Livable City Year 2018–2019
in partnership with
City of Bellevue

CITY OF BELLEVUE

In Partnership with the
University of Washington

WINTER WEATHER ROUTE RESPONSE OPTIMIZATION FOR THE CITY OF BELLEVUE

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Winter – Spring 2019

LIVABLE CITY YEAR

Livable City Year 2018–2019
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www.washington.edu/livable-city-year/

The SnowDawgz team with Project Lead Daniel Lai and Mark Poch, Assistant Transportation Director, in the traffic management center in Bellevue City Hall. Equipment in this room allows transportation staff to monitor traffic 24/7 throughout the city using traffic cameras. From left to right: Project Lead Daniel Lai; Aryton Tediarjo; Nikita Sharma; Pradipta Nurahmat; Mark Poch, Assistant Transportation Director; Gina So; Kevin Castro-Siguenza; and Mohammed Arab. TERI THOMSON RANDALL

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Snow plows and deicing trucks keep winter roads clear for residents of Bellevue.
CITY OF BELLEVUE

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ABOUT LIVABLE CITY YEAR

The University of Washington's Livable City Year (LCY) initiative is a partnership between the university and one local government for one academic year. The program engages UW faculty and students across a broad range of disciplines to work on city-defined projects that promote local sustainability and livability goals. Each year hundreds of students work on high-priority projects, creating momentum on real-world challenges while serving and learning from communities. Partner cities benefit directly from bold and applied ideas that propel fresh thinking, improve livability for residents, and invigorate city staff. Focus areas include environmental sustainability; economic viability; population health; and social equity, inclusion and access. The program's 2018–2019 partner is the City of Bellevue; this follows partnerships with the City of Tacoma (2017–2018) and the City of Auburn (2016–2017).

LCY is modeled after the University of Oregon's Sustainable City Year Program, and is a member of the Educational Partnerships for Innovation in Communities Network (EPIC-N), an international network of institutions that have successfully adopted this new model for community innovation and change. For more information, contact the program at uwlcy@uw.edu.

ABOUT CITY OF BELLEVUE

Bellevue is the fifth largest city in Washington, with a population of more than 140,000. It's the high-tech and retail center of King County's Eastside, with more than 150,000 jobs and a skyline of gleaming high-rises. While business booms downtown, much of Bellevue retains a small-town feel, with thriving, woodsy neighborhoods and a vast network of green spaces, miles and miles of nature trails, public parks, and swim beaches. The community is known for its beautiful parks, top schools, and a vibrant economy. Bellevue is routinely ranked among the best mid-sized cities in the country.

The city spans more than 33 square miles between Lake Washington and Lake Sammamish and is a short drive from the Cascade Mountains. Bellevue prides itself on its diversity. Thirty-seven percent of its residents were born outside of the US and more than 50 percent of residents are people of color, making the city one of the most diverse in Washington state.

Bellevue is an emerging global city, home to some of the world's most innovative technology companies. It attracts top talent makers such as the University of Washington-Tsinghua University Global Innovation Exchange. Retail options abound in Bellevue and artists from around the country enter striking new works in the Bellwether arts festival. Bellevue's agrarian traditions are celebrated at popular seasonal fairs at the Kelsey Creek Farm Park.

Bellevue 2035, the City Council's 20-year vision for the city, outlines the city's commitment to its vision: "Bellevue welcomes the world. Our diversity is our strength. We embrace the future while respecting our past." Each project completed under the Livable City Year partnership ties to one of the plan's strategic areas and many directly support the three-year priorities identified by the council in 2018.

BELLEVUE 2035:
THE CITY WHERE YOU WANT TO BE

Winter Weather Route Response Optimization for the City of Bellevue supports the High Performance Government target area of the Bellevue City Council Vision Priorities and was sponsored by the Department of Transportation.

HIGH PERFORMANCE GOVERNMENT

Bellevue is characterized by high performance government. Our residents live in a safe, clean city that promotes healthy living. The perception of safety contributes to the success of businesses and neighborhoods. Police, fire and emergency personnel are seen by citizens every day, and we ensure that these services reflect high standards and pride.

People are attracted to live here because they see that city government is well managed. Our high quality of customer service ensures that residents realize a direct link between their tax dollar investments and the services they receive. We make public investments wisely, assuring taxpayers that we are living within our means, while also ensuring that we have superb infrastructure to support growing businesses and desirable residential opportunities. We have beautiful public buildings that residents point to with pride. Government plays its role in supporting the careful balance of neighborhoods, commercial and retail growth, diverse residential living opportunities, and amenities that characterize Bellevue. City leadership fosters careful, long-term planning, responsible financial policy, and thoughtful partnerships with businesses, the nonprofit sector, and the region.

We seek input from our residents and businesses, and this input informs city decision-making. We make decisions in a transparent manner. We support public engagement and connectivity. Bellevue does its business through cutting-edge technology. City government uses technology to connect with its residents, giving them voice in their community. Our boards, commissions, and other citizen advisory groups assist the City Council in providing superior leadership by representing the diverse interests of the city and providing thoughtful and creative ideas that assure sound policy direction and decisions.

Our residents care for Bellevue. They speak up and collectively work to address our mutual needs. In Bellevue, our commitment to public service is paramount. Our residents know that their local government listens, cares about, and responds to them.

BELLEVUE 2035:
THE CITY WHERE YOU WANT TO BE

Bellevue welcomes the world. Our diversity is our strength.
We embrace the future while respecting our past.

The seven strategic target areas identified in the Bellevue City Council Vision Priorities are:

ECONOMIC DEVELOPMENT
Bellevue business is global and local.

TRANSPORTATION AND MOBILITY
Transportation is both reliable and predictable. Mode choices are abundant and safe.

HIGH QUALITY BUILT AND NATURAL ENVIRONMENT
From a livable high-rise urban environment to large wooded lots in an equestrian setting, people can find exactly where they want to live and work.

BELLEVUE: GREAT PLACES WHERE YOU WANT TO BE
Bellevue is a place to be inspired by culture, entertainment, and nature.

REGIONAL LEADERSHIP AND INFLUENCE
Bellevue will lead, catalyze, and partner with our neighbors throughout the region.

ACHIEVING HUMAN POTENTIAL
Bellevue is a caring community where all residents enjoy a high quality life.

HIGH PERFORMANCE GOVERNMENT
People are attracted to living here because they see that city government is well managed.

For more information please visit: https://bellevuewa.gov/city-government/city-council/council-vision

EXECUTIVE SUMMARY

By improving route efficiency, the City will save time and other resources.

The purpose of this report is to communicate how a team of six undergraduate students from the University of Washington's Industrial and Systems Engineering Department conceive of optimizing the City of Bellevue's winter weather response system. We, the student team, recognize that snow events impact road conditions during the winter season. If road ice/snow clearing is not executed in a timely and effective manner, winter weather events can create significant safety impacts to the traveling public and also result in added winter response costs to the City. Thus, we offer a set of recommendations for the City of Bellevue to increase the efficiency of citywide deicing and snow plowing operations. Specifically, our recommendations focus on efficient route sequencing because this will reduce the time and resources the City must dedicate to winter road clearing. Our recommendations focus on efficient route sequencing. By improving route efficiency, the City will save time and other resources.

After observing the current system and identifying opportunities to alter the City of Bellevue's winter weather response system, we conducted research on other cities' deicing and snow plowing operations. This enabled us to consider approaches not currently practiced locally. We determined that a vehicle routing problem model (VRP) can be applied to increase the efficiency of Bellevue's winter weather response system.

Part of implementing our recommendations entails the use of Google Sheets to manage and track the City's road clearing operations. Digital worksheets can be used to outline and prioritize the routes each truck will clear, and enable workers to adjust operations based on real-time scenarios. By digitizing these worksheets and by using a platform like Google Drive which makes the documents shareable, real-time visibility of operations becomes possible for vehicle operators and command center supervisors alike.

We validated our recommendations by testing the routes generated by the VRP and comparing the time it takes to complete them with the City's current time estimates for road clearing operations. Upon integrating our recommendations, the City may discover it saves more money than it spends implementing new features within its winter weather response system. This is because the platforms we relied upon are easily accessible and user-friendly in their design.

Under harsh winter storm conditions, the Bellevue Service Center deploys plow trucks continuously to keep roads clear. CITY OF BELLEVUE

INTRODUCTION

A city may dedicate anywhere from hundreds of thousands of dollars to millions of dollars each year to winter road clearing.

Above all else, cities must safeguard the safety of the traveling public. During winter response efforts, a city will devote a considerable amount of resources to ensure its transportation infrastructure is safe and capable of withstanding inclement weather events. The objective of this project has been to provide a set of practical recommendations for the Bellevue Service Center (BSC) to apply to its winter weather response system so that it may realize both cost and time savings.

To complete this project, a team of six industrial and engineering undergraduate students from the University of Washington (referred to as the "SnowDawgz") partnered with the City of Bellevue during the winter and spring academic quarters of 2019. During that time frame, we observed the City's current deicing and snow plowing procedures. We compared the City of Bellevue's winter weather road clearing practices to the procedures in place in other cities. SnowDawgz developed a more in depth comparison between the City of Bellevue's operations and those of Chicago. Compared to Bellevue, Chicago experiences harsher winters, with more snowfall and lower temperatures. As a result, the City of Chicago must abide by a set of plowing and deicing procedures which enable it to maintain its roads clear and safe through the winter months. Compared to Bellevue, Chicago allocates far more resources to clearing roads each winter: Chicago has a fleet of 220 plow trucks, compared to Bellevue's fleet of 15 plow trucks. All of Chicago's trucks come equipped with GPS. This enables them to be strategically deployed around the city when and where they are needed (City of Chicago 2019). In comparison, Bellevue's road clearing operations are not assisted by GPS technology. As a result, most dispatch teams rely on their intuition and knowledge of the city to complete their work. This method is prone to human error and inefficiency. Bellevue's road clearing operations are not assisted by GPS technology and most dispatch teams rely on their intuition an knowledge of the city to complete their work.

CURRENT SYSTEM

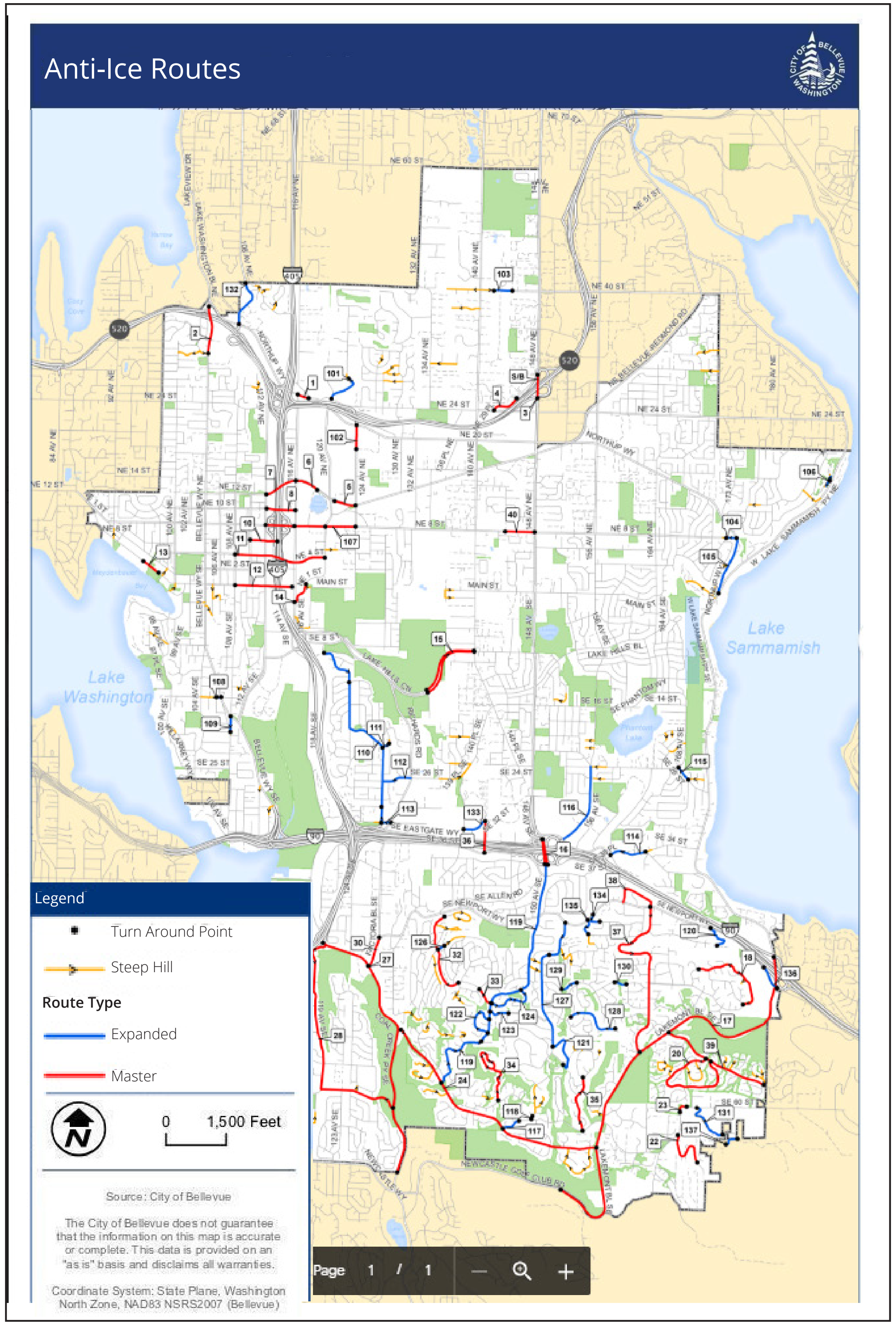
Currently, the Bellevue Service Center (BSC) has three supervisors who direct a command center and oversee winter weather response operations. They dispatch plowing and deicing truck operators to various routes. At the command center, supervisors use pen and paper methods to identify which operators are assigned to each route. The supervisors keep an eye on live operations via cameras installed throughout the city. There are a total of 15 snow plows, capable of plowing one lane at a time. There are two deicing trucks, a one ton truck capable of spraying three lanes at a time and a seven yarder truck capable of spraying two lanes at a time. Chase vehicles, with the ability to spray a single lane, accompany the deicing trucks. Two operators are assigned to each vehicle, one who drives and one who navigates. Since road clearing occurs at 2:00 a.m., navigators use flashlights to look at their driving directions.

Bellevue's current system integrates two maps, one for plowing and another for deicing routes. These maps establish which areas require plowing and deicing, but they do not prioritize which routes should be cleared first. Bellevue's current road clearing maps do not prioritize routes or designate which should be cleared first. BSC's current system also lacks the capacity for operators and supervisors to see exactly which routes have been cleared; this leaves room for the same routes to be cleared multiple times. By implementing a tool which prevents this inefficiency, the City will save substantial time and money. Thus, we set out to create a tool that the City can use to prioritize its routes and to enable its dispatch team to see which routes have been covered and when.

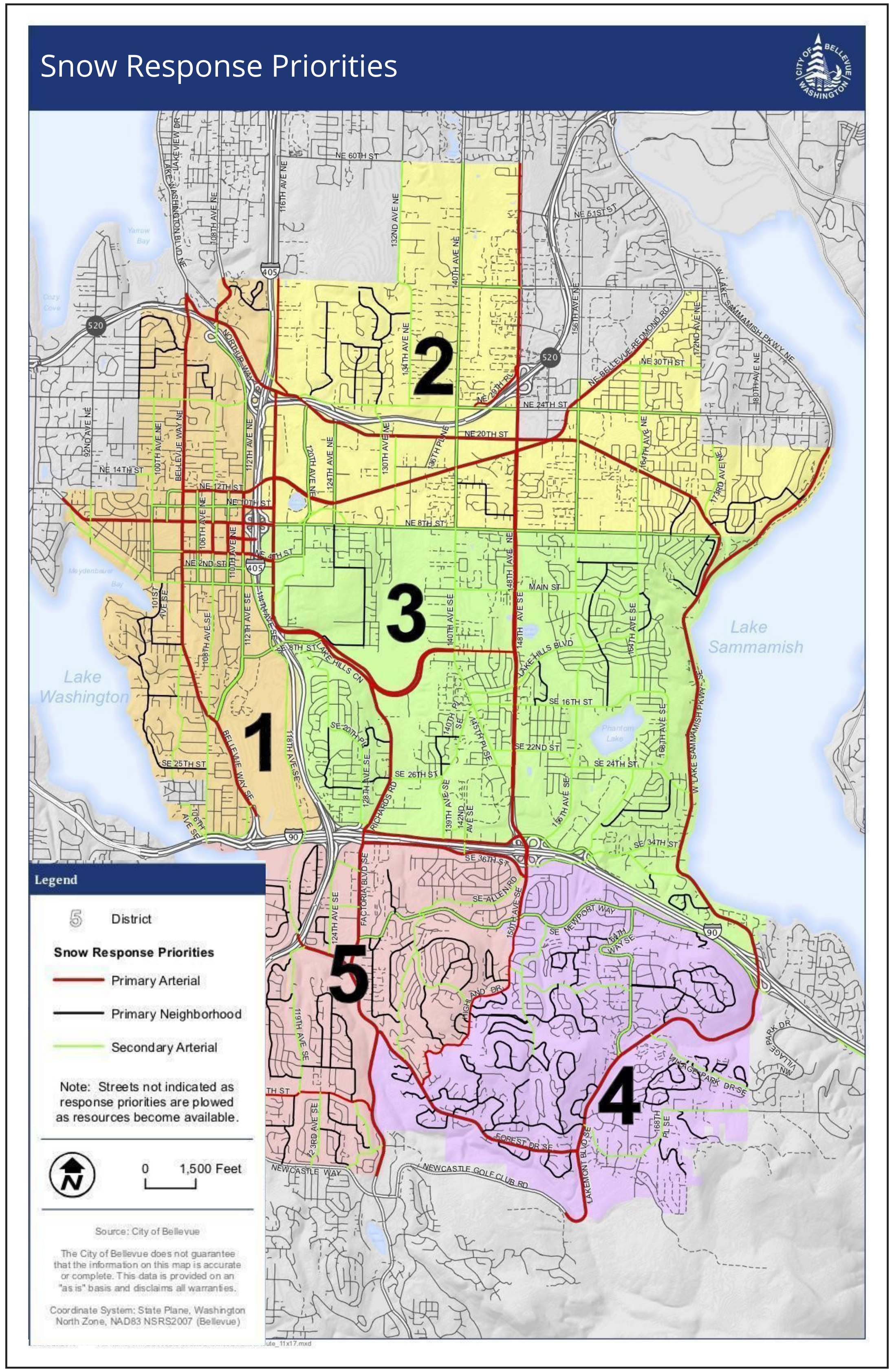
The objective of this project has been to increase the City of Bellevue's winter road clearing route efficiency, and thereby enable the City to

Bellevue's current road clearing maps do not prioritize routes or designate which should be cleared first.

SnowDawgz team member Pradipta Nurhamat looks through a binder of directions that navigators use to guide truck drivers. GINA SO



The red lines indicate master routes and the blue lines designate expanded routes. BELLEVUE SERVICE CENTER



In general, out of the City's fleet of 15 plow trucks, 11 clear main arterial routes (red). The remaining four trucks clear secondary routes (green) and neighborhood routes (black). These four trucks begin from the southern part of Bellevue (areas labeled four and five), where more snow accumulates, and move to the north. BELLEVUE SERVICE CENTER

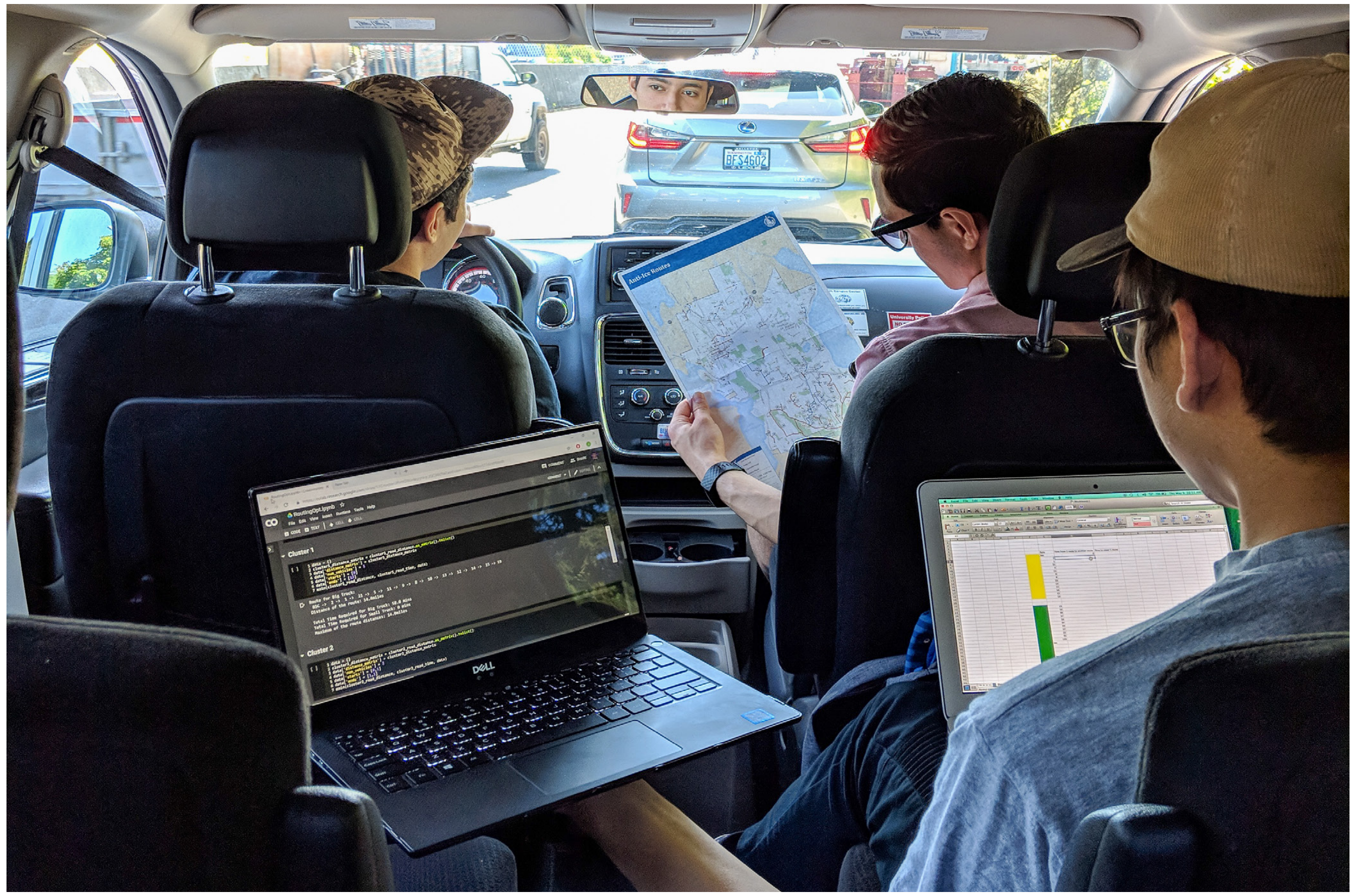
METHODS

reduce the time and money it dedicates to road clearing while optimizing road clearing operations. Students applied a vehicle routing algorithm as a primary method. The team sought to identify and eliminate repetitive road traffic by developing a visibility tool that enables dispatch to see who has been where and which routes have been plowed, deiced, or otherwise cleared of winter debris.

While working on this project, we focused demonstrating how the City can optimize deicing operations. Models throughout this report reflect this determination. Since snow falls at varying degrees of intensity, snow plowing operations are more difficult to measure; and since the City's snow plowing routes cover a far larger network of roads, the work of inputting data would be more time intensive. Thus, creating a model specifically for snow plowing operations was beyond our scope for this project. However, the tools we recommend the City apply to optimize deicing operations can also be used for snow plowing operations.

We applied the follow steps to carry out our project:

1. **Assumptions** We determined a set of viable assumptions to simplify the VRP model. We generated our assumptions from discussions with BSC operators so that they reflect current procedures.
2. **Tasks** We formed a work plan around executing four distinct tasks, all of which were determined by the Project Lead Daniel Lai (see Tasks section).
3. **Data Analysis** We collected data on the roads included in the City's deicing routes. We used Google Maps to find the coordinates for each road so that each route sequence could be applied to the VRP model. This process has been successfully implemented in other cities using Google OR, an open-source tool that simulates the VRP model, and Python Programming.
4. **Operational Recommendations** We formed a set of recommendations for operators and supervisors to effectively sequence routes, prioritize their importance, and communicate about road clearing operations.
5. **Cost Analysis** Finally, we performed a cost analysis to showcase how our recommendations will result in cost savings to BSC.



The LCY student team testing out route traveling times on Main Street in Bellevue. ARYTON TEDIARJO

ASSUMPTIONS

We aligned their work around several assumptions related to optimizing the City's winter weather road clearing practices. These are crucial to consider prior to strategizing around a tool that would optimize the City's winter weather response system. All assumptions are presented below and based on how the Bellevue Service Center currently operates.

1. **Traffic is not considered for deicing operations**
   In our model, we omit the effects of traffic congestion as road clearing operations take place during times when roads are clear of traffic (e.g., 2 a.m.).
2. **Center turn lanes are omitted from the model**
   For analysis simplification, center turn lanes are not represented by the model.
3. **Indifference between the master and expanded routes**
   To simplify our model, we assume that there is negligible difference between the master and expanded routes now used by the City. We also assume that master routes should not be prioritized over expanded routes. This assumption aligns with City of Bellevue's current operations.
4. **Deicing operations are spread between two clusters (North and South Bellevue)**
   During the calculation of the VRP model, the larger truck, which is less capable in steep roads, will be deployed to North Bellevue (comprised of the downtown area). The smaller truck will be deployed to South Bellevue, where there are more significant elevation changes.
5. **No refueling during operations**
   During the span of road clearing operations, there is no need to refuel vehicles.
6. **Refilling deicing solution does not impact operations**
   Routes can be cleared without stopping and refilling the deicing solution.
7. **Each deicing truck has the same average speed**
   Although there are two different sized trucks, with different capacities, all operate at the same average speed of 35 mph.

Thanks to winter road clearing operations, public buses are able to run on snowy days. ORAN VIRIYINCY

TASKS

We tackled four essential tasks, which were determined by the City of Bellevue Project Lead Daniel Lai. The tasks are methodically sequenced, with the first task being important to address prior to moving on to address the second task, and so on and so forth.

Task 1: Deicing Route Optimization

a. Meet with City of Bellevue staff and document their existing practices and workflow
b. Use existing data, maps, and operator experience information to optimize road clearing operations
c. Consider and account for all constraints and operational parameters (e.g., material requirements, capacity of equipment, geographic spread of routes, number of vehicles, and number of operators)
d. Develop a cost and time comparison for existing and after-optimization practices which accounts for labor, material, and fuel costs
e. Develop a list of recommended routes that can be input into a fleet navigation platform

Task 2: Citywide Snow Event: Arterial Optimization

a. Meet with City of Bellevue staff and document their existing practices and workflow
b. Use existing data, maps, and operator experience information to optimize citywide road clearing operations
c. Consider and account for all constraints and operational parameters (e.g., material requirements, capacity of equipment, geographic spread of routes, number of vehicles, and number of operators)

Task 3: Citywide Snow Event: Neighborhood Route Optimization

a. Meet with City of Bellevue staff and document their existing practices and workflow
b. Use existing data, maps, and operator experience information to optimize routing for neighborhood routes
c. Investigate constraints and operational parameters (e.g., material requirements, capacity of equipment, geographic spread of routes, number of vehicles, and number of operators)
d. Develop a list of recommended routes that can be input into a fleet navigation platform

Task 4: Project Documentation

a. Document methodology for each optimization task addressed in the project
b. Prepare information in form of final report
c. Present reasoning for assumptions and recommendations
d. Present quantifiable calculations for cost and time savings based on before and after-optimization practices

The LCY student team gives their final presentation to Bellevue Department of Transportation staff on June 4, 2019. TERI THOMSON RANDALL

DATA ANALYSIS

In this section, we further elaborate on how we approached the tasks outlined in the Methods section. We start with how we analyzed our data, beginning with data collection, transformation and generating the vehicle routing algorithm calculations. Using results derived from those processes, we provide several viable recommendations like the digital worksheet and the map interface that will be accessible to the operators. Lastly, we provide a financial analysis to reveal cost savings related to adopting our recommendations.

After mapping out the City of Bellevue's current winter weather road clearing practices, we began to brainstorm vehicle routing algorithms that could be used to optimize the City's deicing routes. We used Google OR, an open-source software program capable of calculating optimized distances based on a vehicle routing algorithm. Google OR provides users with code-snippets which can be applied to different scenarios. By implementing these code-snippets into Python, a programming software, we generated a set of optimized routes for the City of Bellevue.

To collect and process required data related to generating routes, we relied on three open-sourced technologies concurrently:

- Google Maps Directions Application Programming Interface (API): provides live data from Google Maps for locations entered by midpoint coordinates
- Google OR Library: designed to calculate optimized routes
- Python: used to integrate the two technologies listed above

DATA COLLECTION

To implement vehicle routing using the Google OR-Tools Library, we collected and input midpoint coordinates for all of the roads on all of the City's deicing routes.

DEICING ROUTES DATA

Route	Midpoint	Street	Direction	Length (ft)
BSC	47.639116, -122.188399			
21	47.628776, -122.175088	124th Ave NE	both	1700
1	47.633181, -122.185944	Norhtup Way	both	440
2	47.639846 -122.201360	Bellevue Way NE	both	2300
5	47.622359, -122.183027	NE 12th St	both	5040
8	47.619262, -122.189361	NE 10th St	both	2400
9	47.617312, -122.183159	NE 8th St	both	380

ARYTON TEDIARJO

DATA TRANSFORMATION

After compiling coordinate data, we used Google Maps API to generate distances from one deicing route to another. This provides operators at BSC with a reliable benchmark for the real distances from one midpoint to another. By programming this information in Python, and by using the requested data from Google Maps API, the data was transformed into a cross-tabular matrix which shows the distances from one route to all other routes in Bellevue.

CROSS-TABULAR MATRIX: DISTANCES FROM ONE DEICING ROUTE TO ALL OTHER DEICING ROUTES

Route	BSC	21	1	2	5	8	9
BSC	0	100	60	200	140	170	180
21	100	0	60	200	100	160	120
1	60	60	0	140	130	110	140
2	200	200	140	0	260	200	280
5	140	140	90	220	0	60	90
8	170	160	120	230	100	0	120
9	180	180	120	260	80	40	0

LCY STUDENT TEAM

RESULTS

By feeding the cross-tabular matrix of distances into Python, we generated a route sequence which minimizes the total distance travelled to complete deicing operations. The same methodology can also be implemented for the snow plowing operations to increase route efficiencies and cost savings.

OPTIMIZED ROUTES FOR BELLEVUE SERVICE CENTER

```
Deicing route for truck 1:
BSC -> 9E -> 9W -> 5E -> 5W -> 8E -> 8W -> BSC
Distance of route: 19008ft

Deicing Route for truck 2:
BSC -> 1W -> 1E -> 2S -> 2N -> BSC
Distance of route: 19536ft

Deicing Route for truck 3:
BSC -> 21S -> 21N -> BSC
Distance of route: 10032ft

Total Distance to finish all deicing routes: 48576ft
```

```
Deicing route for truck 1:
BSC -> 21S -> 21N -> 5E -> 8E -> 8W -> 9E -> 9W -> BSC
Distance of route: 20064ft

Deicing Route for truck 2:
BSC -> 2N -> 2S -> 1E -> 1W ->BSC
Distance of route: 19536ft

Total Distance to finish all deicing routes: 39600ft
```

Representations of how Google OR-Tools calculates optimized distances among routes LCY STUDENT TEAM

OPERATIONAL RECOMMENDATIONS

Using our digital worksheets, the Bellevue Service Center can prevent having the same routes unnecessarily cleared more than once.

DIGITAL WORKSHEETS

Our proposed digital worksheets aim at increasing the operational efficiency of the City of Bellevue's winter weather response system. Applying the Google OR routes our team generated, we created new digital worksheets similar to the work orders that Bellevue Service Center (BSC) operators currently use. The work orders list the roads that must be cleared. The key differences between those which the City now uses and those we have created are that our orders prioritize routes and would enable BSC to specify which truck covers which route, as well as when. Using our digital worksheets, the Bellevue Service Center can prevent having the same routes unnecessarily cleared more than once. Because the digital worksheets reflect one of BSC's existing tools, the learning curve for drivers and other staff to begin implementing them will be minor.

EXAMPLE OF DIGITAL WORKSHEET

Big_Truck_Work_Order

File Edit View Insert Format Data Tools Add-ons Help Last edit was 3 days ago

100% $ % .0 .00 123 Arial 10 B I S A

fx

	A	B	C	D	E	F	G
1		Route	Street	Direction	Length (ft)	Time	Status
2	1	21	124th Ave NE	both	1700		
3	2	5	NE 12th St	both	5040		
4	3	11	NE 4th St	both	2600		
5	4	9	NE 8th St	both	380		
6	5	10	NE 6th St	both	1000		
7	6	8	NE 10th st	both	2400		
8	7	2	Bellevue Way NE	both	2300		
9	8	101	108th Ave NE	both	3200		
10	9	1	Norhtup way	both	440		
11	10	102	NE 26th PL (Pike	both	3240		
12	11	103	NE 32nd ST	both	1400		
13	12	104	NE 40th ST	both	2000		
14	13	105	NE 16th PL - Off of west lake sam	both	1000		
15	14	107	North up way	both	3200		
16	15	106	NE 8th ST	both	2100		
17	16	114	SE 26th St	both	1500		
18	17	116	156th Ave SE	both	7200		
19	18	115	SE 32nd St	both	2100		
20	19	113	SE 32nd St	both	740		
21	20	112	SE 26th St/Pl	both	1300		
22	21	111	SE 22nd Pl	both	700		
23	22	110	121st Ave SE	both	18000		

PRADIPTA NURAHMAT

EXAMPLE OF CURRENT WORK ORDER

City of Bellevue
Department of Transportation - Street Division
Anti-Ice Master Route
2018 - 2019

#4067

Date: 12-4-18
Gallons Applied: 104
Miles Applied: 64.3
Radio #: 821, 812
Work Order #:

Starting Temperature: 29°
Ending Temperature: 33°

Starting Humidity: 100 %
Ending Humidity: 100 %

Location #	Street	Section	Direction	Length (Ft.)	Time
21	124th Ave NE	Northup Wy to Transit entrance	Both	1700	2:19
1 W	Northup Wy	WB 116th Ave SE (Bridge Deck Only)	WB	440	2:20
2 S	Bellevue Wy NE	SB Northup Wy to NE 30th PL	SB	2300	2:24
2 N	Bellevue Wy NE	NB NE 30th PL to Northup Wy	NB	2300	2:25
1 E	Northup Wy	EB 116th Ave SE (Bridge Deck Only)	EB	440	2:30
Blue 4 E	NE 29th PL	EB NE 24th St to 14600 Block	EB	2900	
Blue 3	148th Ave NE	SB 520 Bridge Deck Only	SB	330	—
~~4 W~~	NE 29th PL	WB 14600 Block to NE 24th St	WB	2900	—
5 W	NE 12th St	WB At 124th Ave Bridge Deck Only	WB	1800	2:34
6 W	NE 12th St	WB at 11800 Block Bridge Deck Only	WB	270	2:35
7 W	NE 12th St	WB 116th Ave to 112th Ave NE	WB	450	2:36
7 E	NE 12th St	EB 116th Ave to 112th Ave NE	EB	450	2:37
6 E	NE 12th St	EB at 11800 Block Bridge Deck Only	EB	270	2:38
5 E	NE 12th St	EB at 124th Ave Bridge Deck Only	EB	1800	2:39
8	NE 10th St	EB 112th Ave to 116th Ave NE	Both	2400	2:41
9 E	NE 8th St	EB 112th Ave to 124th Ave NE	EB	380	2:41
19	NE 8th St	14400 Block (top of hill) to 148th St	Both	2550	2:53
9 W	NE 8th St	WB 124th Ave to 112th Ave NE	WB	380	2:57
10	NE 6th St	EB 110th Ave to I-405	Both	1000	3:04
11	NE 4th St	EB 108th Ave to 120th Ave NE	Both	2600	3:07
12 W	Main St	WB 116th Ave to 108th Ave NE	WB	2600	3:21
13	NE Lake Washington Blvd	9700 Block (Bridge Deck)	Both	600	3:25
12 E	Main St	EB 108th Ave to 116th Ave NE	EB	2600	3:19
14	SE 1st St	116th Ave to Main St	Both	830	3:[illegible]
15 E	Lake Hills Connector	EB 134th Ave to 140th Ave SE	EB	3130	3:48
36	142nd Ave SE	SE 32nd St to SE 36th St	Both	2700	3:57
16 S	150th Ave SE	SB Eastgate Wy to SE 37th St (All Lanes of Bridge over I-90 except drop lanes)	SB	1400	[illegible]
17	Lakemont Blvd	From roundabout to Newcastle Golf Course	Both	37000	5:28
18	177th Ave SE	From 170th Ave to 175th Ave SE	Both	7900	6 AM
39	Village Park Drive	Lakemont Blvd to City Line (179th Ave SE)	Both	9950	5:40
20	55th Loop (SE 55th/SE 58th)	From Village Park Dr to Village Park Dr	Both	11750	5:41
22	~~168th Pl SE~~	Cougar Mtn. Wy to SE 65th PL (Pinnacle)	Both	5000	—
Blue 23	~~Cougar Mtn. Wy~~	SE 60th Sharp Corner - 100' on both Sides	Both	600	—
24	Forest Drive 132	Lakemont Blvd to Coal Creek Pkwy	Both	21850	6:25
27	Coal Creek Pkwy	From I-405 to City Line (Aprox. SE 69th PL)	Both	24240	[illegible]:41

The letter behind the location #, symbolizes the direction in which the vehicle is to travel

Scanned by CamScanner

Bellevue's current work orders do not specify which truck should cover which routes. The student-created digital worksheets maintain a similar layout and specify which truck should cover which routes. BELLEVUE SERVICE CENTER STAFF

SNOW PLOWING WORKSHEETS

These four digital worksheets are for four different arterial and neighborhood snow plowing routes. No work orders currently exist for snow plowing. Thus, we have provided worksheets for these routes as well. This will allow operators to complete their work without requiring them to contact the monitoring room to find out which route they can clear next.

TRUCK 1 SNOW PLOWING ROUTE

Truck_1_Work_Order

	Route	Time	Note
0	BSC		
1	SE ALLEN RD		
2	SE NEWPORT WAY		
3	N15		
4	Somerset Blvd SE		
5	N17		
6	152nd Ave SE - 151st ave		
7	SE 34TH ST		

TRUCK 2 SNOW PLOWING ROUTE

Truck_2_Work_Order

	Route	Time	Status	Note
0	BSC			
1	N11			
2	119th Ave SE (Northern pt)			
3	N12			
4	119th Ave SE (Sourthern pt)			
5	129th Ave SE to 129th Pl SE			
6	128TH AVE SE - SE 67TH ST			
7	N13			
8	123rd Ave SE			
9	N14			
10	116th Ave SE			
11	Lake Washington Blvd SE			
12	SE 34TH ST			
13	SE 37TH ST - SE 34TH ST			
14	SE 37TH ST - SE 34TH ST			

TRUCK 3 SNOW PLOWING ROUTE

Truck_3_Work_Order

	Route	Time	Status
0	BSC		
1	N8		
2	124th Ave SE		
3	SE 41ST PL		
4	Somerset Dr SE		
5	N16		
6	SE COUGAR MT WAY - 168TH PL SE - SE 60TH ST		
7	N20		
8	N18		

TRUCK 4 SNOW PLOWING ROUTE

Truck_4_Work_Order

	Route	Time	Status	Note
0	BSC			
1	SE 46TH PL			
2	SE 46TH WAY			
3	164th Way SE			
4	N19			
5	VILAGE PARK DR SE			
6	SE NEWPORT WAY (RIGHT-90)			
7	SE NEWPORT WAY (RIGHT)			

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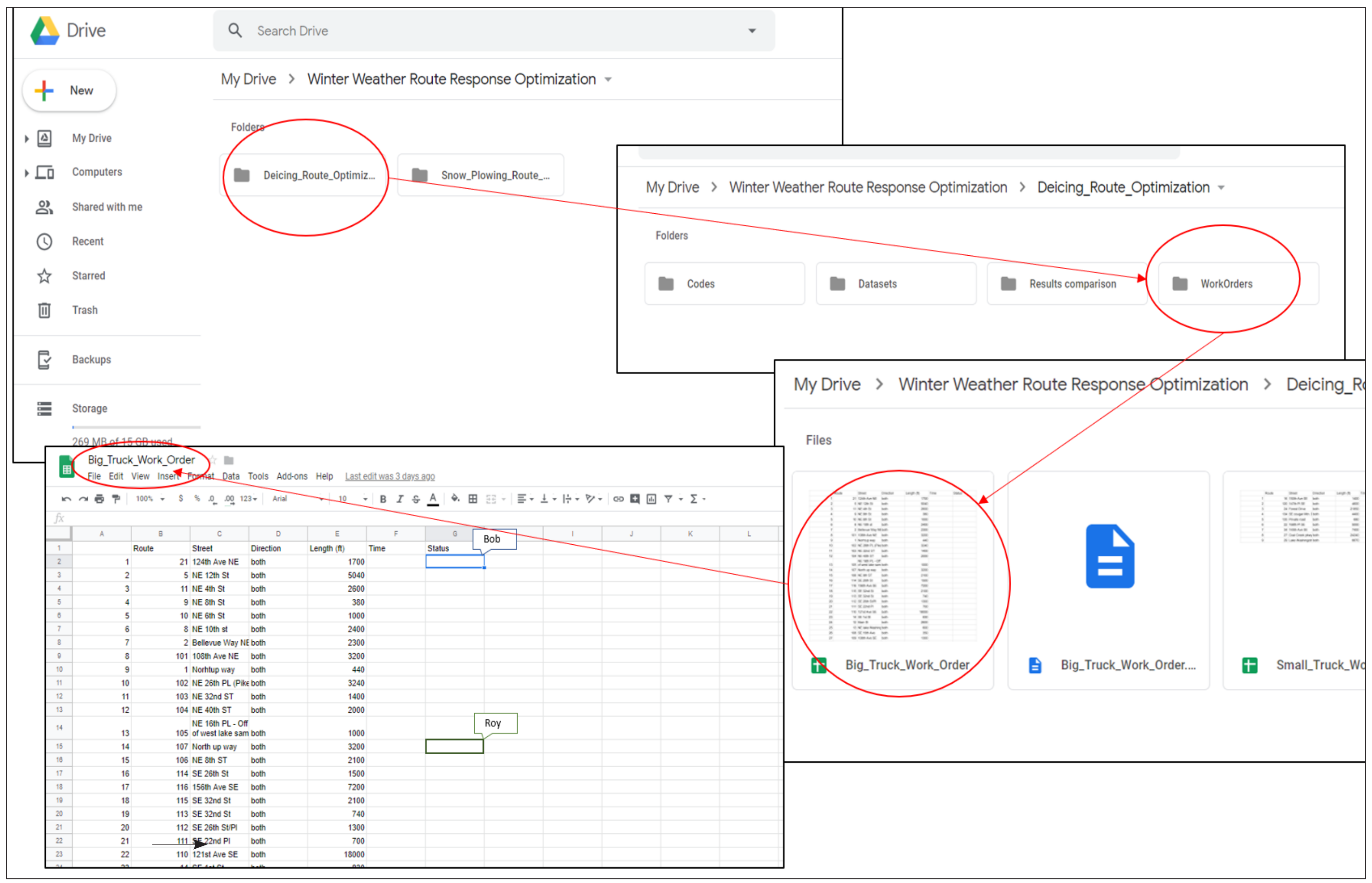
GOOGLE SHEETS

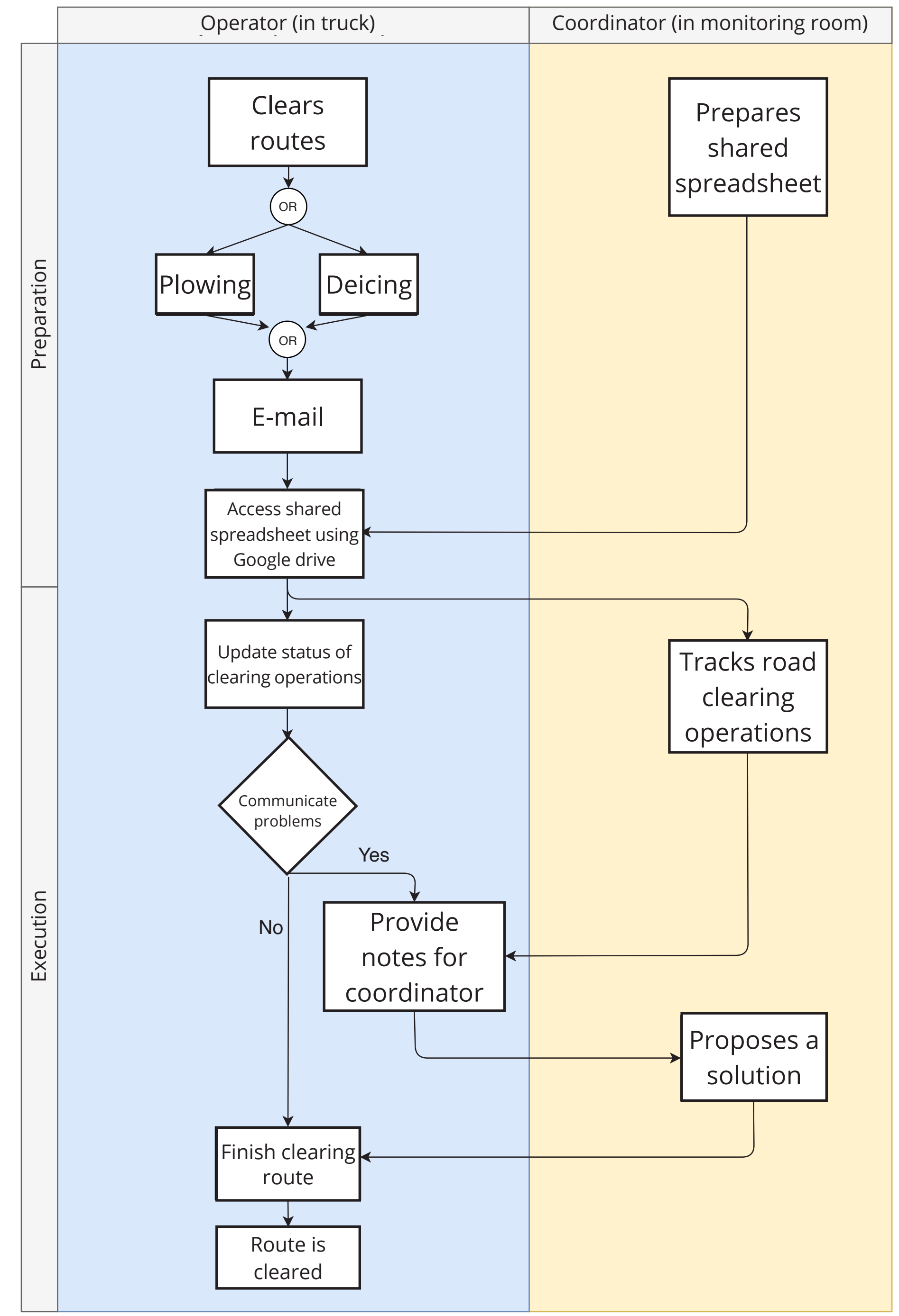
Additionally, we recommend that the BSC operators keep records of work orders through Google Sheets. This information is accessible via a shared Google Drive platform. By using Google Sheets, each driver can let other drivers know of the status of their routes. This increases operations visibility and may reduce inefficiencies.

HOW TO USE GOOGLE SHEETS



To access the new worksheets via Google Drive, simply log in to the individuals BSC email ——► click Google Drive choose deicing route optimization ——► choose work orders folder ——► choose the assigned truck ——► fill in status/time completed LCY STUDENT TEAM

ROAD CLEARING OPERATIONS USING DIGITAL WORKSHEETS



PRADIPTA NURAHMAT

FLEET NAVIGATION PLATFORM

This recommendation concerns the digitization of route guidance for BSC's deicing and snow plowing operations. Google OR generated routes may be implemented into a fleet navigation platform controlled by BSC dispatch. The fleet navigation platform can be accessed by truck operators remotely. This will save time as it will prevent operators from having to look at a physical map and manually input routes into another digital device.

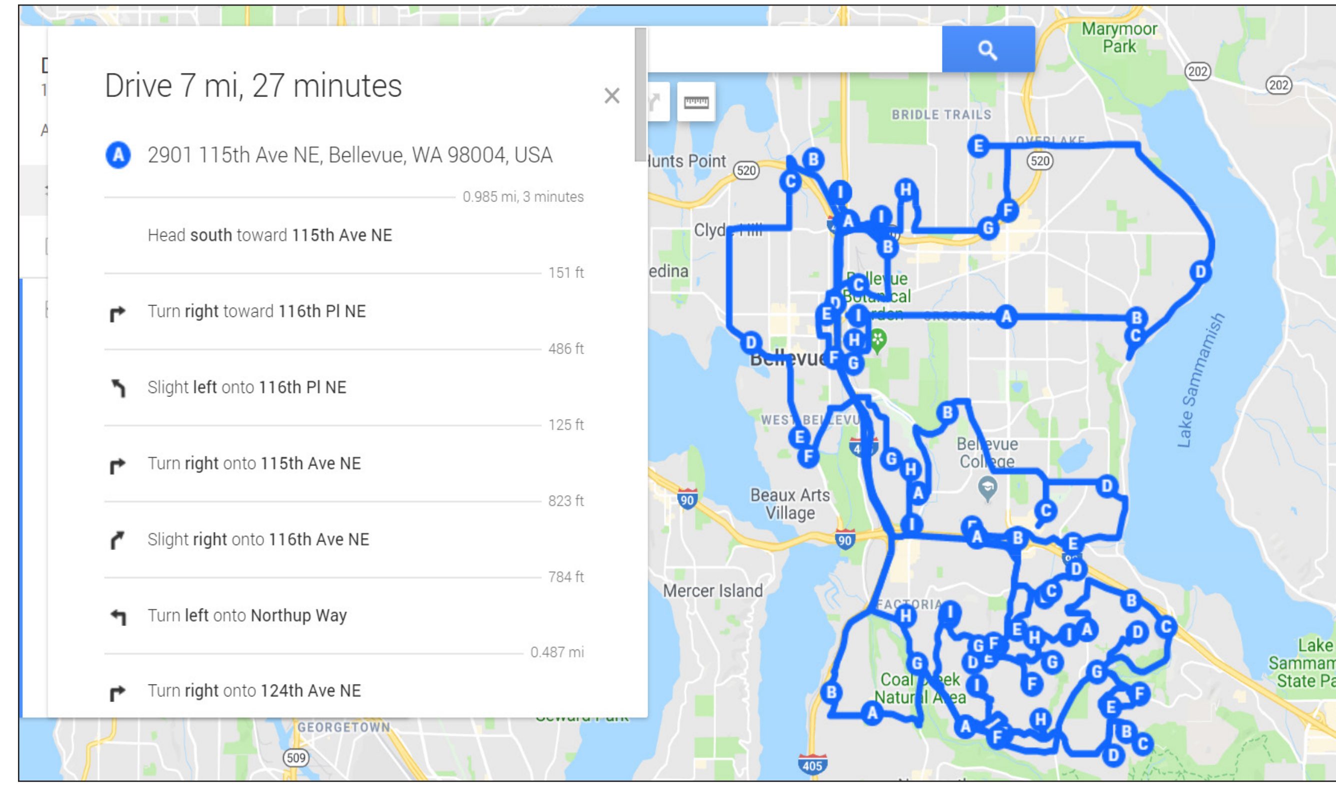
While reviewing different fleet navigation platforms, we considered cost, ease of use, and total time required to complete specific actions. There are two potential fleet navigation platforms we recommend the City of Bellevue consider for future use:

1. **Google My Maps** My Maps is free and user-friendly. It allows one to easily upload routes and organize them in a sequence. Since City of Bellevue operators already use iPads in their daily work, they can easily start using My Maps, at no additional cost.
2. **Magellan Winter Fleet Solutions** Magellan is a handheld GPS device. One useful feature Magellan offers which Google My Maps does not is the ability to record and share notes on route conditions. However, the main difference between using Magellan Winter Fleet Solutions and Google My Maps is that Magellan operates on a subscription basis and would require the City to allocate funds to use it. Since Magellan is already being considered as a potentially viable option, it is likely to gain support and resources required for successful implementation.

INTEGRATED USER-INTERFACE

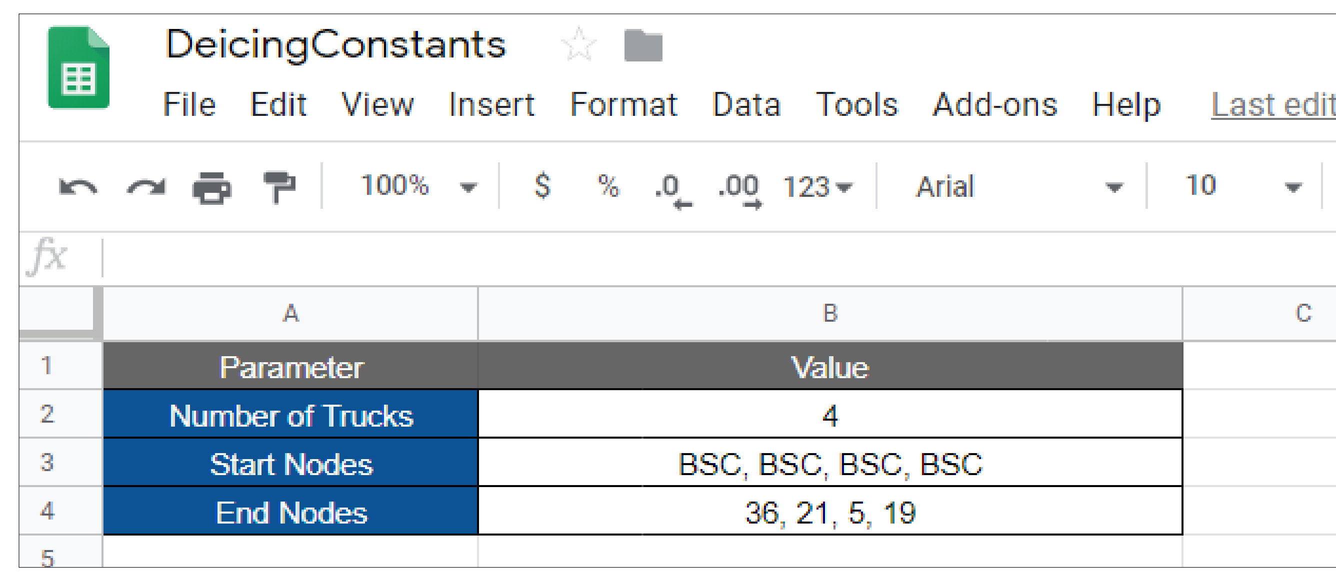
For continuous improvement, we used Google Sheets to design an integrated user-interface that is connected to all Python applications. This interface offers operators the ability to change certain parameters, such as the number of trucks or the start and end nodes of a route. This tool is intentionally designed to be flexible and dynamic, and will allow operators to explore alternative solutions for handling different scenarios.

NORTH BELLEVUE DEICING ROUTES



Google Maps routing recommendations LCY STUDENT TEAM

INTEGRATED USER INTERFACE



	A	B
1	Parameter	Value
2	Number of Trucks	4
3	Start Nodes	BSC, BSC, BSC, BSC
4	End Nodes	36, 21, 5, 19
5		

This Google Sheet allows staff to easily modify and manipulate the VRP model. LCY STUDENT TEAM

COST ANALYSIS

We compared costs associated with our proposed system to those associated with the City's current system. Due to time constraints, we only analyzed the cost efficiency of our proposed system for deicing operations. Nevertheless, our proposed system can be adapted for snow plowing operations. Thus, one can extrapolate from our cost analysis related to deicing that the City would save even more money by implementing our recommendations across all winter weather road clearing operations.

DEICING

We measured the effectiveness of our recommendations through a cost analysis. In order to compare the relative efficiency and cost effectiveness of our system with the City's current system, we estimated deicing costs for both the City's current system and our proposed system. Implementing our system would reduce costs to the City by an estimated 10–15%.

Implementing our system would reduce costs to the City by an estimated 10–15%.

We based our calculations on length of each route by number of lanes cleared for each route. The number of lanes in a route influences the number of times trucks will traverse a given route to completely clear it; this affects the total distance covered for each route. We considered which truck, the smaller seven yarder truck or the larger one ton truck, is better suited for particular routes. For example, the one ton truck is better suited for routes with wide roads as it is able to clear more lanes at once. Finally, we factored in the costs associated with operating chaser vehicles which accompany deicing trucks.

OPERATIONAL CONSIDERATIONS

Route options for each truck based on lane counts:

1. If there are a total of one to two lanes on the road, the seven yarder truck can cover the entire route.
2. If there are a total of two to four lanes on a road, the seven yarder truck will have to go back and forth to cover the entire route.
3. If there are a total of one to four lanes on the road, the one ton truck can cover the entire route.
4. If there are more than four lanes on the road, the one ton truck will have to go back and forth to cover the entire route.

We assumed the following values for the cost analysis:

1. Labor: $55 per hour (average)
2. CaCl2 (deicing solution): $191.38 per ton
3. One ton truck spreading rate: 20 gallons per mile
4. Seven yarder truck spreading rate: 15 gallons per mile

SNOW PLOWING

Since snow plows can only clear one lane at a time, it is important to account for the total number of lanes in each route. According to the data we retrieved from BSC's current system, the City's fleet of snow trucks consists of 15 units. Of those, 11 are assigned to specific arterials. Thus, for the purposes of this project, our primary focus has been on optimizing use of the four remaining trucks across secondary and neighborhood routes.

Due to the multitude of variables associated with snow storms, it is challenging to quantify the number of hours required to complete plowing operations. For instance, since the severity of storms varies, it is difficult to anticipate what will be required to clear roads following a snow storm. Assumptions applied to a scenario in which heavy snow accumulates throughout the day are quite different from the assumptions applied to one in which snow only accumulates over one hour. However, the fact that it is challenging to quantify costs associated with citywide snow events does not mean our recommendation related to deicing operations cannot be applied to snow plowing operations and similarly save the City money and resources.

The SnowDawgz team visited the Transportation Department in Bellevue City Hall on several occasions. This hallway displays several actual-sized tools such as road signs and traffic lights used by the City to manage traffic. From left to right: Pradipta Nurahmat, Aryton Tediarjo, Nikita Sharma, Kevin Castro-Siguenza, Gina So, and Mohammed Arab.
TERI THOMSON RANDALL

CALCULATING COSTS

First, we calculated how many times each truck will have to traverse a given route to clear all lanes. Then, we multiplied that number by the length of the route. This gave us the total distance of each route. After calculating the total distances covered by each truck for each cluster (North and South Bellevue), we multiplied the values by the spreading rate of each truck (20 gallons per mile for one ton truck and 15 gallons per mile for seven yarder truck). As for labor costs, we multiplied the number of operators of the whole fleet (four workers) by the time required to complete deicing operations. To do this, we used data provided to us by BSC.

Within our cost analysis for deicing, we considered labor, type of truck (seven yarder and one ton), fleet size, and quantity of CaCl2 solution. We estimate that the total cost required to complete deicing for all the routes to be around $2,000. This estimate may serve as a measure for BSC to establish a budget for deicing operations.

DEICING COSTS

Truck size	Cluster	Time needed (minutes)	Gallons/mile	Path cleared (miles)	Solution needed (gallons)	Distance traveled (miles)
Big	1	118	20	27.248	544.96	34.8
Big	2	72	20	35.08	701.6	28.26
Small	2	66	15	19.79	296.85	27.68
	Total	256	-	82.118	1543.41	90.74

Resources	Cost/unit	Total resource cost
Labor/hour (2 per truck)	$ 55.00	$ 469.33
CaCl2/ton	$ 191.38	$ 1,554.20
Fuel	$ -	$ -
Vehicle maintenance	$ -	$ -
	Total cost/day	**$ 2023.53**

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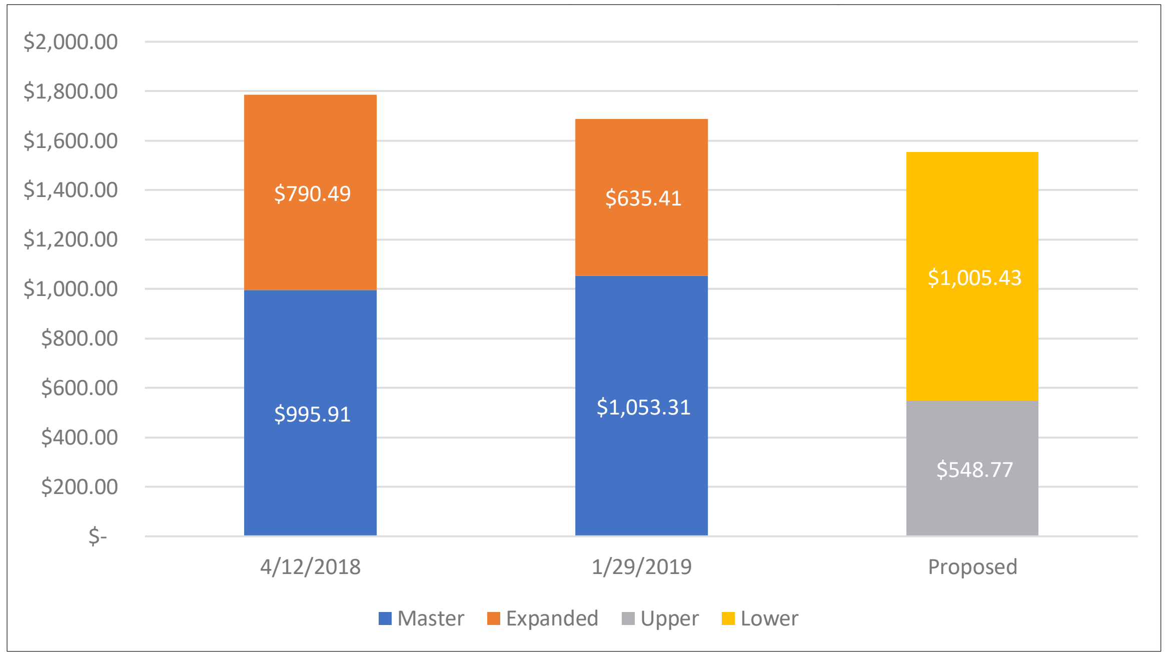
COST SAVINGS

We compared how much the City would spend on deicing solution within our proposed system. In the BSC's current system, route area coverage is divided according to the type of route (Master or Extended). The current system does not provide a means for operators to track which routes have already been covered. Our proposed system divides the areas of coverage into two clusters, representing North and South Bellevue. Our system enables greater transparency through real time data sharing among operators and supervisors at dispatch. The digital worksheets also detail which truck should cover which route for optimal results. This feature will reduce the likelihood of the same route being covered multiple times and increase the cost efficiency of deicing operations. According to the data, BSC spent around $1,786.4 and $1,688.72 for deicing solution on 4/12/2018 and 1/29/2019. Meanwhile our proposed system would cost $1,554.2 for deicing solution, indicating a cost savings.

COST ANALYSIS FOR DEICING SOLUTION



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BENEFITS

Below are benefits that can be gained from implementing our recommendations for citywide deicing and snow plowing operations.

1. **Clear work order**

Our work orders allow operators to view which routes have been completed and which are still in progress. Although our system prioritizes routes in a particular order, operators can also make determinations based on actual circumstances.

2. **Reduced cost**

For deicing, the total estimated cost using our system will save BSC money. For citywide snow events, despite not being able to estimate a total cost, we ascertain that our recommended routes will prevent operators from wasting time covering routes which have already been cleared. This will reduce the total distances covered and the total amount of resources the City of Bellevue dedicates to clearing roads in the winter

VALIDATION

We applied three techniques to validate our model.

1. We test drove each of the routes our model generated and compared them to the City's current routes. Our routes took less time to complete. We predict that deicing operations will take approximately five hours to complete, compared to the six to eight hours BSC currently estimates.
2. We built a simulation model which shows that Google OR generated route orders can be completed in a timely manner.
3. We input the Google OR generated route orders into Google My Maps to show that routes can be completed in a logical and timely manner.

As fall turns to winter, Bellevue transportation staff gather for an annual review of proper plowing techniques. A Tonka truck and navy beans prove useful for the demonstration. CITY OF BELLEVUE

CONCLUSION

By improving and prioritizing routes, the City will save money and maintain roads safe and clear for residents through winter months.

Our project focus has been to increase the efficiency of Bellevue Service Center's (BSC) winter weather road clearing operations. By improving and prioritizing routes, the City will save money and maintain roads safe and clear for residents through winter months.

For the past six months we have worked with City of Bellevue staff to optimize deicing and snow plowing operations. Through data modelling, we have provided a new approach for the City to increase operational efficiencies at almost no cost. Specifically, we have optimized deicing routes and created digital worksheets that will facilitate communications among operators and supervisors at the command system. By integrating these worksheets with Google My Maps or Magellan, BSC will benefit from having a turn-by-turn directions interface that is user-friendly and accessible to all operators in real time. Although we focused on deicing routes, the same process we have followed can be applied to optimize snow plowing routes.

Below is a summary review of our optimization process:

1. **Route ordering using Google OR** Our team met with BSC to teach them how to use Google OR. IT staff at BSC will be able to manipulate the Google OR code to create and modify routes as may be required for different scenarios. BSC staff will also be able to change the number of trucks as well as the start and end points of routes.
2. **Fleet navigation platform** The recommended routes generated from Google OR can be implemented into a fleet navigation platform such as Google My Maps or Magellan to facilitate route navigation.
3. **Digital worksheets** Digital worksheets kept in Google Drive will allow the supervisors and operators to view the status of different routes in real time. This will facilitate communications regarding winter road clearing operations.
4. **Mapping Interface** A mapping interface will help determine which roads within a route should be cleared first to minimize the total distance covered and to prevent overlap among routes.

We are able to reduce the total time required to complete deicing operations and cut costs associated with deicing solution by an estimated 10–15%. Our proposed system offers greater flexibility since the parameters of our VRP model can be modified. The City can reallocate money it saves adopting our system where resources are needed. The sum of all efficiencies generated by our proposed system will result in an improved winter response system that promotes the safety and well-being of residents of Bellevue through the harshest seasons of the year.

The LCY student team, a.k.a. the SnowDawgz, share their work with Bellevue's Deputy City Manager Nathan McCommon at the LCY year-end poster presentation on June 3, 2019. TERI THOMSON RANDALL

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