Eléments de recherche opérationnelle

Winter Optimization

Clearing Snow in Montreal

Goal: We look into optimizing the snow removal plan in Montréal city.

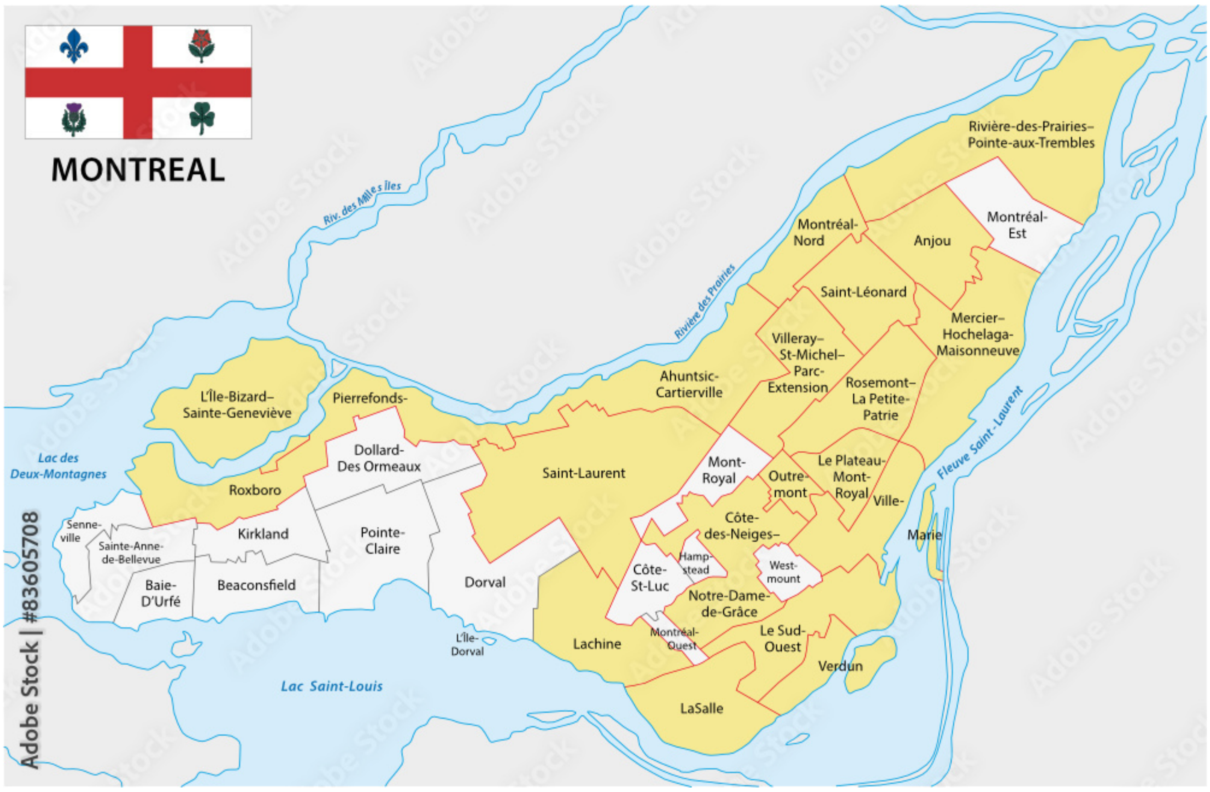

Table of content:

by Barbora Plasovska, Elie Abi Khalil, Elise Baturone, and Enrique Tarabay

I. Introduction:

This research project aims to address the concerns of Montréal residents regarding snowplowing operations while considering the delicate issue of increasing the allocated funds. The objective is to minimize the cost of a typical snowplowing day by finding an efficient and cost-effective path for snowplows around the Montréal road network. Additionally, a drone-based aerial analysis will be performed to identify the sectors requiring immediate snowplowing. The report provides a summary of the data used, the study perimeter, hypotheses, model choices, selected solutions, cost model for snow removal operations, and limitations of the proposed model.

II. Setup:

We begin with the first issue. How can we generate a graph of the city of Montreal ? We decided to use the osmnx library which allows us to load data from open street map. It takes a long time but it allows us to get a very comprehensive map of the city. Because of the exceeding time it takes, we will only load a specific district during our demonstration, however, our submitted code does include the entire city of Montreal.

At this step, we faced an issue for vehicle orientation and routes. We currently have the road network, and the graph of the city as a multigraph. We chose to make the graph eulerian in order to traverse all the edges at least once. For optimisation sake, our code checks if the graph already is eulerian before making it so, though the probability of that being the case are extremely low.

After this, we want our graph to be weighted in order to compute our cost correctly. We therefore need to fetch the length in the data given by osmnx, and make it the weight of each edge.

III. Drone Aerial Check:

To perform an efficient aerial analysis of the road network, a drone with unrestricted navigation capabilities will be utilized. The goal is to find the shortest path(s) for the drone to cover the entire network and gather sufficient data. By identifying the sectors in most need of snowplowing, the snow removal operations can be strategically planned.

We had started out with the Traveling Salesman algorithm but soon realized it may not be the best approach for our case. It led us to the following study. There are several algorithms to solve this problem. We have identified three relevant algorithms with varying performance characteristics:

- Traveling Salesman:
  - Drone travel time: optimal
  - Complexity: factorial
  - Ignores roads
- Directed Eulerian Graph:
  - Drone travel time: average
  - Complexity (n nodes, e edges): (n + e)^3
  - Includes roads
- Simulated Annealing:
  - Drone travel time: indeterminate
  - Complexity: iterative, indeterminate
  - Ignores roads

Algorithms that exclude roads can analyze the entire city in record time if we assume that drones can cover an area with a diameter of at least the longest edge (approximately 150m for the city of Montreal). On a surface scale with 10 edges, the drone would be three times faster. However, the city of Montreal has a huge amount of nodes, and the Traveling Salesman algorithm would require approximately (18,759)! / 2 calculations! The Simulated Annealing method is similar to gradient descent and does not guarantee a maximum solution. Therefore, we have chosen the Directed Eulerian Graph algorithm to solve this problem. This means that all we need to do is find a cycle to represent the drone's path.

IV. Snowplow Path Planning

Following the drone aerial check, the same approach will be applied to the snowplow model. The objective is to find paths for snowplows to remove snow from the identified sectors. The paths should cover the entire zone while ensuring that the snowplows traverse two-way roads only once. By optimizing the snowplow paths, the overall cost of snow removal operations can be minimized.

For the snowplows' traversal, we need to make a small adjustment to our graph and make it directed. Then, we can use the same logic we did previously and simply find a eulerian cycle.The snowplow will pass through the entire graph and, since this is a eulerian circuit calculated based on weight(length in our case), the path found is the most optimized.

V. Cost Model for Snow Removing Operations

To propose a cost model for snow removing operations, the number of available snowplows will be taken into account. The municipality is considering investing in high-performance snowplows, referred to as type II, which can remove snow at a faster rate but come with higher costs. Simulations will be conducted to compare the associated costs for different options, considering factors such as fixed costs, costs per kilometer, and hourly costs.

We had to calculate time and distance cost for both the drone and snowplow path as well as compare these costs when varying the number of employees and machines used. Consequently, we wrote a function that would compute time cost and functions for both drones and snowplows that would compute the distance cost. From there, we made a function to help us choose snowplows' types and numbers. All of these functions are grouped and called in a `calculateDroneCosts` and `calculateSnowplowCosts` functions.

VI. Conclusion

In conclusion, this research project aims to minimize the cost of snowplowing operations in Montréal while providing an efficient snowplow service to the residents. The use of drone-based aerial analysis and optimized snowplow path planning can help achieve this objective. The proposed cost model allows for comparison between different scenarios and the evaluation of investing in high-performance snowplows. However, it is important to acknowledge the limitations of the model(s) and consider further enhancements for real-world implementation.

A snowplow truck costs approximately 500€/day with a speed of 10km/h for the type I and 800€/day with a speed of 20 km/h. Since Montreal has 228 kilometers of roads, the total cost is $11,400. In terms of time, it would take a machine 114 hours to cover the entire city of Montreal. Here is a table showing the parameters and costs for each section in need of snow removal:

District	Drones	Drone Cost	Snowplow I	Snowplow II	Snowplow Cost ($)
Outremont	3	300.48	1	0	607.87
Verdun	5	500.79	0	1	997.22885
Saint-Léonard	12	1201.92	0	2	2095.63625
Rivière-des-prairies-pointe-aux-trembles	27	2704.31	0	4	4354.7325
Le Plateau-Mont-Royal	9	901.43	1	1	1652.90387

Handout Contents:

The handout provided for this research project adheres to the specified constraints. It includes the following components:

1. AUTHORS file: Provides a list of authors involved in the project.
2. README file: Contains instructions for installing and running the project, along with a description of the handout's structure.
3. PDF file: A concise summary of the team's thinking, including details about the data used, the studied perimeter, hypotheses, model choices, selected solutions, comparison between scenarios, and identified limits of the model(s).
4. Script: A demo script showcasing the solution.
5. Subtree - Drone Flight: Deals with the aerial analysis conducted through drones.
6. Subtree - Snow Removal Planning: Includes the snow removal planning for specific