55	50.72	13.34

Figure 3.30 Performance of UDOT routes (left) and proposed routes (right) with new fleet composition for Centerville

With the implementation of the new fleet configuration, the proposed routes yield even greater efficiency in snow removal operations across the entire region. The improvements achieved are as follows:

- Total vehicle minutes is reduced by 13.41%, from 1200.88 minutes to 1039.79 minutes.
- Turnaround time is reduced by 26.35%, from 172.30 minutes to 126.89 minutes.
- Deadhead miles are reduced by 11.84%, from 236.45 miles to 208.44 miles.

3.6 Bothwell Shed

The detailed plowing information for Bothwell is provided in Figure 3.31.

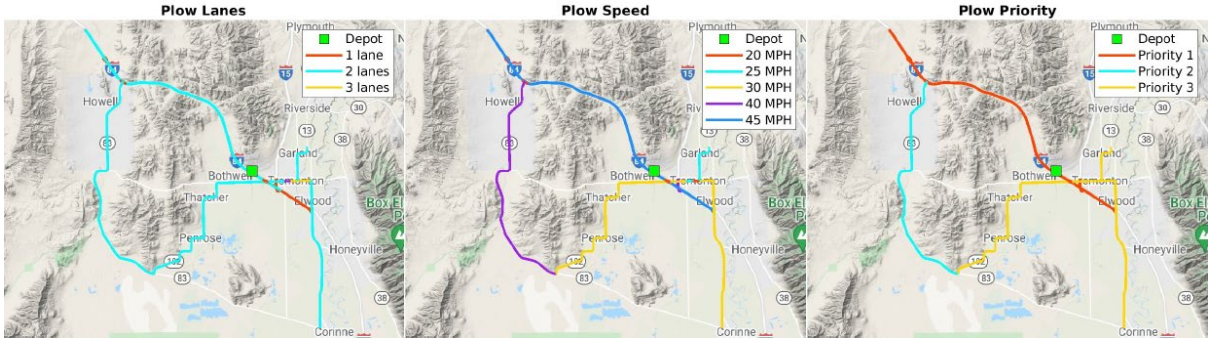


Figure 3.31 Plowing lanes, travel speed and road priorities within Bothwell

The visualization of UDOT routes and proposed routes are presented below:

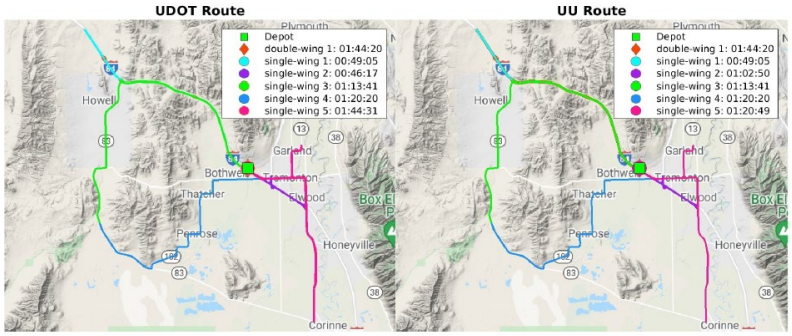


Figure 3.32 The visualization of UDOT plowing routes (left) and proposed plowing routes (right) (animation: https://youtu.be/1xJYxhV-z6M)

Truck ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)	Truck ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
double-wing 1	104.33	71.75	46.85	33.21	4.82	double-wing 1	104.33	71.75	46.85	33.21	4.82
single-wing 1	49.08	35.77	2.66	0.95	4.35	single-wing 1	49.08	35.77	2.66	0.95	4.35
single-wing 2	46.29	29.40	17.71	10.58	2.35	single-wing 2	62.83	36.77	20.08	11.77	3.13
single-wing 3	73.69	50.44	35.56	25.65	3.10	single-wing 3	73.69	50.44	35.56	25.65	3.10
single-wing 4	80.34	42.62	5.67	2.38	5.03	single-wing 4	80.34	42.62	5.67	2.38	5.03
single-wing 5	104.52	48.74	23.38	10.69	4.76	single-wing 5	80.81	38.10	13.84	6.25	3.98
Total	458.25	278.72	131.83	83.46	24.41	Total	451.08	275.45	124.66	80.21	24.41
Max	104.52	71.75	46.85	33.21	5.03	Max	104.33	71.75	46.85	33.21	4.82

Figure 3.33 Performance of UDOT routes (left) and proposed routes (right) for Bothwell

The performance shown in Figure 3.33 reveals that the proposed routes have a modest impact on the turnaround time, which is almost unchanged, reducing only slightly from 104.52 minutes to 104.33 minutes. The total vehicle minutes is reduced by 1.56%, decreasing from 458.25 vehicle minutes to 451.08 minutes. Additionally, the deadhead miles are reduced by 3.89%, decreasing from 83.46 vehicle miles to 80.21 miles. These improvements, although relatively minor, contribute to optimizing the overall efficiency of the system.

3.7 Riverside Shed

The detailed plowing information for Riverside is provided in Figure 3.34.

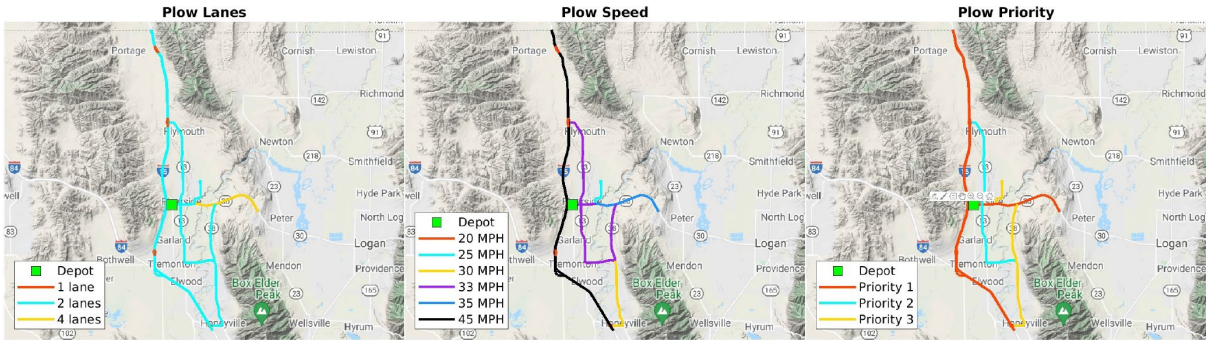


Figure 3.34 Plowing lanes, travel speed and road priorities within Riverside

The roadways are categorized into two groups, and for each group we present both the existing UDOT routes and the proposed routes. Notably, the plowing routes designed by UDOT for the roadways in group 2 are already efficient, so no changes were made.

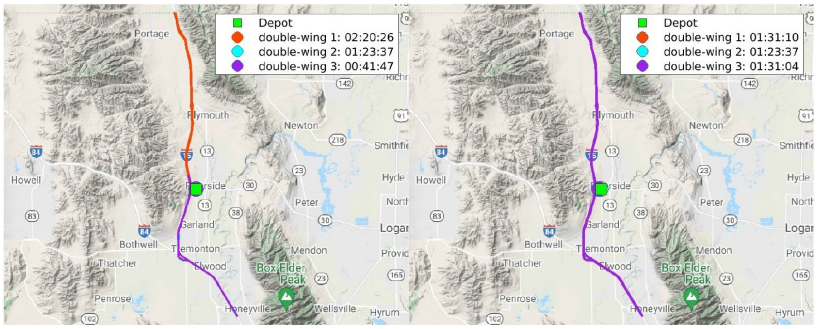


Figure 3.35 (Riverside) UDOT plowing routes (left) and proposed plowing routes (right) along I-15 in group 1 (animation: https://youtu.be/PlLQztuc3K8)

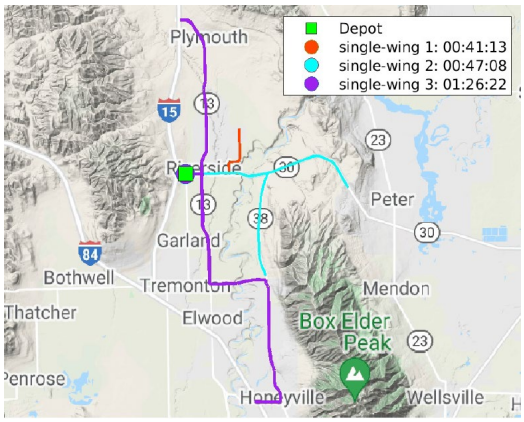


Figure 3.36 (Riverside) UDOT plowing along SR-30, SR-81, SR-38, SR-13 and SR-102 in group 2 (animation: https://youtu.be/FNeJe6U_Hbk)

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	(miles)	Salt (tons)	Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	(miles)	Salt (tons)
I-15						**I-15**					
double-wing 1	140.44	97.10	39.27	28.09	8.63	double-wing 1	91.17	65.53	0	0	8.19
double-wing 2	83.61	57.36	33.76	24.45	4.11	double-wing 2	83.61	57.36	33.76	24.45	4.11
double-wing 3	41.79	29.92	0	0	3.74	double-wing 3	91.06	61.49	39.27	28.09	4.18
SR-30 & SR-81 & SR-38 & SR-13 & SR-102						**SR-30 & SR-81 & SR-38 & SR-13 & SR-102**					
single-wing 1	41.22	21.78	0	0	2.72	single-wing 1	41.22	21.78	0	0	2.72
single-wing 2	47.13	26.64	0	0	3.33	single-wing 2	47.13	26.64	0	0	3.33
single-wing 3	86.37	46.12	0	0	5.77	single-wing 3	86.37	46.12	0	0	5.77
Total	440.56	278.92	73.03	52.54	28.30	Total	440.56	278.92	73.03	52.54	28.30
Max	140.44	97.10	39.27	28.09	8.63	Max	91.17	65.53	39.27	28.09	8.19

Figure 3.37 Performance of UDOT routes (left) and proposed routes (right) for Riverside

In Figure 3.37, the performance of both UDOT routes and proposed routes is showcased. Notably, the proposed routes lead to a significant reduction in turnaround time, specifically by 35.08% (reduced from 140.44 minutes to 91.17 minutes). However, there are no changes in the total travel time and deadhead miles when comparing the two route options.

3.8 Wellsville Shed

The detailed plowing information for Wellsville is provided in Figure 3.38.

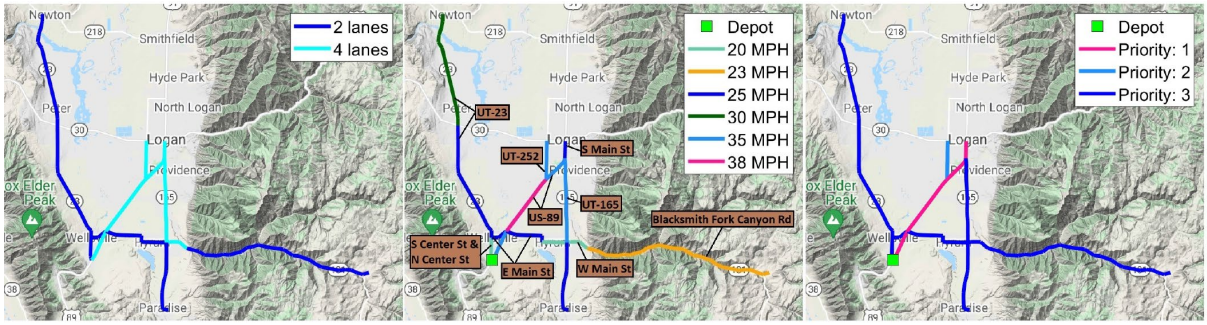


Figure 3.38 Plowing lanes, travel speed and road priorities within Wellsville

In this specific region, we began by optimizing the routes using the commonly used fleet configuration. However, during instances of heavier snowstorms, UDOT resorted to employing five trucks to carry out snow removal operations. As a result, we have proposed alternative routes that include one truck extension to address such situations. Below, we present both the UDOT routes and the proposed routes for a comprehensive comparison.

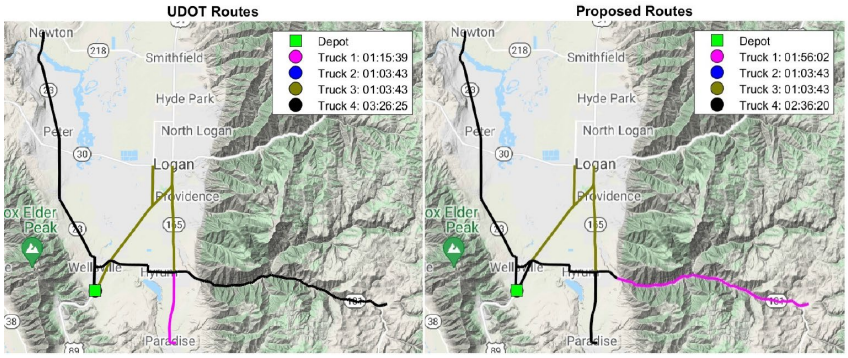


Figure 3.39 UDOT plowing routes (left) and proposed routes (right) with existing fleet configuration for Wellsville (animation: https://youtu.be/VA9zkSb4UaM)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	75.65	29.04	4.80	1.60	3.43
# 2	63.72	36.90	0	0	4.61
# 3	63.72	36.90	0	0	4.61
# 4	206.41	82.92	44.93	16.64	8.29
Total	409.50	185.76	49.73	18.24	20.94
Max	206.41	82.92	44.93	16.64	8.29

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	116.04	45.48	7.68	4.48	5.13
# 2	63.72	36.90	0	0	4.61
# 2	63.72	36.90	0	0	4.61
# 4	156.33	66.60	32.35	13.88	6.59
Total	399.81	185.88	40.03	18.36	20.94
Max	156.33	66.60	32.35	13.88	6.59

Figure 3.40 Performance of UDOT routes (left) and proposed routes with four trucks (right) for Wellsville

The performance of two sets of routes presented in Figure 3.40 shows that the proposed changes resulted in the following adjustments:

- Vehicle minutes reduced by 2.37%, from 409.50 to 399.81 vehicle minutes.
- Turnaround time reduced by 24.26%, from 206.41 to 156.33 minutes.
- Deadhead miles increased slightly by 0.65%, from 18.24 to 18.36 vehicle miles.

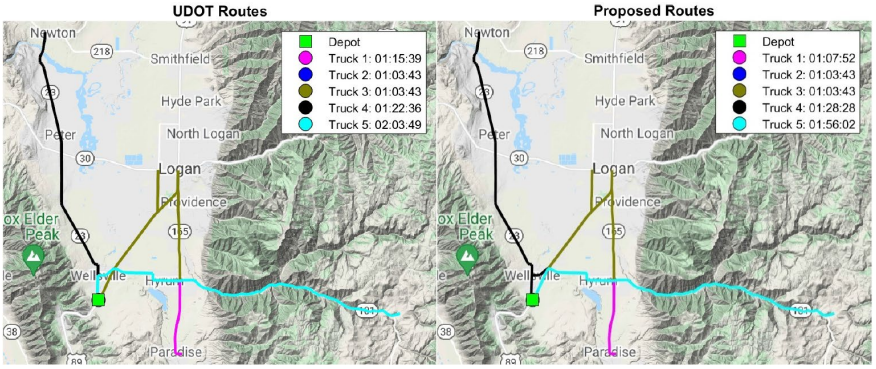


Figure 3.41 UDOT plowing routes (left) and proposed routes (right) with new fleet configuration for Wellsville (animation: https://youtu.be/NON2EUrhxMI)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	75.65	29.04	4.80	1.60	3.43
# 2	63.72	36.90	0	0	4.61
# 3	63.72	36.90	0	0	4.61
# 4	82.60	36.28	4.80	1.60	4.34
# 5	123.81	46.64	40.13	15.04	3.95
Total	409.50	185.76	49.73	18.24	20.94
Max	123.81	46.64	40.13	15.04	4.61

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	67.87	27.88	7.68	4.48	2.93
# 2	63.72	36.90	0	0	4.61
# 3	63.72	36.90	0	0	4.61
# 4	88.46	38.72	0	0	4.84
# 5	116.04	45.48	32.35	13.88	3.95
Total	399.81	185.88	40.03	18.36	20.94
Max	116.04	45.48	32.35	13.88	4.84

Figure 3.42 Performance of UDOT routes (left) and proposed routes with five trucks (right) for Wellsville

The addition of one more truck significantly reduced the turnaround time for both UDOT routes and the proposed routes. Moreover, the proposed routes achieved a remarkable 6.28% reduction in turnaround time compared to UDOT routes (see Figure 3.42). However, there were minimal changes in total travel time and deadhead miles.

3.9 Logan Shed

The detailed plowing information for Logan is provided in Figure 3.43. To maintain a desirable service level, the region is divided into two parts, north Logan and south Logan.

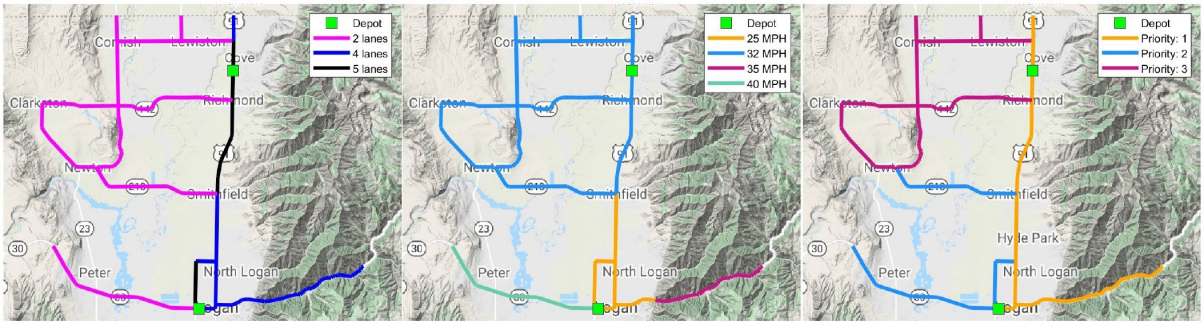


Figure 3.43 Plowing lanes, travel speed and road priorities within Logan

The UDOT routes and proposed routes for north Logan and south Logan are presented as follows.

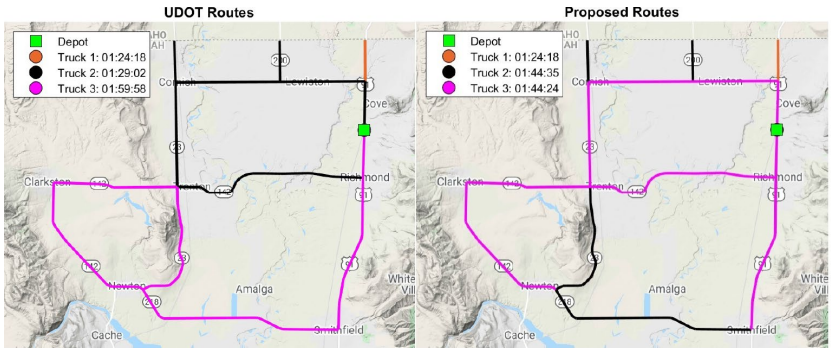


Figure 3.44 UDOT plowing routes (left) and proposed routes (right) for north Logan (animation: https://youtu.be/BhgK-38UUiY)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
#1	84.30	44.96	0	0	5.62
#2	89.03	47.48	3.45	1.84	5.71
#3	119.96	63.98	14.66	7.82	7.02
Total	293.29	156.42	18.11	9.66	18.35
Max	119.96	63.98	14.66	7.82	7.02

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
#1	84.30	44.96	11.21	5.98	4.88
#2	104.59	55.78	3.45	1.84	6.74
#3	104.40	55.68	3.45	1.84	6.73
Total	293.29	156.42	18.11	9.66	18.35
Max	104.59	55.78	11.21	5.98	6.74

Figure 3.45 Performance of UDOT routes (left) and proposed routes (right) for north Logan

Compared with the efficiency of UDOT routes shown in Figure 3.45, the proposed routes reduce turnaround time by 12.8%, decreasing from 119.96 minutes to 104.59 minutes while maintaining vehicle minutes and deadhead miles unchanged.

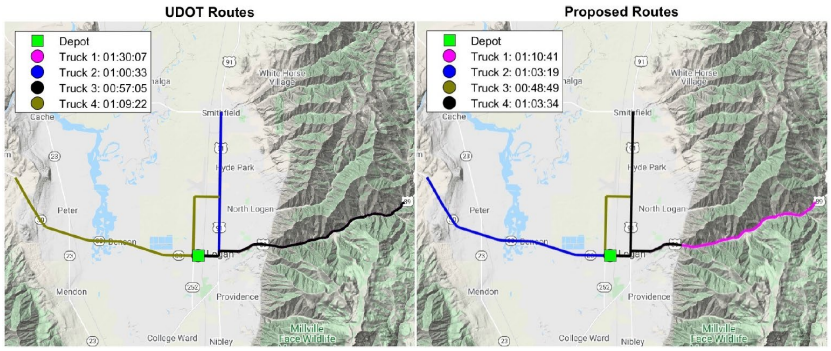


Figure 3.46 UDOT plowing routes (left) and proposed routes (right) for south Logan (animation: https://youtu.be/dOhfWiPWsZo)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
#1	90.12	41.99	21.60	9.00	4.12
#2	60.55	25.23	0	0	3.15
#3	57.09	28.23	8.84	3.68	3.07
#4	69.37	37.08	7.03	2.93	4.27
Total	277.13	132.52	37.47	15.61	14.61
Max	90.12	41.99	21.60	9.00	4.27

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
#1	70.96	38.45	0	0	4.81
#2	63.32	34.56	7.03	2.93	3.95
#3	48.82	20.34	0	0	2.54
#4	63.57	26.49	0	0	3.31
Total	246.67	119.84	7.03	2.93	14.61
Max	70.96	38.45	7.03	2.93	4.81

Figure 3.47 Performance of UDOT routes (left) and proposed routes (right) for south Logan

The proposed routes have brought about substantial improvements over UDOT routes. Specifically, the turnaround time has been significantly reduced by 21.2%, resulting in a decrease from 90.12 minutes to 70.96 minutes. Moreover, vehicle minutes has been optimized by 10.9%, showing a reduction from 277.13 to 246.67 vehicle minutes. Additionally, the implementation of the proposed routes has led to a remarkable reduction of 81.2% in deadhead miles, reducing that distance from 15.61 miles to 2.93 miles.

In addition to optimizing the plowing routes to enhance the overall service level, the local manager aims to improve the efficiency of snow removal on high-traffic roadways, such as US-91 in this region. To achieve this, we propose the implementation of echelon routes, and below, we present the performance of these routes. This approach seeks to further enhance the effectiveness of snow removal operations, particularly on busy roadways to reduce traffic delay.

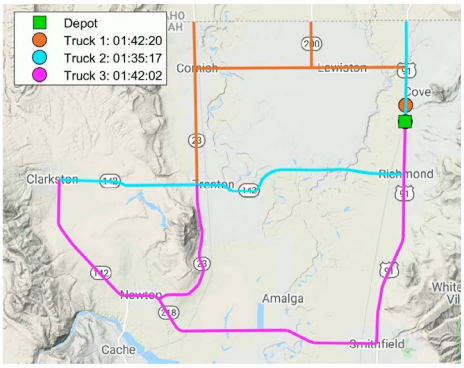


Figure 3.48 Proposed two-truck echelon routes along US-91 within north Logan (animation: https://youtu.be/XFl40J2P8Xs)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
#1	102.86	54.86	3.45	1.84	6.63
#2	95.29	50.82	6.90	3.68	5.89
#3	102.04	54.42	14.66	7.82	5.83
Total	300.19	160.10	25.01	13.34	18.35
Max	102.86	54.86	14.66	7.82	6.63

Figure 3.49 Performance of proposed two-truck echelon routes along US-91 within north Logan

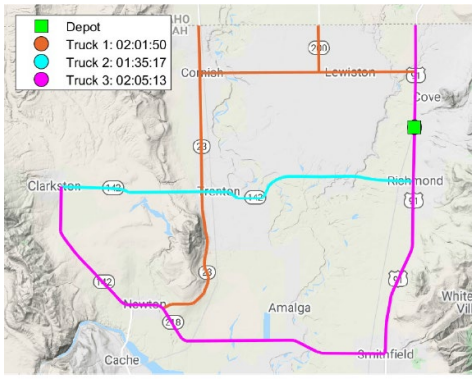


Figure 3.50 Proposed three-truck echelon routes along US-91 within north Logan (animation: https://youtu.be/jv0mpHp21QE)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
#1	121.84	64.98	30.94	16.50	6.07
#2	95.29	50.82	6.90	3.68	5.89
#3	125.21	66.78	29.33	15.64	6.39
Total	342.34	182.58	67.17	35.82	18.35
Max	125.21	66.78	30.94	16.50	6.39

Figure 3.51 Performance of proposed three-truck echelon routes along US-91 within north Logan

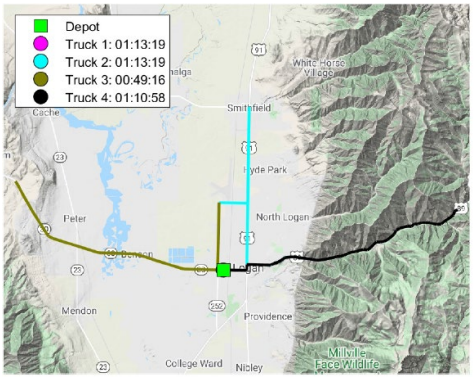


Figure 3.52 Proposed two-truck echelon routes along US-91 within south Logan (animation: https://youtu.be/_ZGcAd7yxRA)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
#1	73.32	30.55	6.38	2.66	3.48
#2	73.32	30.55	9.53	3.97	3.32
#3	49.26	28.70	0	0	3.59
#4	70.96	38.45	11.30	4.71	4.22
Total	266.86	128.84	27.21	11.34	14.61
Max	73.32	38.45	11.30	4.71	4.22

Figure 3.53 Performance of proposed two-truck echelon routes along US-91 within south Logan

3.10 Laketown Shed

The detailed plowing information for Laketown is provided in Figure 3.54.

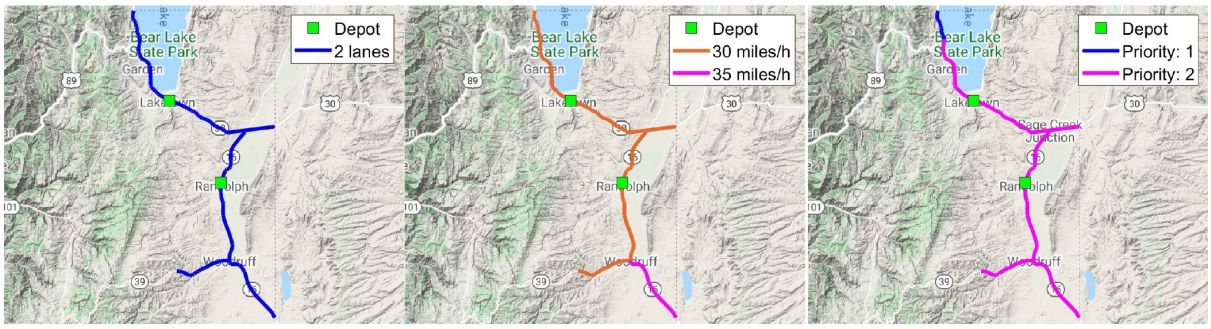


Figure 3.54 Plowing lanes, travel speed and road priorities within Laketown

The UDOT routes and proposed routes as well as performance are presented as follows.

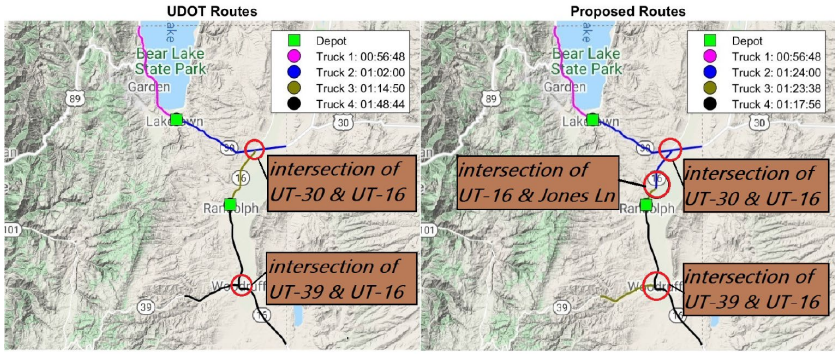


Figure 3.55 UDOT plowing routes (left) and proposed routes (right) for Laketown (animation: https://youtu.be/avGqgboAR50)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	56.80	28.40	0	0	3.55
# 2	62.00	31.00	0	0	3.88
# 3	74.84	37.42	21.14	10.57	3.36
# 4	108.74	57.34	21.14	10.57	5.85
Total	302.38	154.16	42.28	21.14	16.64
Max	108.74	57.34	21.14	10.57	5.85

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	56.80	28.40	0	0	3.55
# 2	84.00	42.00	0	0	5.26
# 3	83.64	41.82	42.28	21.14	2.59
# 4	77.94	41.94	0	0	5.24
Total	302.38	154.16	42.28	21.14	16.64
Max	84.00	42.00	42.28	21.14	5.26

Figure 3.56 Performance of UDOT plowing routes (left) and proposed routes (right) for Laketown

The proposed routes have led to notable improvements in the turnaround time, which has been significantly reduced by 23% while there are no changes in vehicle minutes in and deadhead miles (see Figure 3.56). This reduction has resulted in a decrease from 108.74 minutes to 84 minutes, allowing for quicker completion of snow removal operations and improved response time to weather events.

3.11 Ogden Shed

The responsible roadways within Ogden are divided into six groups and the detailed plowing information for each group is provided in Figures 3.57-3.62.

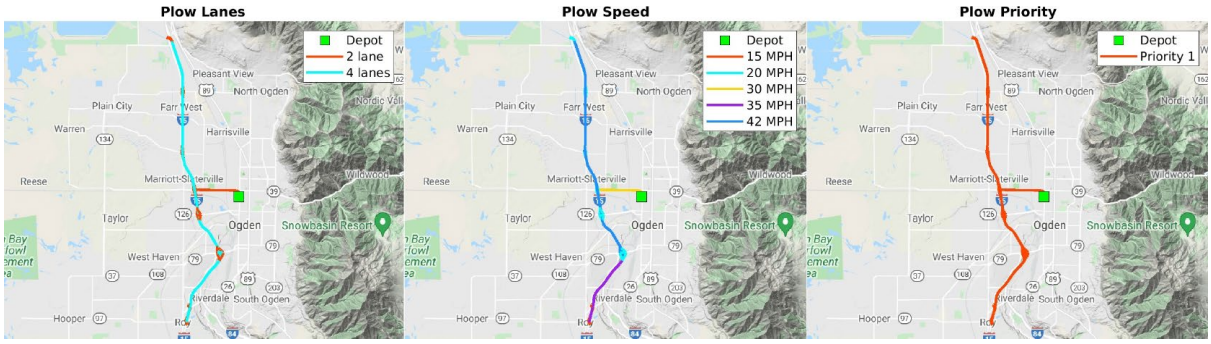


Figure 3.57 Plowing Lanes, travel speed, road priorities in group 1 within Ogden

Figure 3.58 Plowing Lanes, travel speed, road priorities in group 2 within Ogden

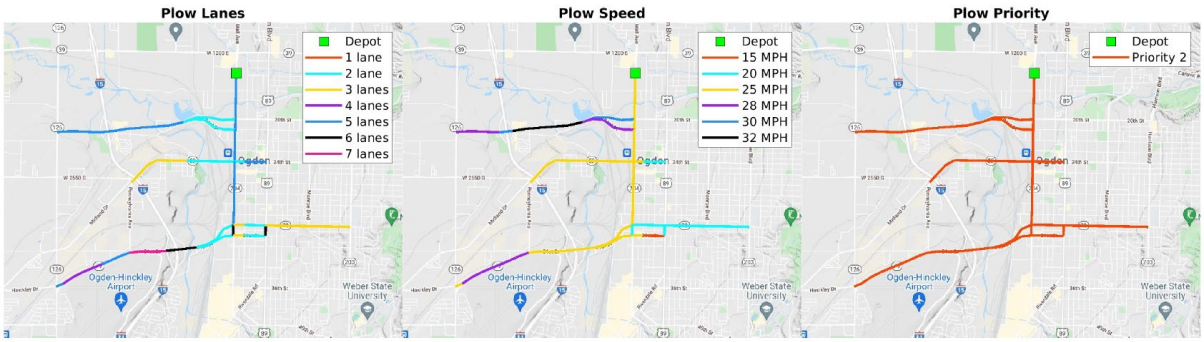


Figure 3.59 Plowing Lanes, travel speed, road priorities in group 3 within Ogden

Figure 3.60 Plowing Lanes, travel speed, road priorities in group 4 within Ogden

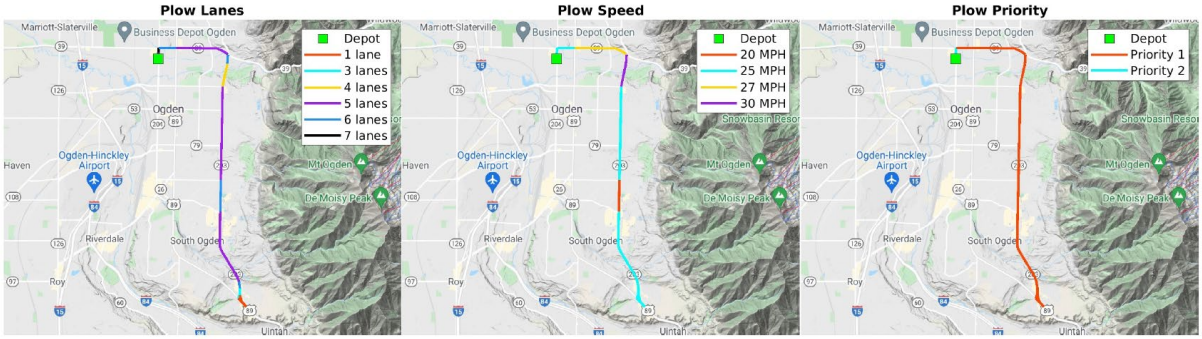


Figure 3.61 Plowing Lanes, travel speed, road priorities in group 5 within Ogden

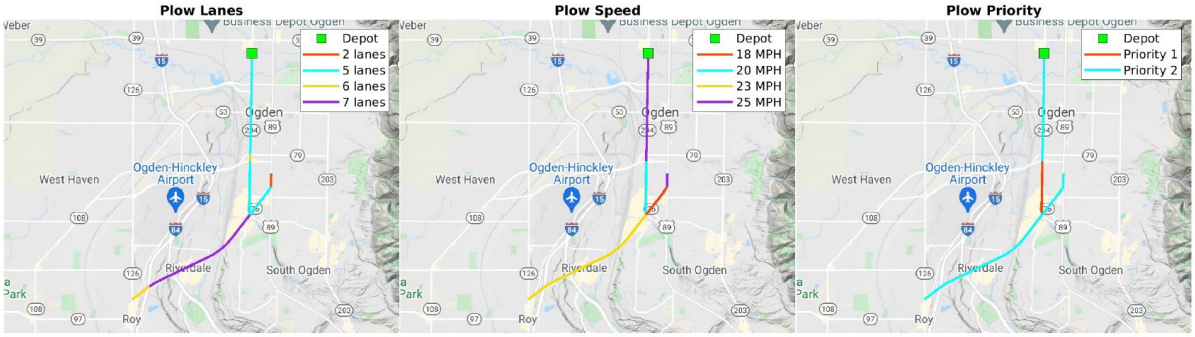


Figure 3.62 Plowing Lanes, travel speed, road priorities in group 6 within Ogden

Among the six groups, we optimized the plowing routes for two groups (group 3 and group 5), while maintaining the existing routes for the remaining groups, as UDOT routes are already considered highly efficient. The specific details of both UDOT routes and proposed routes are presented below.

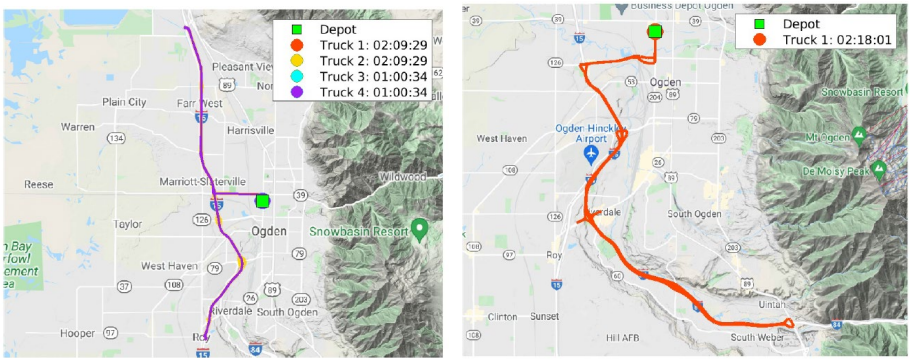


Figure 3.63 UDOT plowing routes for group 1 (left), group 2 (middle) and group 4 (right) (Animation: https://youtu.be/tuDKJwQ1vcg; https://youtu.be/ItlHGFShIHs)

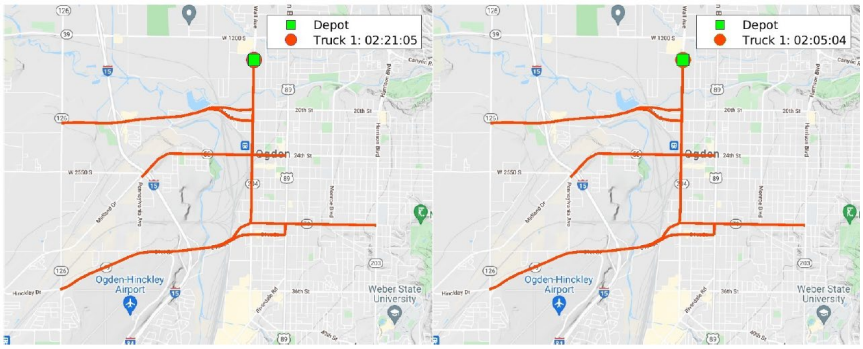


Figure 3.64 UDOT plowing routes (left) and proposed routes (right) for group 3 (animation: https://youtu.be/5dG2EtTJjPg)

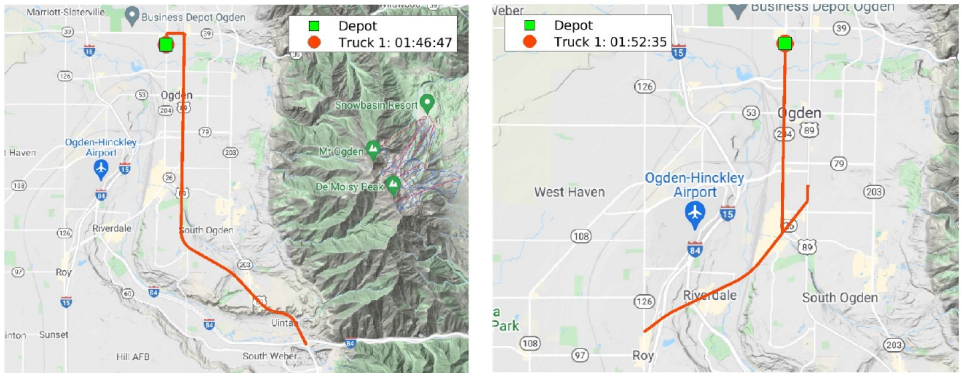


Figure 3.65 UDOT plowing routes for group 4 (left) and group 6 (right) (animation: https://youtu.be/KzaDzHUn1M8; https://youtu.be/wwdKOz9FQIA)

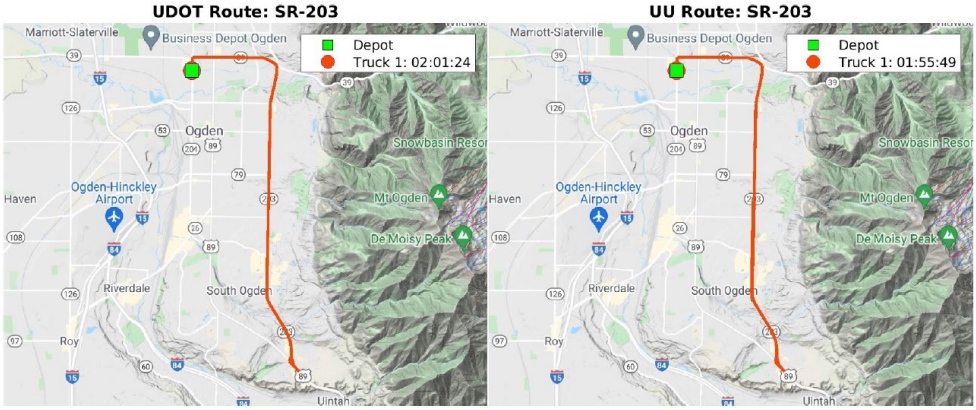


Figure 3.66 UDOT plowing routes (left) and proposed routes (right) for group 5 (animation: https://youtu.be/uUvWl3K1ybA)

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
Group 1					
1	129.49	70.10	55.56	30.99	4.89
2	129.49	70.10	64.35	35.39	4.34
3	60.57	35.70	21.58	9.62	3.26
4	60.57	35.70	21.58	9.62	3.26
Total	380.12	211.60	163.07	85.62	15.75
Max	129.49	70.10	64.35	35.39	4.89
Group 2					
1	138.01	71.06	25.33	12.74	7.29
Total	138.01	71.06	25.33	12.74	7.29
Max	138.01	71.06	25.33	12.74	7.29
Group 3					
1	141.09	59.12	28.69	13.01	5.76
Total	141.09	59.12	28.69	13.01	5.76
Max	141.09	59.12	28.69	13.01	5.76
Group 4					
1	106.79	38.85	0.00	0.00	4.86
Total	106.79	38.85	0.00	0.00	4.86
Max	106.79	38.85	0.00	0.00	4.86
Group 5					
1	121.40	50.78	18.96	9.18	5.20
Total	121.40	50.78	18.96	9.18	5.20
Max	121.40	50.78	18.96	9.18	5.20
Group 6					
1	112.58	40.87	16.62	6.06	4.35
Total	112.58	40.87	16.62	6.06	4.35
Max	112.58	40.87	16.62	6.06	4.35

Truck No.	Duration (mins)	Distance (miles)	Deadhead (mins)	Deadhead (miles)	Salt (tons)
Group 1					
1	129.49	70.10	55.56	30.99	4.89
2	129.49	70.10	64.35	35.39	4.34
3	60.57	35.70	21.58	9.62	3.26
4	60.57	35.70	21.58	9.62	3.26
Total	380.12	211.60	163.07	85.62	15.75
Max	129.49	70.10	64.35	35.39	4.89
Group 2					
1	138.01	71.06	25.33	12.74	7.29
Total	138.01	71.06	25.33	12.74	7.29
Max	138.01	71.06	25.33	12.74	7.29
Group 3					
1	125.06	53.02	19.47	6.91	5.76
Total	125.06	53.02	19.47	6.91	5.76
Max	125.06	53.02	19.47	6.91	5.76
Group 4					
1	106.79	38.85	0.00	0.00	4.86
Total	106.79	38.85	0.00	0.00	4.86
Max	106.79	38.85	0.00	0.00	4.86
Group 5					
1	115.81	48.27	16.38	6.67	5.20
Total	115.81	48.27	16.38	6.67	5.20
Max	115.81	48.27	16.38	6.67	5.20
Group 6					
1	112.58	40.87	16.62	6.06	4.35
Total	112.58	40.87	16.62	6.06	4.35
Max	112.58	40.87	16.62	6.06	4.35

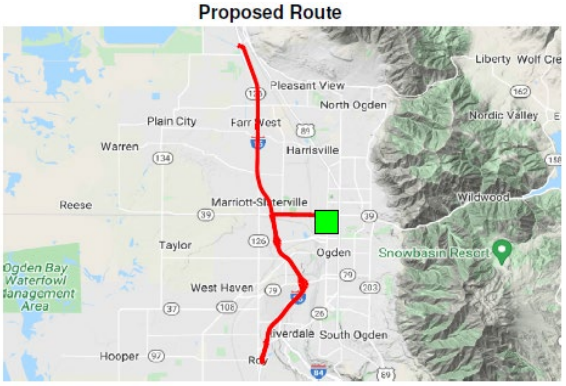
Figure 3.67 Performance of UDOT routes (left) and proposed routes with five trucks (right) for Ogden

The proposed routes have resulted in significant improvements for both group 3 and group 5 shown in Figure 3.67. In group 3, there is a remarkable reduction of 11.36% in total vehicle minutes, decreasing from 141.09 minutes to 125.06 minutes. The turnaround time has also been reduced by 11.36%, decreasing from 141.09 minutes to 125.06 minutes. Additionally, deadhead miles have experienced a substantial decrease of 46.89%, going from 13.01 miles to 6.91 miles. Similarly, in group 5, the proposed route for one truck has led to a reduction of 4.60% in total vehicle minutes, decreasing from 121.40 minutes to 115.81 minutes. Furthermore, deadhead miles have significantly decreased by 27.34%, going from 9.18 miles to 6.67 miles. These improvements highlight the efficiency gains achieved by the proposed routes in optimizing vehicle minutes, turnaround time, and deadhead miles for both groups, ensuring more effective snow removal operations and enhanced traffic flow in those regions.

4. PROPOSED ROUTING DIAGRAMS

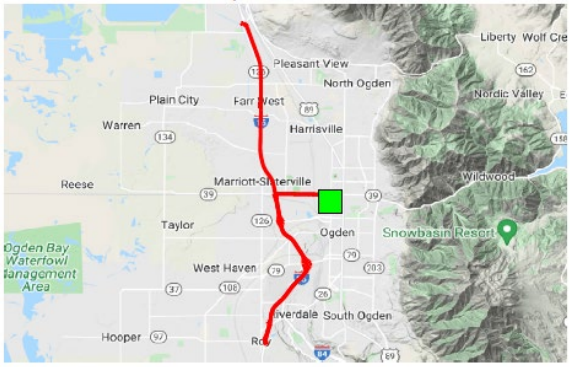
Ogden

Proposed Route



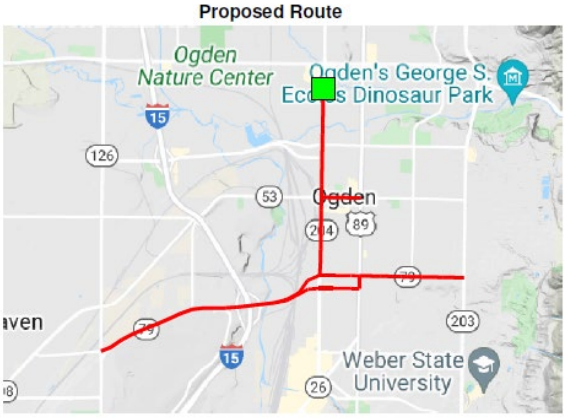
Depot — Ogden Route 1

Proposed Route



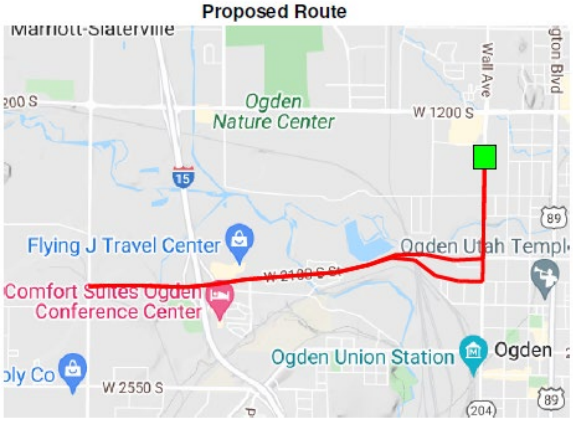
Depot — Ogden Route 2

Proposed Route



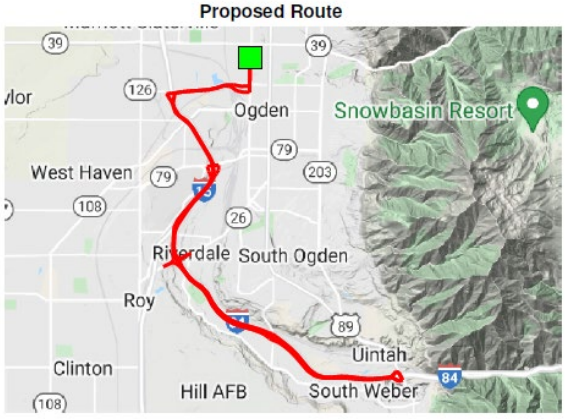
Depot — Ogden Route 3

Proposed Route



Depot — Ogden Route 4

Proposed Route

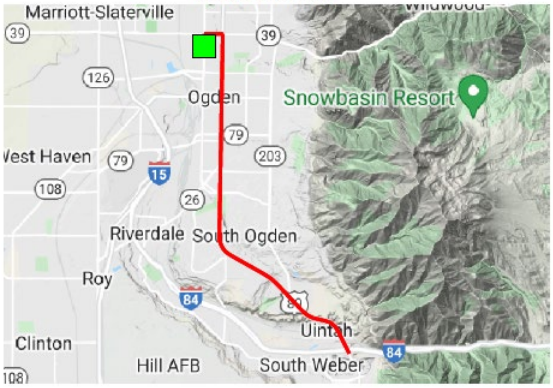


Depot — Ogden Route 5

Proposed Route

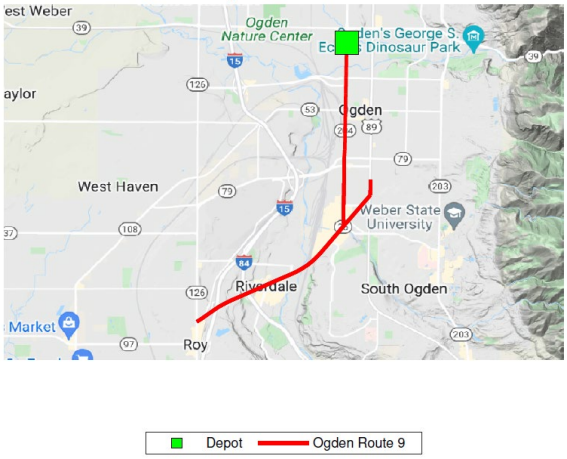
Depot — Ogden Route 6

Proposed Route



Proposed Route

Proposed Route

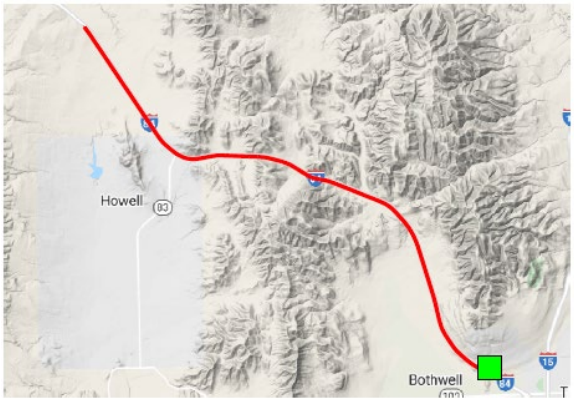


Bothwell

Proposed Route

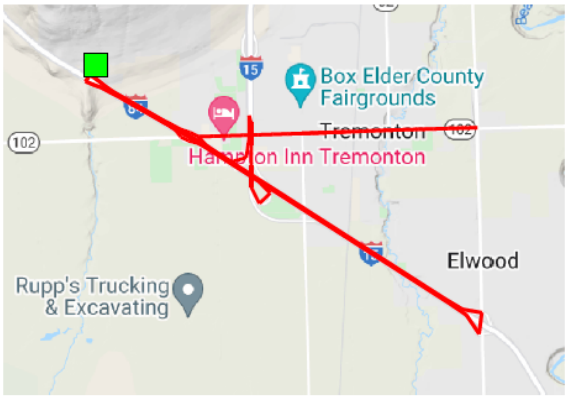
Depot — Bothwell Route 1

Proposed Route



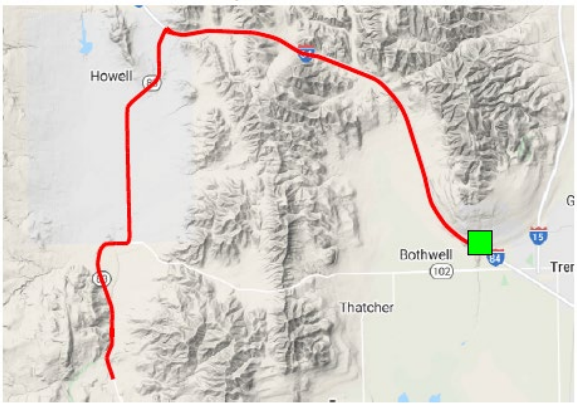
Depot — Bothwell Route 2

Proposed Route



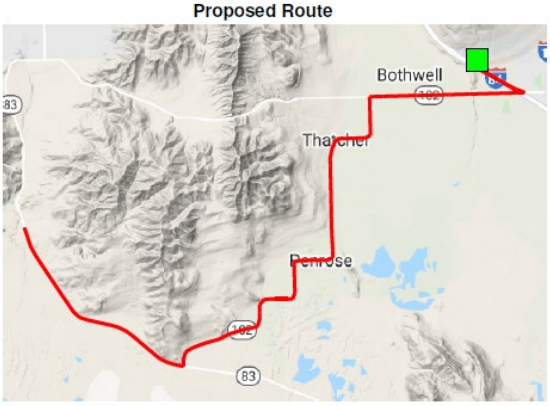
Depot — Bothwell Route 3

Proposed Route



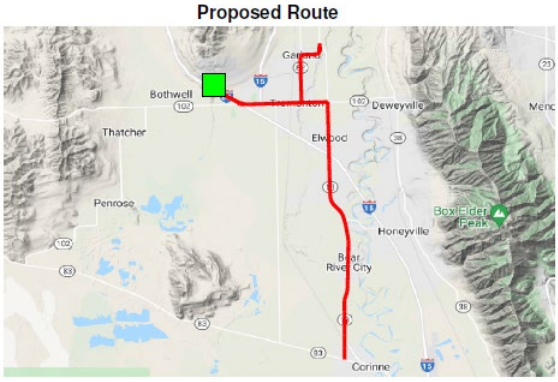
Depot — Bothwell Route 4

Proposed Route



Depot — Bothwell Route 5

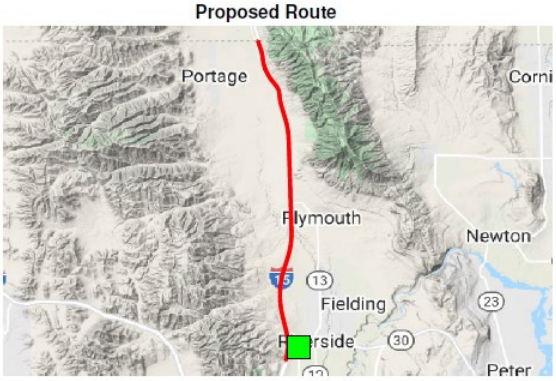
Proposed Route



Depot — Bothwell Route 6

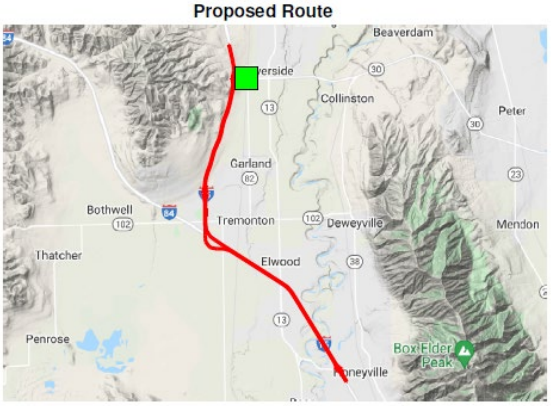
Riverside

Proposed Route



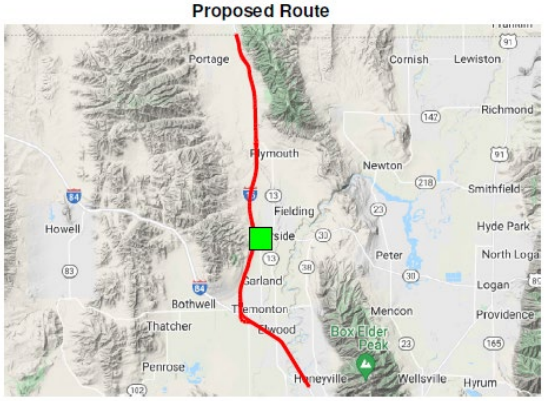
Depot — Riverside Route 1

Proposed Route



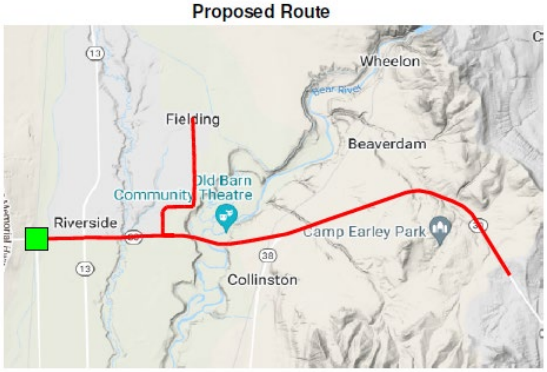
Depot — Riverside Route 2

Proposed Route



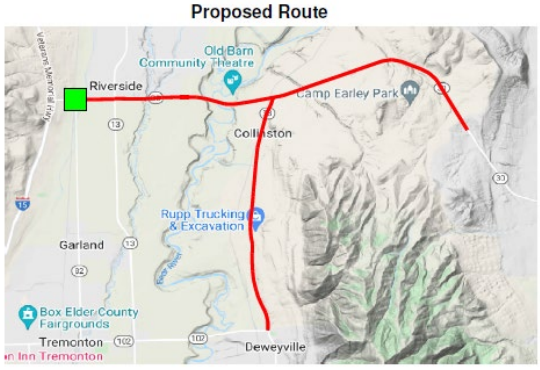
Depot — Riverside Route 3

Proposed Route



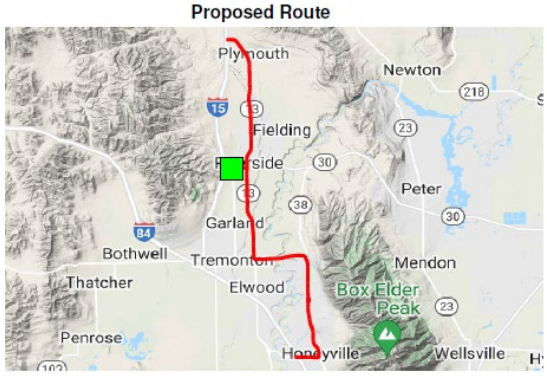
Depot — Riverside Route 4

Proposed Route



Depot — Riverside Route 5

Proposed Route



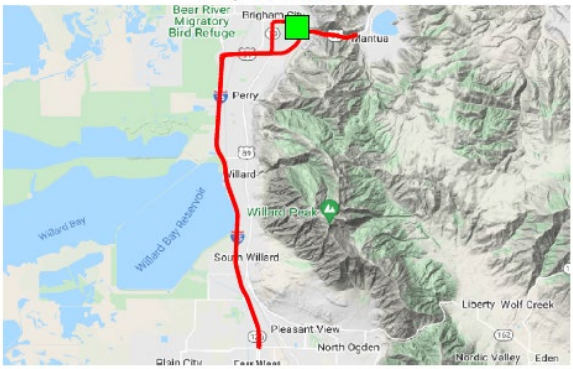
Depot — Riverside Route 6

Brigham City

Proposed Route

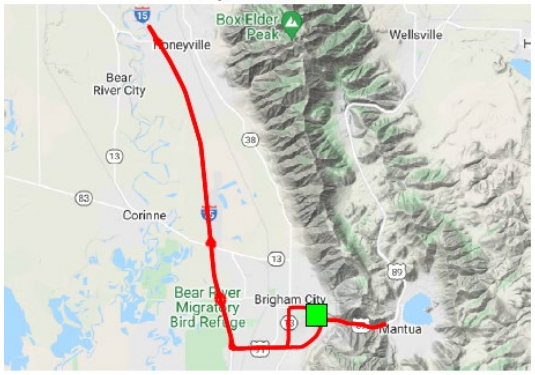
Depot — BrighamCity Route 1

Proposed Route



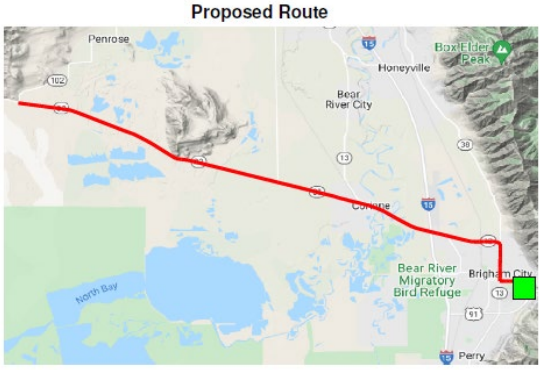
Depot — BrighamCity Route 2

Proposed Route



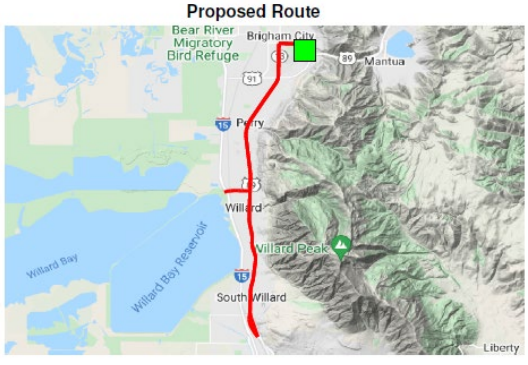
Depot — BrighamCity Route 3

Proposed Route



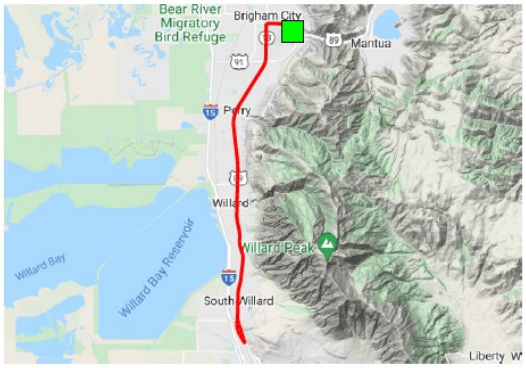
Depot — BrighamCity Route 4

Proposed Route



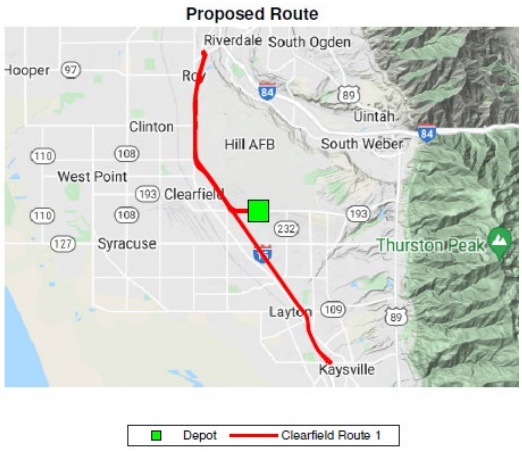
Depot — BrighamCity Route 5

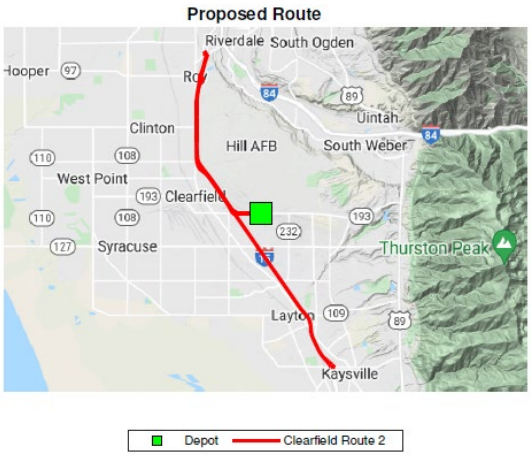
Proposed Route

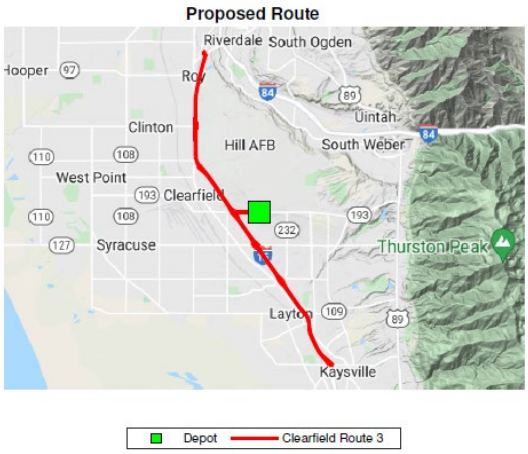


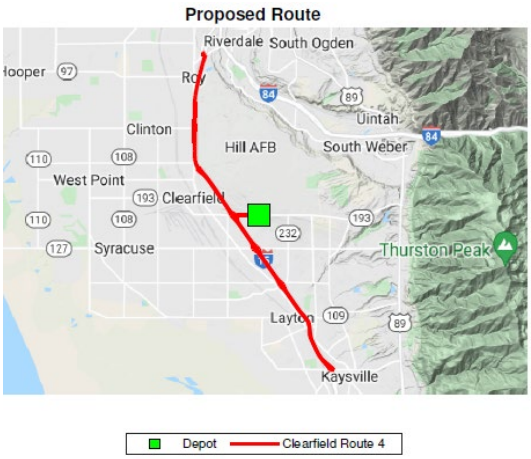
Depot — BrighamCity Route 6

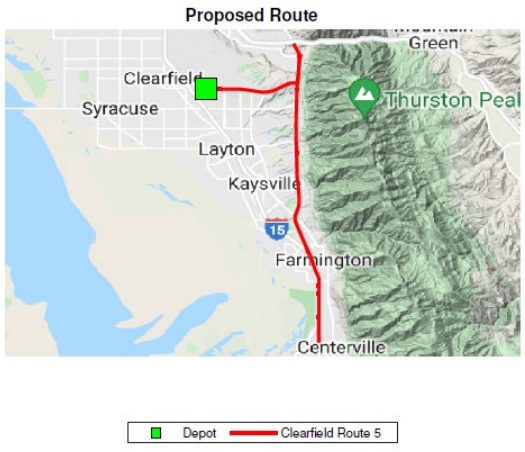
Clearfield

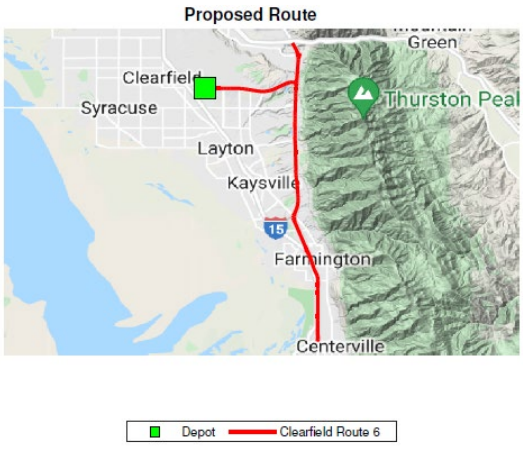

Proposed Route
Riverdale
South Ogden
Hooper
Roy
Clinton
Hill AFB
Uintah
South Weber
West Point
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Depot
Clearfield Route 1


Proposed Route
Riverdale
South Ogden
Hooper
Roy
Clinton
Hill AFB
Uintah
South Weber
West Point
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Depot
Clearfield Route 2

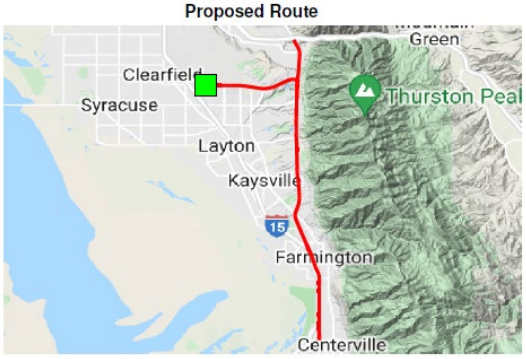

Proposed Route
Riverdale
South Ogden
Hooper
Roy
Clinton
Hill AFB
Uintah
South Weber
West Point
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Depot
Clearfield Route 3


Proposed Route
Riverdale
South Ogden
Hooper
Roy
Clinton
Hill AFB
Uintah
South Weber
West Point
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Depot
Clearfield Route 4


Proposed Route
Green
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Farmington
Centerville
Depot
Clearfield Route 5

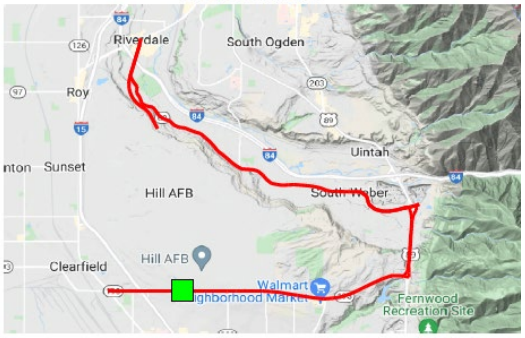

Proposed Route
Green
Clearfield
Syracuse
Thurston Peak
Layton
Kaysville
Farmington
Centerville
Depot
Clearfield Route 6

Proposed Route



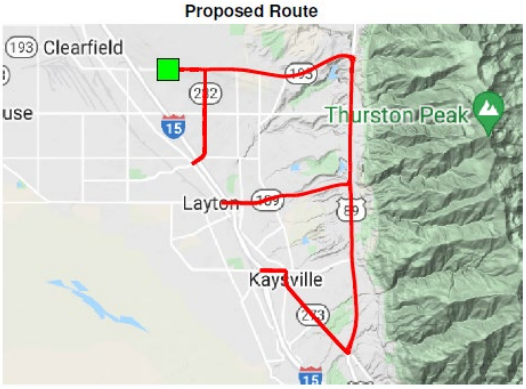
Depot — Clearfield Route 7

Proposed Route



Depot — Clearfield Route 8

Proposed Route



Depot — Clearfield Route 9

Morgan

Proposed Route

Depot — Morgan Route 3

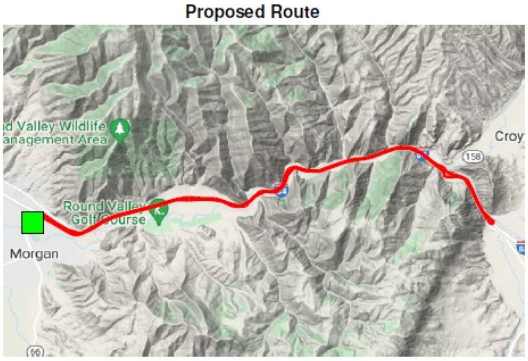
Proposed Route

Depot — Morgan Route 1

Proposed Route

Depot — Morgan Route 2

Proposed Route

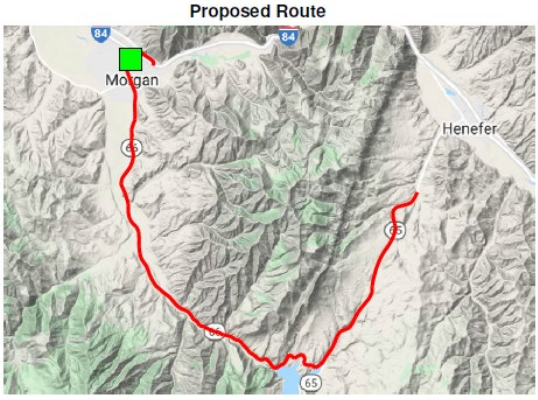


Depot — Morgan Route 4

Proposed Route

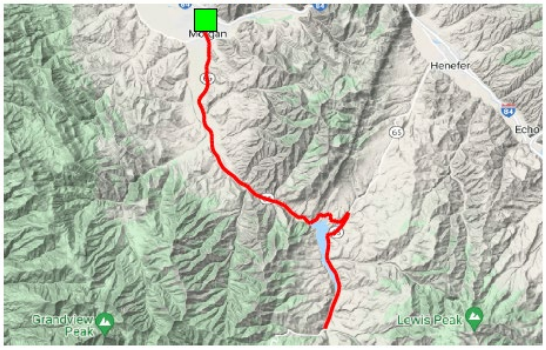
Depot — Morgan Route 5

Proposed Route



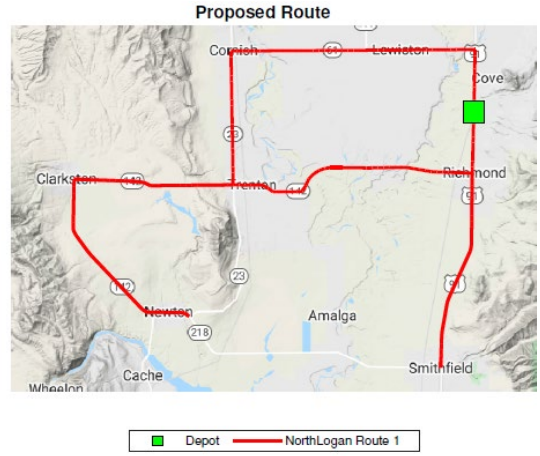
Depot — Morgan Route 6

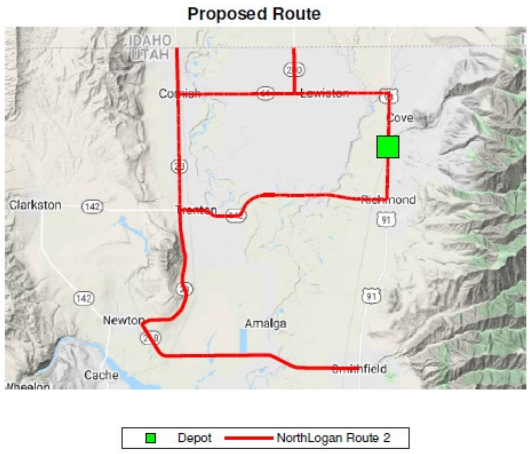
Proposed Route



Depot — Morgan Route 7

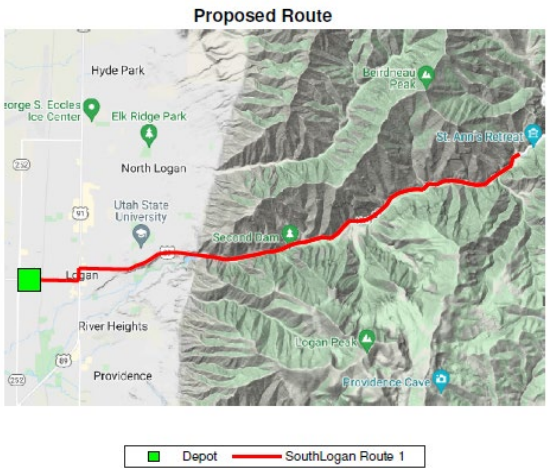
North Logan

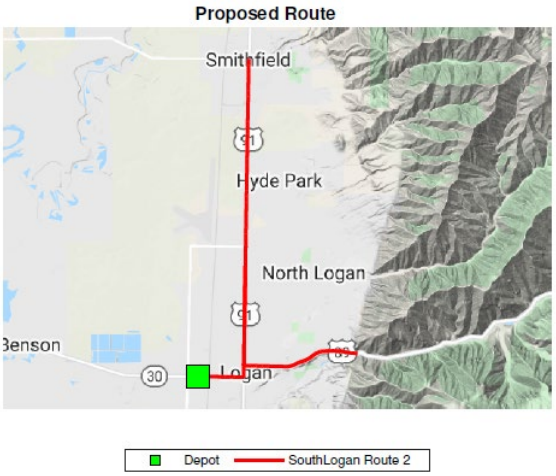

Proposed Route
Cornish
Lewiston
Cove
Clarkston
Trenton
Richmond
Newton
Amalga
Cache
Smithfield
Depot
NorthLogan Route 1

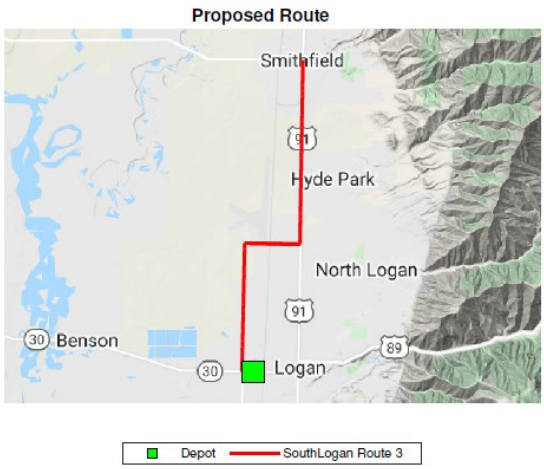

Proposed Route
IDAHO
UTAH
Cornish
Lewiston
Cove
Clarkston
Trenton
Richmond
Newton
Amalga
Cache
Smithfield
Depot
NorthLogan Route 2

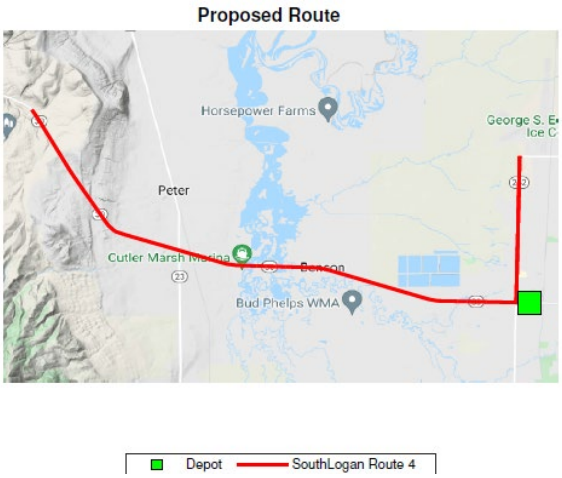

Proposed Route
IDAHO
UTAH
Cornish
Lewiston
Cove
Trenton
Richmond
Amalga
Smithfield
Depot
NorthLogan Route 3

South Logan


Proposed Route
Hyde Park
Elk Ridge Park
North Logan
Utah State University
Logan
River Heights
Providence
Depot
SouthLogan Route 1

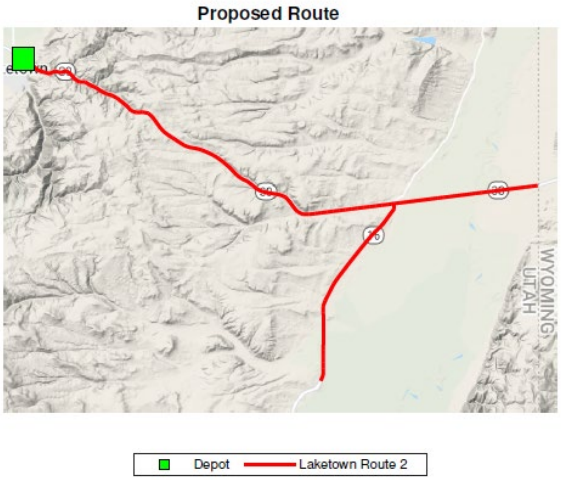

Proposed Route
Smithfield
Hyde Park
North Logan
Logan
Depot
SouthLogan Route 2

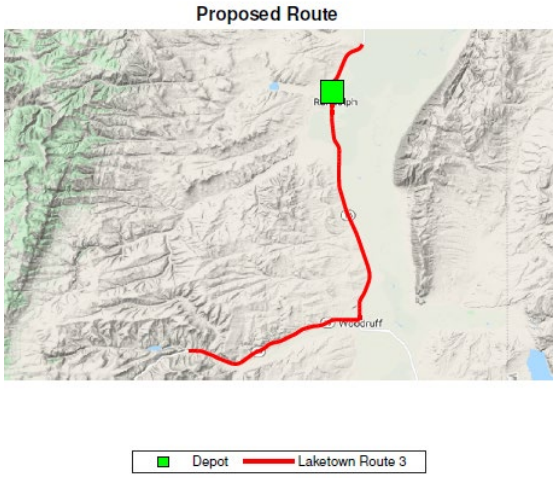

Proposed Route
Smithfield
Hyde Park
North Logan
Benson
Logan
Depot
SouthLogan Route 3

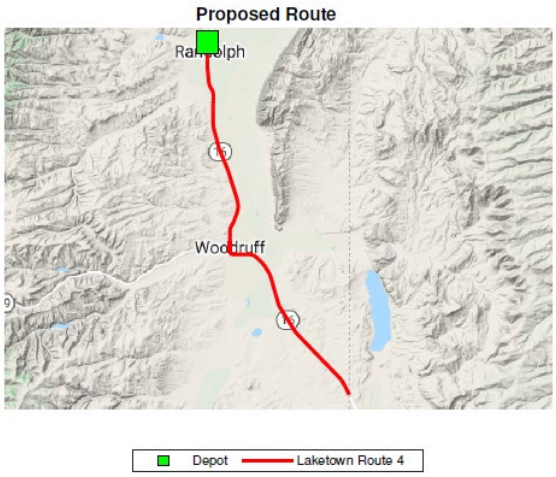

Proposed Route
Horsepower Farms
Peter
Bud Phelps WMA
Depot
SouthLogan Route 4

Laketown


Proposed Route
IDAHO
UTAH
Bear Lake
Garden City
Bear Lake
State Park
Garden
Depot
Laketown Route 1


Proposed Route
WYOMING
UTAH
Depot
Laketown Route 2


Proposed Route
Depot
Laketown Route 3


Proposed Route
Woodruff
Depot
Laketown Route 4

Huntsville

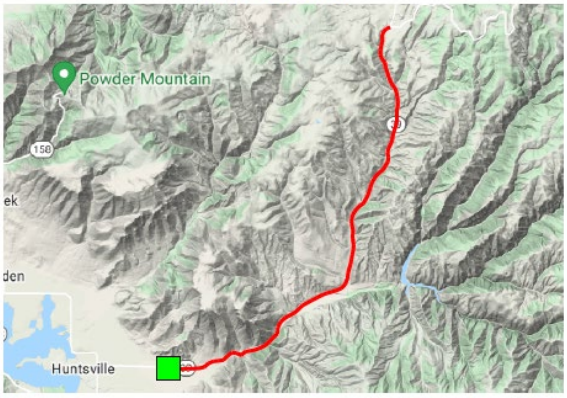
Proposed Route

Depot — Huntsville Route 1

Proposed Route

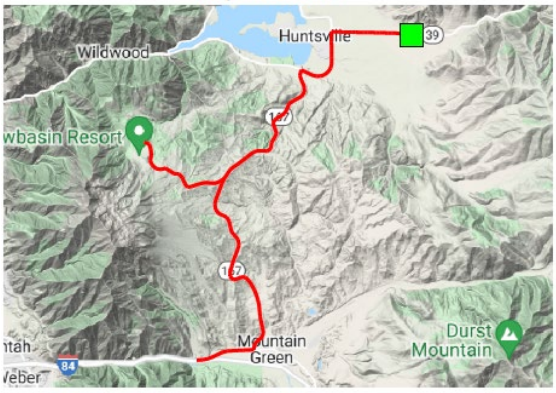
Depot — Huntsville Route 2

Proposed Route



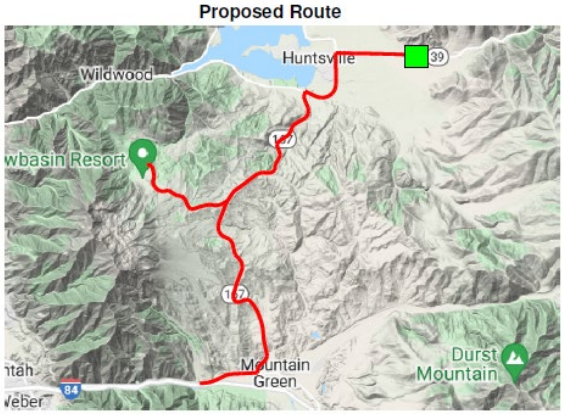
Depot — Huntsville Route 3

Proposed Route



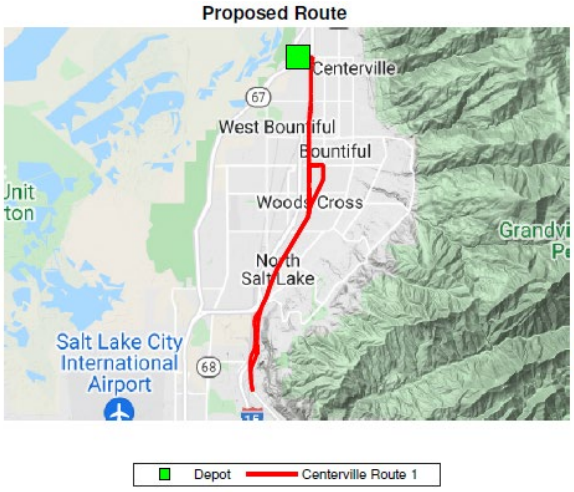
Depot — Huntsville Route 4

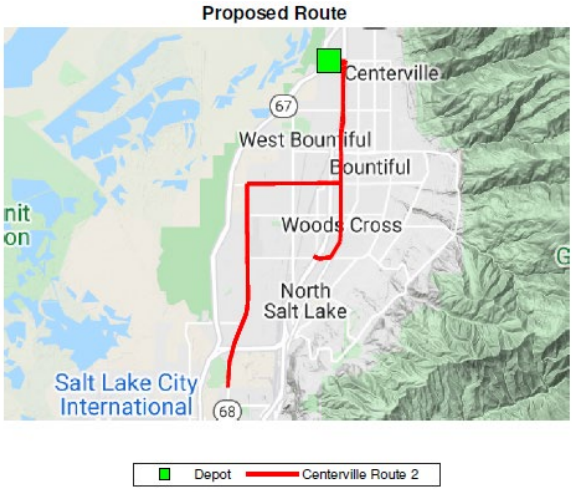
Proposed Route

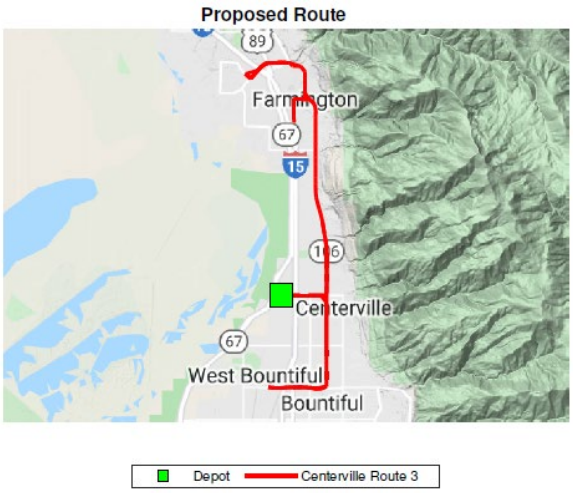


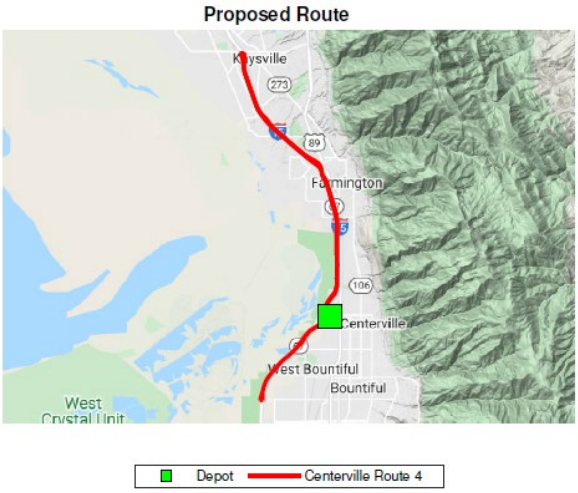
Depot — Huntsville Route 5

Centerville

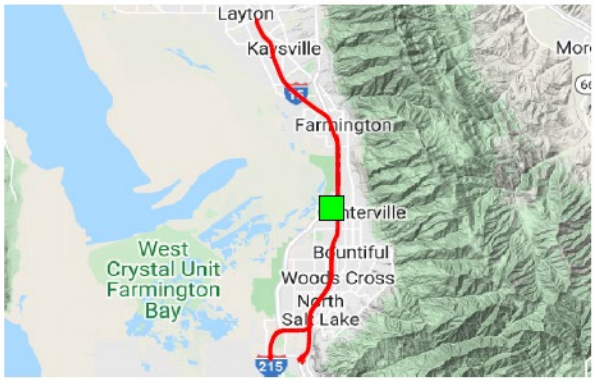






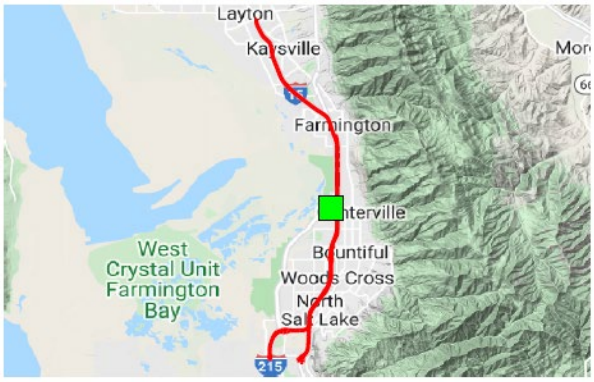


Proposed Route



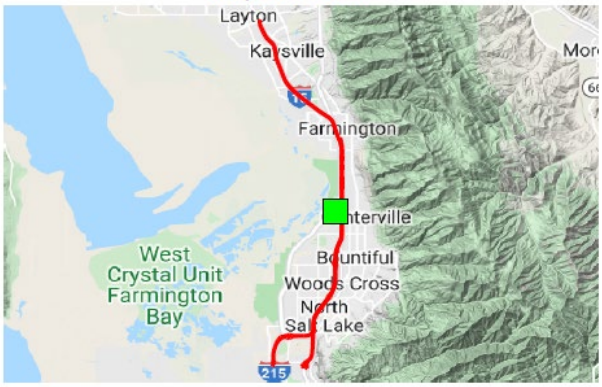
Depot — Centerville Route 7

Proposed Route



Depot — Centerville Route 8

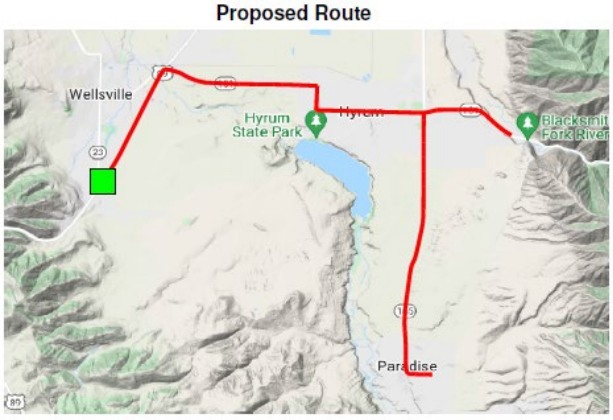
Proposed Route



Depot — Centerville Route 9

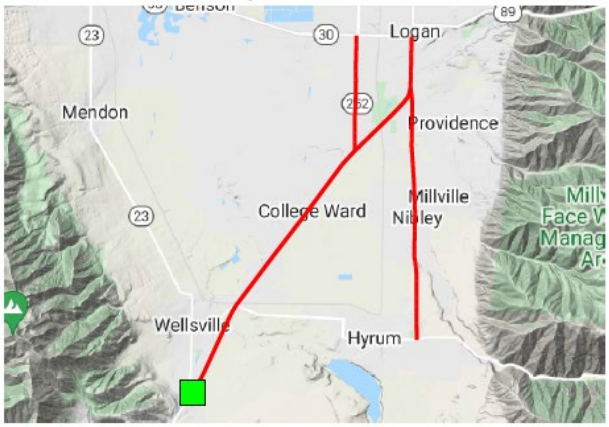
Wellsville

Proposed Route



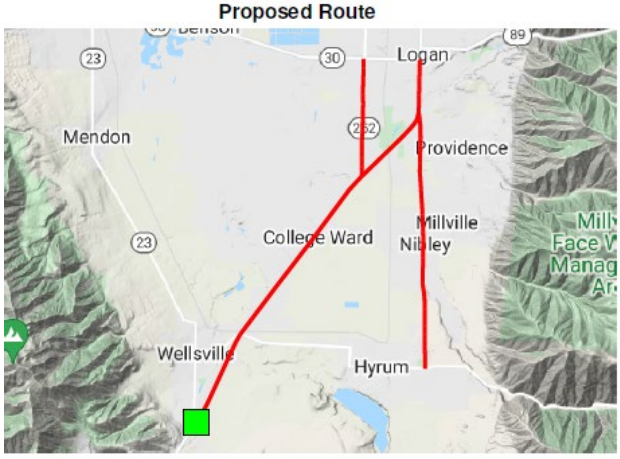
Depot — Wellsville Route 1

Proposed Route



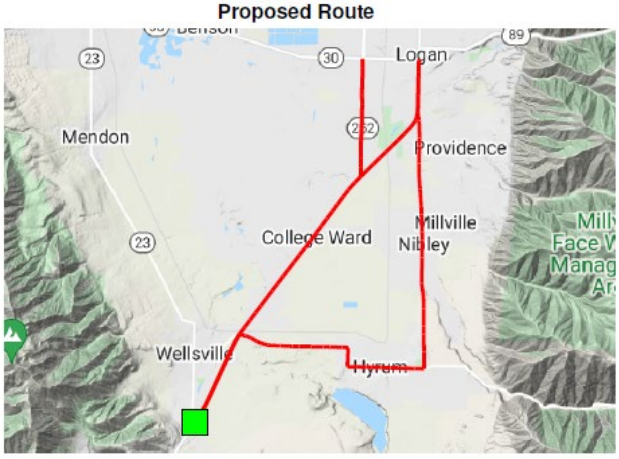
Depot — Wellsville Route 2

Proposed Route



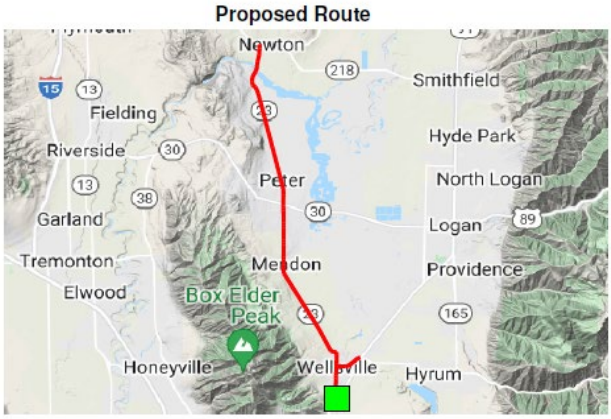
Depot — Wellsville Route 3

Proposed Route



Depot — Wellsville Route 4

Proposed Route



Depot — Wellsville Route 5

Proposed Route

Depot — Wellsville Route 6

5. APPENDIX

The Appendix includes plowing routes for regions where the road network is relatively simple or for some regions with newly assigned plowing roadways.

5.1 Snowville Shed

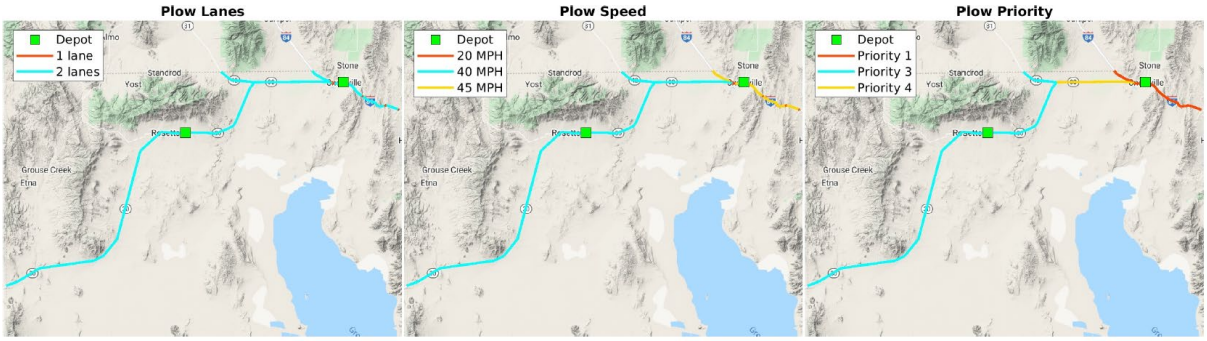


Figure 5.1 Plowing Lanes, travel speed, road priorities within Snowville

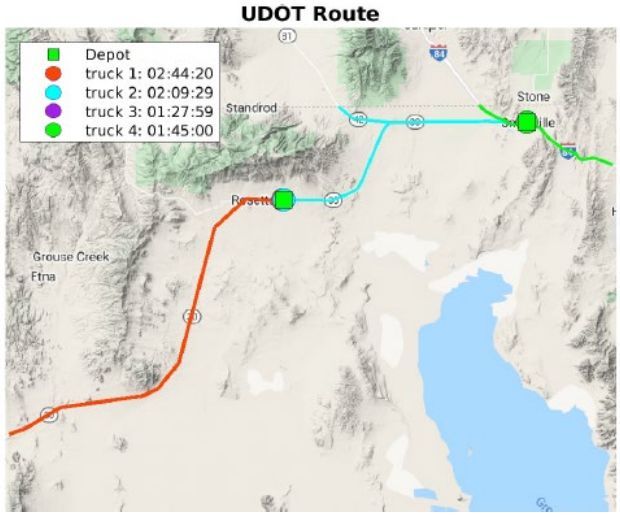


Figure 5.2 UDOT plowing routes (animation: https://youtu.be/O7WuDVgQLs8)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	164.42	109.61	0	0	13.70
# 2	129.48	86.32	0	0	10.79
# 3	87.98	58.51	21.13	13.89	5.58
# 4	105.46	70.95	41.09	27.17	5.47
Total	487.34	325.39	62.22	41.06	35.54
Max	164.42	109.61	41.09	27.17	13.7

Figure 5.3 Performance of UDOT plowing routes for Snowville

5.2 Paint Shed

Figure 5.4 Plowing Lanes, travel speed, road priorities within Paint

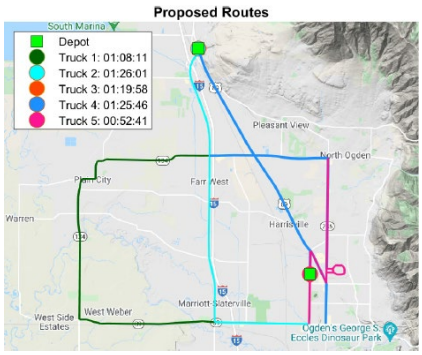


Figure 5.5 Proposed plowing routes for Paint (animation: https://youtu.be/rhCsKgMmJ2w)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	(miles)	Salt (tons)
# 1	68.18	31.04	3.37	1.38	3.71
# 2	86.01	43.25	16.08	8.33	4.37
# 3	79.96	39.46	8.21	4.24	4.40
# 4	85.76	42.86	28.86	14.01	3.61
# 5	52.68	21.40	6.97	2.69	2.34
Total	372.59	178.01	63.49	30.65	18.43
Max	86.01	43.25	28.86	14.01	4.40

Figure 5.6 Performance of proposed plowing routes for Paint

5.3 Logan Summit Shed

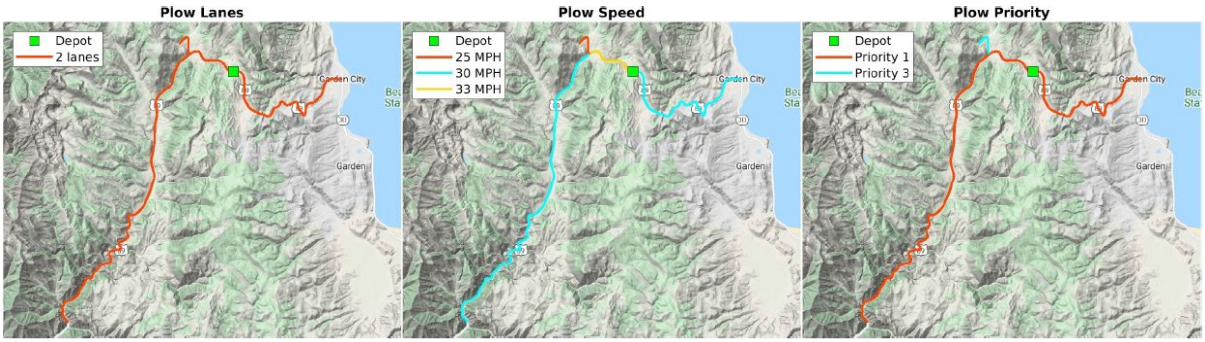


Figure 5.7 Plowing Lanes, travel speed, road priorities within Logan Summit

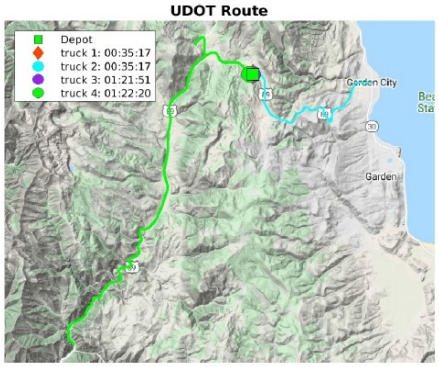


Figure 5.8 UDOT plowing routes for Logan Summit
(animation: https://youtu.be/RaRfwzAGtYg)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	35.28	17.64	0	0	2.21
# 2	35.28	17.64	0	0	2.21
# 3	81.85	40.84	0	0	5.11
# 4	81.85	40.84	0	0	5.11
Total	234.26	116.96	0	0	14.62
Max	81.85	40.84	0	0	5.11

Figure 5.9 Performance of proposed plowing routes for Logan Summit

5.4 Sardine Summit Shed

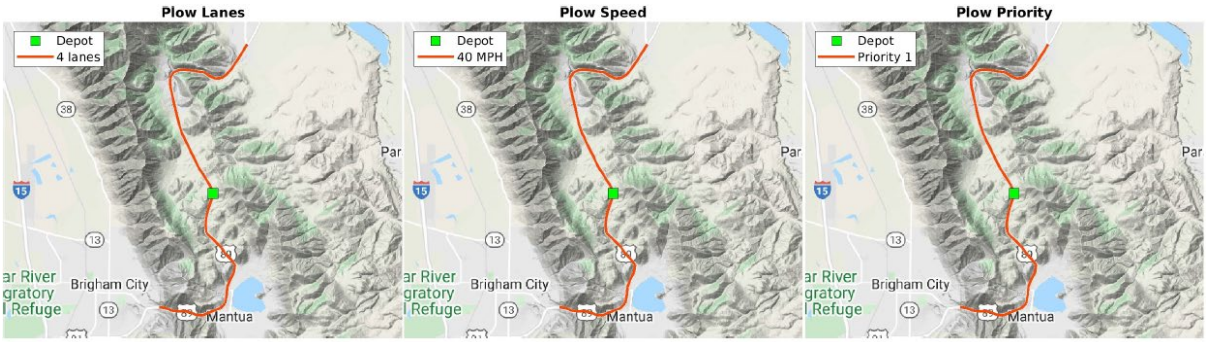


Figure 5.10 Plowing Lanes, travel speed, road priorities within Sardine Summit

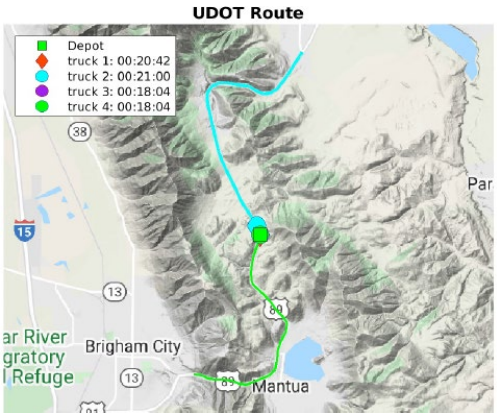


Figure 5.11 UDOT plowing routes for Sardine Summit
(animation: https://youtu.be/TcAgY1qpcM8)

Route ID	Duration (min)	Distance (miles)	Deadhead (min)	Deadhead (miles)	Salt (tons)
# 1	20.70	13.80	0	0	1.73
# 2	20.70	13.80	0	0	1.73
# 3	18.06	12.04	0	0	1.51
# 4	18.06	12.04	0	0	1.51
Total	77.52	51.68	0	0	6.46
Max	20.70	13.80	0	0	1.73

Figure 5.12 Performance of UDOT plowing routes for Sardine Summit