Optimizing Vancouver's Snow Plow Route System

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1 Introduction

The *snow plow routing problem* (SPRP) is an optimization problem that specifies designated routes for snow plows to follow. Like any major cities in the US and Canada, Vancouver has already adopted a snow plow routing plan, however, after their response this winter season, we have come to conclude that it is insufficient as many roads were left unplowed and unsalted for days after snowfall.

The SRPR minimizes either the total cost or the total time required to clear a network of streets. Given the heavy snowfall that has hit Vancouver this past winter, and the City of Vancouver's unpreparedness, our model focuses on the latter. We hope to improve service without increasing the costs too much. We solve the SPRP for a network of major roads in Vancouver; under the constraints of fleet size and specifications.

Our choice to minimize the total time required to clear the network of roads is based on the safety and economics of hazardous icy road conditions. Without the initiative to plow and salt the roads, it allows for snow and ice to accumulate, causing unsafe road conditions for commuters. The decreased quality of road conditions also increases commuting time, the number of insurance claims, and response times for emergency services.

2 Data

Our dataset of Vancouver streets was obtained through [6]. The list of 1279 streets was then subjected to our priority points system criteria to yield our set $V = 1, 2, ..., 326$ intersections we used for this paper. The points system is described as; every intersection is awarded 1 point according to the following historical data: part of Vancouver's current snow plow route, one of Canada's top 15 worst bottlenecks[2], a crash site resulting in casualties or damage property only[7], and part of a major bus route, and also being within 2 intersections of Vancouver General Hospital, St. Paul's Hospital, BC Children's Hospital, and Mount St. Joseph. A minimum score of 3 was required for the intersection to be included in our dataset. Every connecting adjacent intersection was then a job number 1 to 1056.

Data concerning the fleet of plow trucks was obtained through the City of Vancouver Engineering Services. The fleet has a size of 44 trucks, which we assume to be homogeneous. Average Truck fuel mileage and salt capacity were determined for an average rate of plowing of 40km/h. According to a memorandum from Jerry Dobrovolny, General Manager of Engineering Services for the City Vancouver, to the Mayor and his council, there was a good supply of salt reserves and easy access to more if needed, so we will assume that there is an endless of supply of salt. The snow plow depot is located in the surrounding area of Manitoba Street and South West Marine Drive. We assume it is at the closest intersection included in our set of intersection.

3 Model

We base our model off of the mixed-integer program (MIP) from Kinable et al. (2016). However, We simplify it by assuming every road is a single lane street going in 2 directions, only having one snow plow depot, and homogeneous plows.

3.1 Mathematical Model

The MIP model consists of the following variables:

1) Binary variables X_{ij}^k, where k represents plow k, $k = 1, 2, 3, ..., 44$. This machine travels from intersection i to j, where it executes job J, $J = 1, 2, 3, ..., 1056$.

2) Integer variable C^i that records the time of job I completion.

3) Integer variables F_i^k and S_i^k indicate the amount of fuel and salt left in the truck after the completion of job i:

- f_{ij}^k is the amount of fuel required to get from job i to job j plus the fuel required to finish the job j for the certain vehicle k
- $F^k =$ maximum fuel capacity of the truck.
- s_{ij}^k is the amount of salt required to get from job i to job j plus the amount of salt machine needs to finish complete the job j for vehicle k.
- with $S^k =$ maximum salt capacity of the truck.

Objective for the model is to minimize the total time $C^{(n+1)}$ for the total number of jobs that are required to be done in the main Vancouver area:

min $C^{(n+1)}$(1)
subject to:
$\sum(X_{0j}^k) = \sum(X_{i,n+1}^k) = 1, \forall k \in K$ (2)

$\sum(X_{ji}^k) = \sum(X_{ij}^k), \forall i \in V$ (3)

$\sum(\sum(X_{ij}^k)) = 1, \forall i \in \overline{J}$ (4)

$\sum(\sum(X_{uj}^k) + \sum(X_{uj}^k)) = 1, \forall i \in \overleftarrow{J}, u = \overleftarrow{j}_i, v = \overrightarrow{j}_i$ (5)

$F_j^k \leq F_i^k - f_{ij}^k + \overline{F}^k(1 - x_{ij}^k), \forall i \in J \cup 0, j \in J \cup n + 1, k \in K$ (6)

$F_j^k \leq \overline{F}^k - f_{ij}^k X_{ij}^k, \forall i \in F, j \in J \cup n+1, k \in K$ (7)

$S_j^k \leq S_i^k - s_{ij}^k + \overline{S}^k(1 - x_{ij}^k), \forall i \in J \cup 0, j \in J \cup n+1, k \in K$ (8)

$S_j^k \leq \overline{S}^k - s_{ij}^k X_{ij}^k, \forall i \in S, j \in J \cup n+1, k \in K$ (9)

$0 \leq F_i^k \leq \overline{F}^k, \forall i \in V \cup 0, n+1$ (10)

$0 \leq S_i^k \leq \overline{S}^k, \forall i \in V \cup 0, n+1$ (11)

Constraint (2) defines the starting and ending points of the plow route, thus every vehicle must start and end at the depot. Constraints (3) enforce flow preservation. Each job must be performed just once (4 and 5), however we do not assume that this road can be cleaned just once, because otherwise trucks will not be able to leave the depot. Constraint (7) orders the refueling jobs, where job $u \in F^i$ must be performed before the job $v \in F^i$, where $v > u$, same works for the constraint (8) that does the same but for the salt amount. This constraint reduces the amount of symmetry in the model. Similar way constraints (6) and (9) manage fuel and salt levels of the vehicles at each intersection, where we switch from job i to job j, thus every next job must start with the smaller amount of fuel and salt compare to the previous one. Vehicle leaves a refueling/resupply node with a full tank and full salt supply. Constraints (10) and (11) are fuel and salt capacity constraints.

3.2 Assumptions

We are not looking at pre-snowfall activities like brining the roads. We also assume that every road has snow coverage. One lane roads connect the appropriately adjacent intersections in 2 directions, as in there a two-way street with one lane going in either direction. To simplify scheduling constraints, we assume that there is an endless supply of labour at any point in time. Workers will also receive no breaks. Plows will plow and salt at a constant rate with the truck speed of 40km/h, in the absence of traffic lights, other vehicles and traffic accidents, and anything else that may cause road blockages. Additionally, we assume that trucks are plowing and salting all the time even if the road is already clean. All turns performed by plows are easy, effortless, and feasible, i.e. the plow will not slow down while turning, and is not prevented from left or right turns due to traffic signs. Each truck will drive one route, starting and returning to the depot at the end of every route to resupply, refuel, or end the workday. We also assume that there is always sufficient salt and fuel supplies at the depot and resupplying and refueling are instant and will require no time. Trucks will require no servicing and all 44 trucks available at depot are of the same type (snow plow), same make (Freightliner), same model (SD114) and are equiped with the same engines (Detroit Diesel 13). We are limited to this information as the City of Vancouver did not provide us with detailed information about truck fleet composition.

3.3 Techniques

We use an open-source optimizer for Microsoft Excel called OpenSolver. It is similar to Excel's Solver where one tries to optimize an objective function given constraints in spreadsheet format, however, OpenSolver has the ability to work with larger amounts of decision variables. OpenSolver solves the SPRP by assigning a value of 1 to any truck k (1 to 44) performing job j (1 to 1056) in their assigned route. The homogeneous trucks can hold 227L of fuel and 16000kg of salt. We use the Gurobi solver engine option available from OpenSolver.

4 Results

Our solution has all 44 trucks in operations, achieving a minimum total operating time of 22.64 hours. There are 12 trucks that have operating times less than 20 minutes. Comparatively, Vancouver's current snow plow routes consist of 14 routes of similar length. In reality, the City may not have all available trucks on the road. Short routes may just be plowed by trucks that are already in the area. Although trucks are plowing and salting while in operation, our solution may not target trouble areas receiving large amounts of snowfall. From our analysis, our assumptions of fuel and salt usage may largely underestimate the actual salt and fuel required along the routes. That is so as the real snow plowing require trucks to stop and accelerate all the time what causes differences in the fuel economy and salt distribution rate. Additionally, it has already been mentioned that we do not assume time delays on the street lights, trucks service, refueling and resupplying, which is another factor that leads to an underestimate of the actual time required. As a result, we end with the maximum amount of used fuel of 5.1 litres and 3037 kg of salt. These results are underestimates of the actual fuel and salt required, because our constant fuel economy rate assumes that all heavy duty trucks operate more efficiently than in reality.

5 Discussion

For a more realistic solution, one could include every street intersection in the City of Vancouver. Since smaller streets suffered from days without being plowed, the analysis of this would have possible relevant results. To obtain more accurate data, one could use a dataset including accurate data for multiple lane roads, one-way streets, prevention of left turns and other bylaws and driving conditions. Improvements can be done by gathering the accurate heterogeneous plow truck fleet data rather than using homogeneous plow trucks. Smaller trucks could be assigned to clear and salt smaller streets. One could also include rate of servicing required for specific trucks, the length of time required to refuel and resupply, and breaks for employees in order to obtain a more accurate estimate of the time required to clear the roads in Vancouver. Additionally, there is also an option of using ground elevation levels to predict potential trouble areas with steep hills and greater amounts of snow accumulation. An option to increase the quality of road conditions is to have busy roads and areas with heavy snowfall covered in multiple truck routes.

The city of Vancouver is currently in the process of installing GPS devices into individual plow trucks. The data gathered from the devices could better predict operating speeds along certain stretches of roads with the inclusion of traffic lights and other cars on the road. It could also help plows to avoid getting stuck in traffic due to accidents on the road. The possibility of using live data collected through open lines of communication between Translink, the Ministry of Transportation, Vancouver School Board, ICBC, BC Ambulance Services, Vancouver Police Departments, Vancouver Fire and Rescue Services, and residential complaints via Vancouver's Vanconnect app, 3-1-1 and various forms of social media, allowing for greater flexibility in routes which plow trucks would cover, as needed.

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