SNOW AND ICE REMOVAL IN AN URBAN ENVIRONMENT*

THOMAS M. COOK† AND BRADLEY S. ALPRIN†

Although important answers regarding the efficient removal of snow and ice reside in the domain of good planning and the behavioral sciences, the primary thesis of this paper is that cities can significantly improve their snow and ice removal operations by improving the routing of salt spreader trucks. A dynamic routing heuristic totally different from the static routing in general use was developed. The value of this heuristic was demonstrated to the satisfaction of city officials using a discrete simulation model of a large midwestern city. In addition, the simulator was used to answer questions of salt pile location and equipment configuration and location. Although applied to only one city, this routing heuristic, together with the simulation approach, is of potential value to all city governments that experience snow and ice emergencies.

Introduction

Today's modern metropolitan areas, dependent on surface transportation for the movement of food, merchandise and people to and from market places, schools, hospitals and places of employment, require that their transportation networks remain open to traffic. However, nature does not always cooperate. Cities situated where climatic conditions are likely to bring on winter snowstorms are faced with a major problem of keeping their streets and highways open.

To indicate the magnitude of the problem: "The Department of Sanitation of the City of New York expended more than $65,000,000 in direct expenditures from the 'Snow Budget' in carrying out its responsibilities to remove snow and ice from the streets," [5] during a period of 10 years beginning in 1960.

There is no quick and easy answer to the snow and ice removal problem. Each city has its own unique conditions that make the problem increasingly complex. A city with a large suburban population trying to get to and from a centralized business district has a completely different set of problems from a city with several separate business areas. New York City, for example, with a population of eight million people, and an average annual snowfall of over 30 inches, has snow removal problems quite different from a city like Tulsa, Oklahoma, with a population of approximately 500,000 and an average annual snowfall of only 10 inches. An example of the difference would be that a major problem in New York City is the plowing and removal of snow whereas the city of Tulsa has no plowing equipment or snow plowing plans. Tulsa relies solely on the spreading of salt and abrasives to keep the major traffic arteries clear in an ice or snow emergency. However, some generalized concepts can be applied in both cases. Common sense and good management approaches to the problem of ice and snow removal are well documented (see [2], [3], [6], and [10]).

Typically, large northern cities like Chicago, New York and Minneapolis establish procedural manuals for snow and ice emergencies. These manuals outline the steps to be taken by the street maintenance department in the event of a snow emergency. Often a snow emergency route (major traffic arteries) has been identified using traffic counts and other criteria and divided into routes for plowing and/or salt-spread ing

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† The University of Tulsa.
operations. The purpose of this plan is to move traffic and prevent accidents. The objective, therefore, is to minimize the time required to clear the snow route. In a Chicago study it was found that,

The vehicular accident rate is highest when a light snow or freezing rain has not been given treatment . . . Therefore, early salt application can significantly reduce the number and severity of accidents which create congestion and involve the cost of lost time, property damage and personal injury . . . The accident rate on a wet or slippery pavement, a condition produced by a light untreated snow, is 330 percent that of a dry pavement. . . . Light snow or freezing rain create the most severe accident problems. If the rate can be cut in half by faster, better handling, the potential annual saving (to Chicago) is $1,500,000 or more. [3]

Snow emergency procedures, therefore, strive to reduce the time necessary to clear a designated network of streets. Many factors are important in achieving this goal. For example, the mobilization plan from the weather forecasting to the final decision to mobilize the crews necessary to operate the equipment is important. Men must be properly motivated to get out in bad weather at odd hours and fight a snowstorm. Adequate equipment must be available, properly designed and maintained and well located. The list could go on and on. Because many of the issues involved are treated elsewhere, (see [3], [8]–[10]) this paper’s primary focus is the improvement of urban snow and ice removal operations by improving the routing of the salt/sand spreader trucks.

Methodology

The approach taken by this research was to develop a routing heuristic that promised to minimize the time it takes for a given number of spreader trucks to cover all the branches in a network of streets. In order to test the heuristic, a simulation model was developed using data collected in Tulsa, Oklahoma. In addition, the simulator was used to help solve the equipment requirements and location problems.

Routing Heuristic

The objective in routing spreader trucks over a snow route is to minimize the time required to spread salt over a given network of streets. The basic technique used by many cities to route salt spreader trucks is to divide the network of streets to be salted into a set of preassigned routes. One truck is assigned to each route. In dividing the street network, an attempt is made to balance the routes with respect to the time required and the distance traveled. This balancing is complicated by load capacities of the trucks which require repeated trips back to the salt pile to be refilled. On the surface, the problem seems to be a classical branch routing problem for which solution methodology exists [4], [9]. However, due to the unique nature of the spreading problem, traditional branch routing algorithms do not apply because they seek to minimize deadheading. Deadheading is the term used for the time spent traveling over the branches in the network more than the required number of times [4]. Most streets on emergency snow routes are major arteries—it takes two passes to spread salt on the street. Because salt spreading occurs on both sides of the street, a spreader truck can spread half its load on a street segment and turn around and spread the other half on the other side of the street, hence no deadheading. In the case of one way streets, deadheading is unavoidable unless there exist adjacent one-way streets in the other direction. If this is the case the problem is solved simply by structuring the street segments properly. The real objective is to balance the work load as much as possible and thus clear all streets in the network in the minimum time.

The heuristic developed for this research is defined as follows: When a spreader truck has been checked out and loaded with salt, and is available for a salting
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Operation, it is assigned to a street segment that (1) can be covered with one truck load of salt, (2) as yet has not been salted, and (3) is the closest unassigned street segment to the starting point (salt pile facility) for the truck. A street segment as used in this paper is defined as the distance that can be salted on both sides of the street at the desired application rate with one truck load of salt. As the severity of the ice or snow storm changes and the temperature changes, the rate of application of salt must also change. This change, however, is typically treated discretely. For example, in Tulsa approximately 90% of the ice and snow storms can be handled using one rate of application. In other cities with more variable weather conditions several sets of different sized street segments might be necessary. This implies that a truck will be able to salt one side of the street, turn around and salt the other side with a single truck load of salt.

The use of the closest street heuristic has several advantages which can be demonstrated using the hypothetical case shown in Figure 1.

There are forty streets, each one mile long, to be salted in the network, with the salt pile located at the lower left corner of the network. Assume that there are two trucks (A and B) available for salting and that each can salt a distance of two miles, both sides of the street, with one truck load at the desired application rate. Then a street segment is considered to be two miles in length. The time required to travel a one-mile distance is assumed to be three minutes. Also assume that each truck has been assigned to salt a specific set of streets, truck A has streets 1–20, and truck B has streets 21–40. Applying these assumptions to the network in Figure 1, total travel time for truck A will be 108 minutes, ignoring the time it takes to do the actual salting. Truck B will require 252 minutes for traveling back and forth from the salt pile (see Tables 1 and 2). One can easily see that this is a very unbalanced situation. Truck B has the same distance to salt but requires more than twice the time to travel back and forth to the salt pile. Situations like this can occur in real life where each truck is given a preassigned set of streets to salt. Applying the closest street heuristic to this case, the travel time changes to 180 minutes for each truck. This gives a savings of over 70 minutes in the total time required to complete the salting operation because the work load is now evenly distributed between the two trucks.
Another advantage of this heuristic is that the salting coverage radiates out from the salt pile. The first streets salted by truck A are 1 and 2, while truck B salts 5 and 14. When truck A returns to the salt pile, it is reassigned to the next closest street segment, streets 6 and 15. To get to this new street segment, truck A travels over street 1 which has already been salted. Therefore, the trucks will have less difficulty due to stalled traffic in getting to their assigned salting operations. Also, a truck will be able to travel at a higher rate of speed in getting to its destination due to the fact that the streets have already been cleared and are less hazardous.

The use of this heuristic implies that in any given unit of time the number of streets that are salted is maximized. Let us assume, for ease of calculation, that it takes fifteen minutes to salt a street segment, assuming uniform street length. Then, using the previous assumptions for travel time and street assignments and reference to Figure 1, ten streets would be salted in roughly the first hour, six by truck A and four by truck B, using the same preassigned streets as before. Switching to the closest street
heuristic as the method to route the trucks results in twelve streets being salted in the first hour, six streets by each truck. Again, one can see that the work load is evenly distributed between the trucks.

Tables 1 and 2 show the calculations for the two methods of routing the trucks. Table 1 assumed preassigned routes, and Table 2 used the closest street heuristic. It is apparent that the preassigned routes could have been selected to give better results. However, as will be seen when simulation results are discussed, the closest street heuristic significantly outperforms existing preassigned routes in balancing workloads.

A fifth advantage that has not been mentioned before involves truck breakdowns. If each truck had a preassigned set of streets to salt, and a truck did break down, then the remaining part of the route assigned to the truck would be delayed until either the truck was repaired or another truck finished its scheduled route and could be reassigned. This obviously is not the most desirable situation. With the closest street heuristic, only that street segment assigned to the truck that broke down would be delayed. The other available trucks would take up the slack and salt the remaining streets in the network. In other words, the closest street heuristic affords automatic coverage if a truck breaks down. The sixth advantage is that a driver is not required to remember a long and complicated route. He or she simply is given a different two-mile segment each time he or she returns to the salt pile for another load. This is important because due to many union contracts which give each employee equal overtime opportunities, the composition of the snow and ice emergency crew changes with each snowstorm.

Finally, the tedious job of determining the preassigned routes for each truck is eliminated. The routes must be carefully worked out in an attempt to balance the work load and minimize the time it takes to complete the salting operation, often with little success. If new trucks are acquired or a new salt pile facility is added or new streets are added to the system, the routes must be redesigned. With the closest street heuristic, new trucks are automatically taken into the system and assigned to salting operation. For new salt pile facilities, distances must be calculated to determine the closest streets, but this is a one-time problem and can be automated with the use of a computer.

Several advantages of the closest street algorithm have been described. To reiterate, these advantages are: (1) total time necessary to cover a street network is reduced; (2) total distance covered with salt per unit of time is increased; (3) work load is balanced between trucks; (4) trucks travel more safely over previously salted streets; (5) there is automatic coverage in case of truck breakdown; (6) drivers are not required to learn a long route, and (7) the tedious job of determining routes is eliminated.

### The Simulation Model

In order to test and measure the utility of the routing heuristic described above, two simulation models were programmed using the Xerox General Purpose Discrete Simulator (GPDS) language and executed on a Xerox Sigma 6 computer using 24k words of storage. The first model was built using the closest street heuristic and the second model simulated the routing method currently employed by the city of Tulsa. Each model included a matrix that described the coordinates of the streets that appear on the snow map for the city of Tulsa (see Figure 2). In each model a simulated spreader truck went through the operations which are diagrammed in Figure 3. The operations were: (1) if necessary, mount an insert type spreader on a truck body (some trucks have permanently mounted spreaders and can by-pass this step); (2) safety check the truck; (3) load the truck with salt; (4) travel to the salting operation; (5) salt the street segment, and (6) return to the salt pile for reloading. All data
necessary to build the generating functions and validate the model were collected during the winter of 1975 in the city of Tulsa. General and technical aspects of the simulation models and their validation appear elsewhere [1].

In addition to using the simulator to measure the utility of the closest street heuristic, the simulator was used experimentally to determine the utility of additional equipment and additional salt pile locations.

![Snow Route Network for Tulsa, Oklahoma for the 1974-75 Snow Season.](image)

**Figure 2.** Snow Route Network for Tulsa, Oklahoma for the 1974-75 Snow Season.

**Experimental Results**

The experiments conducted using the two simulation models fell into three categories. The first category compared the closest street heuristic to Tulsa's preassigned routes while keeping the number of trucks and salt piles constant. The second category used the same number of trucks but varied the number and location of salt pile facilities. The third category varied the number and type of trucks while using only one salt pile.

Category 1 experiments included simulating a snow emergency 12 times and each time the closest street algorithm significantly outperformed the preassigned route of the city of Tulsa. The mean of the total time required to spread salt on the snow route network was 5.25 hours, a savings of almost 3 hours or 36% over the preassigned routes method.
The city of Tulsa currently has one main salt pile location, but the street maintenance department was considering the storage of salt at two additional facilities, one existing and one to be built on city property. Therefore, experiments were conducted looking at the various combinations of potential salt pile locations. As expected, the best mean of the total time to salt the snow route occurred with the use of all three salt piles. This mean time was 3.8 hours. The experiments with different combinations of two salt pile locations gave results that varied by only 6% with a mean value of approximately 4.75 hours. The mean time for the main salt pile

![Flowchart of operations of a simulated salt spreader truck]

**Figure 3.** Operations of a Simulated Salt Spreader Truck.

<table>
<thead>
<tr>
<th>Number of 8-Ton Trucks</th>
<th>Number of 4-Ton Trucks</th>
<th>Total Truck Tonnage</th>
<th>Mean Total Time (Hrs: Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>20</td>
<td>104</td>
<td>5:57</td>
</tr>
<tr>
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<td>24</td>
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<td>132</td>
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</tr>
<tr>
<td>3</td>
<td>34</td>
<td>160</td>
<td>5:12</td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>156</td>
<td>4:53</td>
</tr>
</tbody>
</table>

**Table 3**

*Sensitivity of the Number of Trucks and Truck Tonnage*
location operating alone was 5.25 hours. Given these results, the city has decided to use only one salt pile during the winter of 1975-76.

The time required to salt the snow route was relatively insensitive to the number of trucks and truck tonnage used during a snow emergency (see Table 3). Using 20 4-ton trucks and 3 8-ton trucks as the base, a 9 percent increase in tonnage resulted in only a 5 minute or 1.4% decrease in the average time required to salt the snow route. A 27% increase in truck tonnage to 3 8-ton and 27 4-ton trucks resulted in a 12% decrease in total salting time. A 50% increase in truck tonnage resulted in only an 18% decrease in the time required for the salting operation. Consequently, no new equipment other than replacement equipment is planned for the future.

Implementation

To implement the closest street heuristic (i.e., the dynamic routing of spreader trucks) very little would have to be accomplished. First, the snow route would have to be divided into the appropriate street segments. These street segments would then be listed in order of the distance from the salt pile facility or facilities. As each truck was loaded with salt at the time of the required safety check, the foreman would merely tell the driver which segment he was to salt. Once that segment had been assigned, it would be marked off the list so the next spreader truck would be assigned the next closest segment. In short, implementation of the closest street heuristic would be extremely easy and entail no additional cost.

After the conclusion of the study reported in this paper, a meeting was held with the Street Commissioner and personnel from the Street Maintenance Department to discuss the major results and recommendations. At this meeting it was strongly recommended by the authors that the city adopt the usage of the closest street routing heuristic. After much discussion, it was agreed that no serious disadvantages to using the heuristic could be identified and it would be useful to try the routing heuristic during the next winter season. In addition, based on simulation results and other data, decisions were made to locate salt in only one location and not to increase the size of the salt spreader truck fleet.

References

10. Snow Removal Equipment and Procedures, Department of Public Works, Minneapolis, Minn. (1968).