SPANNING TREE APPROACH ON THE SNOW CLEANING PROBLEM

Master Thesis
Computer Engineering-Applied Artificial Intelligence
Nr.E3877D

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Dalarna University, Sweden
June 2010
DEGREE PROJECT
Computer Engineering

Programme
Masters Programme in Computer Engineering - Applied Artificial Intelligence

Reg. Number
E3877D

Extent
15 ECTS

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Year-Month-Day
2010-06-17

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Title
Spanning Tree Approach on the Snow Cleaning Problem

Keywords
Snow Cleaning, Minimum Spanning Tree, Heuristic, prim’s algorithm, Greedy Algorithm.
Abstract

Snow cleaning is one of the important tasks in the winter time in Sweden. Every year government spends huge amount money for snow cleaning purpose. In this thesis we generate a shortest road network of the city and put the depots in different place of the city for snow cleaning. We generate shortest road network using minimum spanning tree algorithm and find the depots position using greedy heuristic. When snow is falling, vehicles start work from the depots and clean the snow all the road network of the city. We generate two types of model. Models are economic model and efficient model. Economic model provide good economical solution of the problem and it use less number of vehicles. Efficient model generate good efficient solution and it take less amount of time to clean the entire road network.
Acknowledgement

At first I would like to thanks to Almighty Allah, who has given me the strength to successfully reach to the end of this program.

I would like to express my deepest gratefulness to my supervisor Dr. Pascal Rebreyend, for his valuable time and taking his time to explain a lot of things to me in order to complete this thesis.

Also, special thanks to Dr. Mark Dougherty and my sincere thanks to the entire faculty member in Computer Engineering department for their support in various ways.

Finally, we would like to thank my parents, family members and friends for their never ending love and support during the thesis process.
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<td>SCP</td>
<td>Snow Cleaning Problem</td>
</tr>
<tr>
<td>SNRA</td>
<td>Swedish National Road Administration</td>
</tr>
<tr>
<td>AADT</td>
<td>Annual Average Daily Traffic</td>
</tr>
<tr>
<td>SPP</td>
<td>Shortest Path Problem</td>
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Chapter 1

Introduction

1.1. Introduction

In the winter season road maintenance is an important issue during the heavy snowfall country. Winter road maintenance Sweden government and municipalities together spend close to 1 billion SEK every year [1]. Approximately half of it is snow cleaning cost. In Sweden heavy snow is falling throughout the winter season. For that reason Sweden spends lot of money. It is very important time and cost effective road maintenance system.

We need to optimized snow cleaning process and decrease expenditure by minimized time and number of vehicle need to maintain the road network during the winter season. If we can allocate resource, create an optimum routes and crew scheduling then optimization is possible.

1.2. Purpose

Snow cleaning is an important task in winter time. Vehicles used to clean the snow are located in a depot and when snow is falling, they drive to the depot and have to clean the entire road network. Depending on the importance of road, road have to be cleared between 2 hours to 6 hours at regular intervals. The purpose of this thesis is to find a planning with optimize the compromise between cost and quality of snow cleaning based on data used.

1.3. Problem formulation

The following question of this thesis want to answer is:

- How can we generate set of periodic routes in road network for snow ploughs?
• How can we generate a solution in a reasonable time?
• What will be the good quality of solution?
• How can we improve the design of the algorithm?
• How can we even say that the solution that we have found so far is the optimal one or even near to optimal solution?

In this thesis problem can be divided into sub problems. And according to well known journalist's question of who, what, when, where, why and how will be formulated for this problem. We can answer some of the questions will be directly, but other question answer will remain for further investigation [3].

• Who will use that application framework to generate road network to snow plough?
• What optimization method will be used to provide that solution?

Now I am trying to answer these questions, we get:

• Swedish Road transports Administration (SNRA) authority are responsible for the snow plowing.
• Our main goal is to establish the road network as soon as possible. For this reason we try to optimized the time and cost. We use spanning tree algorithm to find the shortest network of the city. After generating shortest road network we use simple greedy method to find the depots position of the city. Number of depots totally depends on the total distance of the city area. We describe more in the implementation chapter.

1.4. Delimitations

In this thesis we need to generate a road network using open street map (OSM) data. We take the data from openstreetmap.org site. When we take the data from www.openstreetmap.org that
time data format is map.osm. OSM file contains lot of unnecessary information. For that reason we take only important data from the OSM file. After taking the important data we makes some calculation in the excel application software for finding distance between two points. Finally we create the text input file. This input file directly read our “C” program for creating shortest road network of the city. After generation shortest road network we put different depots, depending on the total area of the city. In the implementation chapter we describe more about the solution.

1.5. Outline

Chapter 1: This chapter provides the problem formulation, research method and other introductory information.

Chapter 2: This chapter provides a background to the snow cleaning problem and the winter road maintenance regulations, which must be considered.

Chapter 3: This chapter describes theoretical background of the problem and reviews some previous year thesis paper.

Chapter 4: In this chapter describe how we solve the snow cleaning problem and also describe which methodology use for the solution.

Chapter 5: In this chapter describe the step by step implementation of the solution of the snow cleaning problem. At end the chapter describes the result analysis.

Chapter 6: In this chapter describe the conclusions of the whole work and give some description what we do in future.

1.6. Prerequisite

The reader is assumed to have basic understanding of software development, data-structure, optimization theory, graph theory and algorithm. The solution and result analysis chapter will be inaccessible to the reader without some basic concept of programming language.
Chapter 2

Problem Background

2.1. Road information of Sweden

The Swedish road network comprises approximately 138,000 km of public roads, 75,000 km of private roads receiving state subsidies, and a very large number of private roads without state subsidies, mostly forest motor roads. There is also an estimated 31,000 km of pedestrian and bicycle paths in the municipalities. 10,700 km of state roads are gravel roads. There are 37 ferry routes on the state road network. Most human transport within Sweden takes place by road. Road transport accounts for just over 90% of the total volume of travel. Private car travel alone accounts for 76% of the total human transport mileage in Sweden [4] [2].

According to Roads and Traffic [4], the road transport system in Sweden consists of the following:

- The people who use the system - car drivers and passengers, pedestrians, cyclists, bus passengers, etc;
- The physical infrastructure - roads, streets, bridges, cycle paths, etc;
- Vehicles - bicycles, cars, buses, trucks, etc; and
- The rules and information, which support the system.

The Swedish National Road Administration (Vägverket), SNRA, generates and administers the road transport system utilizing society's combined creativity and expertise to maintain the quality of the Swedish roads.
The public road network is divided into three different network categories:

- The national road network (trunk roads)
- The regional road network (regional roads)
- The local network (local roads)

The national road network is specified in the national road management plan while the regional and local road networks are specified in the regional road management plans.

2.2. Snow Cleaning and Winter Road Maintenance

Heavy snow falling countries, snow and ice on the roads lead to significant maintenance costs and socioeconomic penalty such as increased accident risks, reduced accessibility, increased fuel consumptions and vehicle deterioration costs [1] [5]. The maintenance of roads done by SNRA, i.e. salt spreading, gritting, and snow removal, including planning, purchase of equipment etc generates costs for the government up to SEK 1.75 billion and maintenance of the municipal roads about 1 billion every year of which the half corresponds to the snow removal of roads.

![Figure 2.1: Winter maintenance cost of national road network over the duration of five years.](image-url)
The distribution of the annual road maintenance cost over different types of operations for winter road maintenance of the national road network is depicted by the figure 2.2 [5]:

![Winter road maintenance cost distribution](image)

**Figure 2.2: Winter road maintenance cost distribution.**

According to Golamreza[5] and Sajjadul [1] thesis paper, to guide the winter road maintenance, operative standards for road conditions services are set forth by the SNRA. These standards describe in detail the demands on the road condition services for snow and skid-free roads as well as snow-covered roads. Golamreza [5] specified that a snow and skid-free road is defined as a road normally free from snow and ice, and if possible dry in fair weather within a certain time after precipitation. A snow-covered road way is the one that is packed of ice and snow during winter. In fair weather within a certain time after precipitation, the surface must be even and free of loose snow, in addition to having satisfactory friction over the surface.

### 2.3. Swedish Road Network Standard Classes

The road network is divided into different standard classes according to traffic flow and road category in Sweden. Table 2.1 sees the manual road condition services in Sweden [6], defines
the traffic flow, Annual Average Daily Traffic (AADT), as the number of axle pairs for the total bi-directional traffic flow, which is further based on an average day of 24 hours during a calendar year for a certain road section. The road database reflects the traffic flow for motorways as flow per direction and the flows must be added together to obtain the total bidirectional traffic flow.

<table>
<thead>
<tr>
<th>Road Category</th>
<th>Traffic Flow, Annual Average Daily Traffic</th>
<th>National Trunk Road Network</th>
<th>Regional and Local Road Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Trunk Road Network</td>
<td>16000 or More</td>
<td>A1</td>
<td>A2</td>
</tr>
<tr>
<td>National Trunk Road Network</td>
<td>8000 -15999</td>
<td>A2</td>
<td>A3</td>
</tr>
<tr>
<td>Regional and Local Road Network</td>
<td>2000 -7999</td>
<td>A3 alternative B1</td>
<td>A3 alternative B1</td>
</tr>
<tr>
<td>Regional and Local Road Network</td>
<td>500 – 1999</td>
<td>B1 alternative A4</td>
<td>B1 alternative A4</td>
</tr>
<tr>
<td>Regional and Local Road Network</td>
<td>Less than 500</td>
<td>B1</td>
<td>B2</td>
</tr>
</tbody>
</table>

Table 2.1 Standard with Regard to Traffic Flow and Road Category

<table>
<thead>
<tr>
<th>Time Period within a road segment must be ploughed</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard class according to Operation 96</td>
<td>A1</td>
<td>A2</td>
<td>A3, A4, B1</td>
<td>B2</td>
</tr>
</tbody>
</table>

Table 2.2 Classification of roads segments by SNRA standards. Time periods given in hours

**A1** - This class of road have a period of 2 hours, which means that these must be ploughed every 2 hours during snowfall.

**A2** - This class of road must be ploughed every 4 hours during snowfall.

**A3, A4, and B1** - These classes of roads must be ploughed every 6 hours during snowfall.

**B2** - This class of road segment must be ploughed every 8 hours during snowfall.
Due to the large cost of snow removal, decreasing the total cost becomes an important issue. It can be achieved by undertaking different measures such as:

- Determine the depot position minimum one in main city. It’s save lot of time and cost.
- Determine the optimal distribution and allocation of resources and equipments.
- Determine the optimal set of routes for snow ploughs.
- Determine the optimal crew-scheduling program.
- Determine the unimportant road, which is useless amount of traffic.
Chapter 3
Theoretical Background of the Problem

3.1 Sweden Road Network

The test data used in this thesis represents the Sweden road network. Sweden is a Nordic country on the Scandinavian Peninsula in Northern Europe. Sweden has land borders with Norway to the west and Finland to the northeast. Figure 3.1 shows the map of Sweden.

![Map of Sweden](image)
3.2 The Network

We extract information from open street map project (OSM). In this data we find all the Sweden road network information. Using the OSM data we can create a Sweden road network. Form the open street map site we download Sweden different city’s road information. In this data we find nodes and edges information. Node represents the junction or position of one end of the road. Edges represent the road segments. We also need to calculate distance of every edge between two nodes. When we find the distance of every node then we can generate the shortest road network using minimum spanning algorithm. Another very important work is to find the depots position of the city. It is not easy to find the exact position of the depots in the road network. For that reason we apply our own idea to find the position of the depots. Number of depots depends on total area of the city. When we find the exact position of the depots then it is very easy to move vehicle from depots to the entire road network.

Each road segment can be divided into separate segments where every segment defines an edge in the network. The division of each road segment into edges is based on the type, width and the standard class of the road. The following data has been applied to every edge in the network:

- Plowing cost: The cost of plowing the corresponding road segment.
- Plowing time: The time needed to plow the corresponding road segment.
- Transportation cost: The cost of driving the corresponding road segment without plowing it.
- Transportation time: The time needed to drive the corresponding road segment without plowing it.
3.3 SCP Problem and Literature review

The amount of scientific work on the snow cleaning problem is limited. But it is very importance to cleaning snow, disposal, gritting and salt spreading in winter time. SCP problems have not been extensively studied even though the annual expenditures in countries where the problems mention here are major issues. In this section we write the overview of some existing research on SCP is given and an effort is made to introduce various presented solution approaches to these problems.

Early 1970's, Mark and Stricker [7] worked on routing of public service vehicles and in particular discussed the snow cleaning and garbage collection problems. The main difference between these two problems lies in priority constraints in SCP. In general a single vehicle cannot cover the entire road network. They suggest solving the incapacitated version of garbage collection by solving Mixed-Chinese Postman Problem, and explain the similarity between these problems.

In Cook and Alprin (1976) [8] worked on the problem of routing the salt spreader vehicles in an urban environment based on the capacity restrictions of the vehicles. The objective was to minimize the time required to spread salt over a given road segment. Minsk (1979) [9] present the framework for a system analysis of snow removal consists of the following four steps:

- Operating conditions - Climate, road, and traffic.
- System - Traffic of the road.
- System objectives - Keep the network operational during and after periods of snow at minimum cost.
- Control measures - Mechanical/chemical removal, application of abrasives, traction aides on vehicles, closing of routes.
He described that every component of the system along with their associated effects on each other and examines the equipment factors involved in performing the basic functions of snow removal.

In 1984 Lemieux and Campagna [10] worked on the single-depot single-vehicle routing in SCP. Using graph theory he developed the algorithm and finding an Eulerian circuit which is subjected to street priorities ensuring that the main streets are ploughed first and other streets in decreasing order of their importance. The model is described for undirected graph representation of the road network.

In 1991 Halsam and Wright [11] present a multi-objective heuristic for routing problem of snow ploughs in rural environment. This problem is defined as creating a set of routes with minimal cost which is calculated by the number of used snow ploughs and the total distance traveled. The fundamental road network contains road segments that do not belong to the operational city under consideration. They develop an ad hoc algorithm. This has a multi-step procedure in which a route originating from, some seed node is generate successively by adding possible edges to the route having a predefined class and length. The seed nodes are chosen by experts having the knowledge of the geographical configuration of the network. Once the route is generated with non-treated edges then the rout is added to network. If the route is not ended to the depot, the shortest path is added back to the depot by deadheading. Intelligent choices of seed nodes and by varying number of vehicles, the user should be able to reach a solution in polynomial time.

In Campbell and Langvein (1995) [12] presented the snow cleaning problem as a multi-resource generalized problem where the objective is to minimize the total transport cost from sectors to disposal sites, weighted by the annual volume of snow, subjected to capacity constraints on disposal cities and assigning each sector to exactly one site. They suggested two phase heuristic because the inherent complexity (NP-hard) of the problem. The first phase they
used penalty based assignment procedure for disposal of each sector and in the second phase they used two-opt exchange procedure. It carried out to assign the sectors and sites pair wise to decrease the objective value.
Chapter 4

Solution Method

4.1 Open Street Map Data

In this thesis paper we used Open Street Map (OSM) data. OSM is a United Kingdom project to create and provide free geographic data such as street maps and so on. We use the OSM data for creating road network. OSM project provide different types of data such as:

- Nodes- nodes are points with a geographic position.
- Ways- ways are lists of nodes, representing a polygon.
- Relations- relations are groups of nodes, ways and other relations which can be assigned certain properties.
- Tags- tags can be applied to nodes, ways or relations.

We use node, ways, relations and tags for creating city road network. First we take the data from the OSM file then it converted into different format. For example: when we want find the distance between two nodes that time we use latitude and longitude value for finding the distance.

4.1.1 Distance Calculation Using Latitude and Longitude Points

Distance calculation is very important part to find shortest road network. When we want to generate a road network that time we need the distance value between two nodes. Our main goal is to find the shortest road network from the specific city. For that reason we need to calculate every node to node distance. OSM data provide nodes, edges, latitude data and longitude data. We use the ‘Haversine’ formula for calculate great circle distances between the
two points. Using this formula, it is very easy to calculate the distance between two nodes. Haversine formula is:

\[
\begin{align*}
R &= \text{earth’s radius (mean radius = 6,371km)} \\
\Delta \text{latitude} &= \text{latitude}_2 - \text{latitude}_1 \\
\Delta \text{longitude} &= \text{longitude}_2 - \text{longitude}_1 \\
a &= \sin^2(\Delta \text{latitude} / 2) + \cos(\text{latitude}_1) \cdot \cos(\text{latitude}_2) \cdot \sin^2(\Delta \text{longitude} / 2) \\
c &= 2 \cdot \tan^{-2}(\sqrt{a}, \sqrt{1-a}) \\
d &= R \cdot c
\end{align*}
\]

We apply the Haversine formula for calculating distance between two nodes. In the formula R is the radius of the earth that is 6371 km.

**4.2 Minimum Spanning Tree Algorithm**

A minimum spanning tree (MST) is a connected, undirected graph. A spanning tree of a graph is a sub graph which is a tree and all the vertices are connected together. One graph can have many different spanning trees. We can also assign a weight of each edge. A MST is a spanning tree with weight less than or equal to the weight of every other spanning tree [13]. In thesis paper we use the minimum spanning tree algorithm for finding shortest road network of the city. It is very important to find the shortest road network. First priority is clean the shortest road network. When heavy snow is falling in the city that time we need to clean snow from the shortest road first. If shortest road network is established then people can move every node of the city. We provide the data from OSM file. This file contains node, distance between two nodes and node relation. Here distance means weight of each node. Using minimum spanning tree algorithm we find the shortest road network of the city. This network also provides the total shortest path distance. In the below figure we give one example:
Figure 4.1: Bold back line represent the minimum spanning tree in the graph.

In the above graph represent minimum shortest path of the graph. In this graph total node is 10, total edges 21. Total graph distance is 139. After applying the minimum spanning tree algorithm the shortest distance is 38. If we consider the graph as city then a man can visit all the places very shortly. This shortest path saves lot of time and it also save lot of money.

The first time minimum spanning tree algorithm developed by Czech scientist Otakar Boruvka in 1926. He tries to find an efficient electrical coverage of Moravia. That’s why he innovate this algorithm. In the present time two algorithms commonly used Prim's algorithm and Kruskal's algorithm. Both the algorithm is greedy algorithms that run in polynomial time [13]. In this thesis problem we apply prim’s algorithm for finding the minimum shortest path in the city.
4.2.1 Prim’s Algorithm

Prim's algorithm applies for finds a minimum spanning tree for a connected weighted undirected graph. This algorithm finds a subset of the edges that forms a tree that includes every vertex. When we calculate the total weight of all the edges in the tree is minimized [13]. The prim’s algorithm continuously increases the size of a tree or road network, one edge at a time, starting with a tree consisting of a single vertex, until it visits all vertices.

The Algorithm

1. **Input:** A connected weighted graph with vertices \( V \) and edges \( E \). The Graph should be non empty and weights are non negative.

2. **Initialize:** \( V_{\text{new}} = \{x\} \), where \( x \) is an arbitrary node from \( V \), \( E_{\text{new}} = \{\} \)

3. **Repeat until** \( V_{\text{new}} = V \):
   
   a. Choose an edge \((u, v)\) with minimal weight such that \( u \) is in \( V_{\text{new}} \) and \( v \) is not (if one or more number of edges with the same weight than any of them may be selected)
   
   b. Add \( v \) to \( V_{\text{new}} \), and \((u, v)\) to \( E_{\text{new}} \)

4. **Output:** \( V_{\text{new}} \) and \( E_{\text{new}} \) describe a minimal spanning tree

We implement this algorithm using adjacency matrix graph representation. After graph representing we find the minimum weight edge from adjacency graph. This algorithms running time complexity is \( O(V^2) \).
4.2.2 How the Prim’s Algorithm Works

Figure 4.2: Green line shows minimum path of the graph.

Original graph are weighted connected undirected graph as shows in the figure 4.2 and the number represents the weight of the graph. Node D has been arbitrarily select as a starting point. Nodces A, B, E and F are connected to D through a single edge. A is the node closed to D and will be select as the second node along with the edge AD. The next node select is the node closed to either D or A. B is 9 away from D and 7 away from A, E is 15, and F is 6. F is the smallest distance. That’s why highlight the node F and the arc DF. Now the node B is 7 away from A. that why it is also highlighted. Now we can select between C, E, and G. C is 8 away from B, E is 7 away from B, and G is 11 away from F. E is close. That’s why we highlight the node E and the arc BE. Available node are C and G. C is 5 away from E, and G is 9 away from E. C is select. That’s why it is highlighted along with the arc EC [13].

4.3 Vehicle Routing Problems

Vehicle Routing Problem (VRP) is a central place of distribution management. It is also an important combinatorial optimization problem that came up with several powerful exact and approximated solution methodologies. The VRP is an NP-hard [14] problem that is extremely difficult to solve to optimality. Non-deterministic polynomial-time hard (NP-hard) is a class of problem where a known polynomial-time algorithm is there for non-deterministic machine to
get an answer. In excess of 50 cities there is no exact algorithm can consistently solve the VRP instances. That’s why only practical approach is the use of heuristics. Heuristic is a method that is used rapidly come to a solution that is hoped to be close to the best possible solution.

### 4.3.1 Heuristic Solution Techniques

Lot of real-life optimization problems cannot be find solution using any known optimization technique. Even if a technique exists, data requirements or computing time may make using an optimization approach inappropriate. For these types problems a heuristic solution technique may be the only alternative. Heuristic solution very effective finds the optimum result.

### 4.3.2 Heuristic Process

Heuristic is a method that is used rapidly come to a solution that is hoped to be close to the best possible solution. A heuristic method is a "rule of thumb", an educated guess, a sensitive decision or kind of common sense. This method gives a general way of problem solving methodology [13].

Heuristic problem solving method finds different types of rules that give satisfactory solutions to a specific problem. Heuristics describe algorithms which search for good (i.e. close to optimal) solutions at a reasonable computational cost [2]. They are normally used when no well-known optimizing algorithm is available or when an optimizing algorithm is too many costly. Heuristics are often applied to a problem in order to generate a feasible solution. This method can produce lot of different solutions. The heuristic solution will regularly fluctuate from the optimal solution by some unknown margin. Heuristics computational cost relatively low.
4.3.3 Greedy Heuristic

A greedy heuristic is any algorithm that follows the problem solving heuristic of creation the locally optimal choice at each period with the hope of finding the global optimum [1]. One solution generation method and maybe the maximum used heuristic method is the greedy method. The general idea of the method is to start with no assignments of values to variables and from then on, in every step, to assign a value to one variable. The general approach is to select the variable and value that minimizes the increase in the objective function [2].

In the snow cleaning problem we need to find the depots position. Here we apply our own idea to find the position of the depots in the city. After find the shortest road network we know the shortest road network distance. We also need to find number of depot needed in the city. Depot number totally depends on the area size of the city. After calculating the depot number then we go to find the depots position of the city. Here we apply simple idea to find the depot position. First we find maximum area covered connected node. If number of depot is 3 then first three maximum connected node is the depot position. We give more explanation on the implementation chapter.
Chapter 5
Implementation and Result Analysis

5.1 Solution Steps

The data extract from the open street map (OSM). OSM data contains lot of unnecessary information. For that reason we extract important information from the OSM file. In the OSM file we find node id, node latitude, node longitude, way tags and so on. We use C programming for solve this thesis problem. For that reason we extract the important data from the OSM file and calculate in excel application software. Finally we make an input file. In this thesis we need to calculated distance between two nodes. Using the ‘Haversine’ formula we calculate distance between two nodes. In the following example shows how we calculate the distance between two nodes. For example:

\[
\text{latitude}_1 = 23.7970719 \\
\text{latitude}_2 = 23.7945667 \\
\text{longitude}_1 = 90.3800429 \\
\text{longitude}_2 = 90.380618 \\
\text{Distance} = 280 \text{ meter or } 0.28 \text{ km (using Haversine formula)}
\]

Now we can easily calculate the total distance of the specific city. Our main goal is find the shortest way to cleaning the snow of the road network. For that reason it is very important to find the shortest road network for cleaning the snow of the city. After finding the shortest road network we can easily travel all the nodes of the city in the shortest way. In this thesis we use minimum spanning tree algorithm for finding the shortest road network of the specific city. We use prim’s algorithm for find the shortest road network. In the following graphs shows how we convert original road network graph to shortest road network using prim’s algorithm.
In the figure 5.1 shows the original road network. For example node 0 to node 1 distance is 448 meter. In this city total number of node is 11 and total number of road is 50. This city road distance 34.054 km. After collection whole network information then we make an input file. Finally we compile our program and the program generates the shortest road network of the city. Figure 5.2 shows the shortest road network.
Figure 5.2 Program generates the Shortest Road Network. Green line shows the road network.

In the figure 5.2 represent the shortest road network in 50 roads of the city. Green line represents the shortest road network. The shortest road network total distance is 4.536 km. blue numbers represent the distance of every node. Figure 5.3 represent the depot position. Red color shows the depot exact position. Vehicles start working from the depot and cleaning all the snow from the road network.
Figure 5.3: Red color shows the depot position of the road network.

It is very important to find the depot position for efficient snow cleaning from the road network. It is also not easy to find the position of the depot. Figure 5.3 shows the multiple depots. We apply greedy heuristic for find the multiple depots position. One depot can cover 15000 meter area because it is easy to cover the vehicle in that area. It also saves the return time to the depot. It also saves the transportation cost and transpiration time. Number of depot totally depends on total city area. If the city area is big then the program generates more depots depending on the city size. The minimum number of depot is one in a city. Later in this chapter we will discuss more how we create the multiple depots position. Number of vehicle also very
important part of the snow cleaning problem. Snow cleaning vehicle number also totally depends on the city area size. In this paper we propose two types of mode to cleaning the snow from the specific road network. The models are “Economic Model” and “Efficient Model”. The Economic model provides the cheapest solution to clean the snow from city road network and the efficient model find the model to cleaning the snow from the city road network in quick time.

In the economic model, our first target is to establish the shortest road network within time. For that reason first cleaning the snow from the shortest road network of the city and it should be on time. It is very important to establish the road network within time. The shortest road network will be established within 4 hours. After cleaning the shortest road network we go to remove other road network of the city. The vehicles will work until cleaning the whole city road network. The economic model has some advantages. This model need less number of vehicles, less number of worker and less amount of money need to establish this model. According to money concern economic model is best because this model save lot of money. One major disadvantage is there. Economic mode can established shortest road network very quickly after that it takes lot of time to remove the snow for other road network of the city.

In the efficient model, our goal is quickly remove the snow from the shortest road network and also remove the snow as early as possible from the other road network of the city. Efficient model establish shortest road network in quick time. After establishing shortest road network of the city, the vehicle go to remove the other road network of the city and it also takes very short time to clean the snow of the other road network. This model use sufficient number of vehicles, need less amount time to remove the snow from the whole city network and this model takes more money as compare to the economic model.
5.2 Flow Chart of the Overall Program Solution

Start

Data extracted from the openstreetmap.

Read the OSM data and calculate the distance of every node in excel using latitude and longitude point.

Find the shortest distance road network using minimum spanning tree (Prim’s) algorithm.

Calculate the number of depot need depending on road network distance.

Apply greedy heuristic for finding the position of depots.

Generate two types of model. First one is “Economy Model” and second one is “Efficient Model”.

In Economic Model calculate number of vehicles need to clean the snow from road network and calculate total time need to clean the snow from the road network. In Efficient Model also calculate number of vehicles need to clean the whole road network. It also calculates the time.

End

Figure 5.4 The Overall Program.
5.3 Apply Prim’s Algorithms

Prim’s algorithm used for find a shortest road network in specific city. This algorithm generate shortest road network using the OSM data. Using OSM data first calculate distance (weight) in the excel application software. After calculating the distance we make an input file. Using this input file the prim’s algorithm create shortest road network in the city.

5.4 Find the Depots Position

We already generate shortest road network in any city using the above algorithm depending on data used. Now our target is to find the exact depots position on the read network. It is very important to find the multiple depots position in different place of the network. We apply greedy heuristic to find the multiple depots position. When we generate multiple depots position that time we need shortest road network data. We apply our own idea here. First we find total distance of the shortest road network. Now the question is how many depot we search in a city? It is totally depends on whole city road network distance. For that reason we also find the total city road network distance. We fixed the value, every 15000 area equal one depot. First we calculate total city road network distance then the distance divided by 15000 meters. Then we find the how many depot need for whole city road network. Now our goal is to put the multiple depots on exact position of the city road network. We apply simple procedure to find the position of the depots. First we find the every nodes adjacency. It means that every node connected edges in the shortest road network. After that we find the summation of every node connected edges weights in the shortest road network. Finally we put the maximum values node position as a depot position. If total number of depots is 3 then the program give first three nodes maximum values position are the depots position. Figure 5.3 show one example how we find the depot position. In this figure total node number is 11. Node “0” is connected to other 3 nodes. It means node “0” is connected node “1” and the distance is 448 meter. Again node “0” connected to node “2” and the distance is 310 meter. Again node “0” is connected to node “4” and the distance is 337 meter. The total distance of three nodes is 1095 meter. This
value put into the array which shows in the figure 5.5. Node “1” is connected only one node which is node “0”. The total distance of node “1” is 448 meter. Node “2” is connected two nodes which are node “0” and node “3”. Node “2” total distance summation 585 meter and it also put in the array. In the same way we calculate all the node distance summation which is shows in the figure 5.5. Finally we sort the array value. In this example total number of depots is three. So the depots nodes are node “8”, node “5” and node “0”. It is shows in the figure 5.3.

![Array Image](image)

Figure 5.5: Summation of every node adjacency distance connection.

![Program Output](image)

Figure 5.6: Program Output shows the result of number of depots need in this city.
5.5 Results

This program generates two types of model. First one is economic model and the second one is efficient model.

5.5.1 Economic Model

In the economic model, our first target is to establish the shortest road network within 4 hours. For that reasons first cleaning the snow from the shortest road network of the city. After cleaning the shortest road network we go to remove other road network of the city. The vehicles will work until cleaning the whole city road network. Now we represent statistical result of Economic Model. In this model we consider the road size is 12 foot for each lane and we also conceder all the roads are double lane. The Interstate Highway System uses a 12-foot standard for lane width [13]. In the following we give calculation formula that is use in the economic model.

\[
\text{Snow cleaning time (hours)} = \frac{(\text{DSRN} \times \text{Road Lane} \times \text{Road lane width})}{\text{PMC}} / 60 \text{ minutes}
\]

\[
\text{No. of vehicle} = \frac{\text{Snow cleaning time (hours)}}{\text{TL}}
\]

Here, DSRN = Distance of the Shortest road network
PMC = per minute snow cleaning distance. Here it is 50 meter.
TL = Time limit. For economic model we use 4 hours.

<table>
<thead>
<tr>
<th>Road length in Meter</th>
<th>Road lengthin Square Meter</th>
<th>Lane</th>
<th>No of vehicles</th>
<th>Time in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>34054</td>
<td>249275.28</td>
<td>2</td>
<td>3</td>
<td>27.6973</td>
</tr>
<tr>
<td>43600</td>
<td>319152.00</td>
<td>2</td>
<td>9</td>
<td>11.8204</td>
</tr>
<tr>
<td>44700</td>
<td>327204.00</td>
<td>2</td>
<td>7</td>
<td>15.5811</td>
</tr>
</tbody>
</table>
Table 5.1: Economic model of the total city area road network information

In the table 5.1 shows the economic model of the total area road network information. In this table provide three city’s information. Each vehicle can clean every one minute equal to 50 square meter areas snow. First city total area is 34.054 km. they use only 3 vehicles to clean the entire road network snow and it takes approximately 28 hours. Second city total area is 43.6 km. Number of vehicles used 9 and it takes close to 12 hours to clean the snow of the entire road networks. Third city’s total area is 11.3 km. To clean the entire road network it used 7 vehicles and it takes 15.58 hours.

<table>
<thead>
<tr>
<th>The road length in Meter</th>
<th>The road length in Square Meter</th>
<th>Lane</th>
<th>No of Vehicles</th>
<th>Time in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>4536</td>
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<td>2</td>
<td>3</td>
<td>3.6893</td>
</tr>
<tr>
<td>14700</td>
<td>107604.00</td>
<td>2</td>
<td>9</td>
<td>3.9853</td>
</tr>
<tr>
<td>11300</td>
<td>82716.00</td>
<td>2</td>
<td>7</td>
<td>3.9389</td>
</tr>
</tbody>
</table>

Table 5.2: Economic model of shortest city area road network information

In the table 5.2 shows the economic model of shortest road network snow cleaning information. First city’s shortest road network is 4536 meter. Three vehicles can clean the shortest road network within 4 hours. Second city used 9 vehicles and third city used 7 vehicles clean the shortest network. This model totally focused on the shortest road network cleaned first within 4 hours.

5.5.2 Efficient Model

In the efficient model, our goal is quickly clean the snow from the shortest road network and also remove the snow as early as possible from the other road network of the city. Efficient model establish shortest road network within 2 hours. After establishing shortest road network...
of the city, the vehicle go to remove the other road network of the city. In the following we give some calculation formula that is use in the efficient model.

Snow cleaning time (hours) = ((DCRN * Road Lane * Road lane width) / PMC) / 60 minutes

No. of vehicle = (Snow cleaning time (hours) / TL)

Here, DCRN = Distance of the total city road network

PMC = per minute snow cleaning distance. Here it is 50 meter.

TL = Time limit. For economic model we use 8 hours.

<table>
<thead>
<tr>
<th>The road length in Meter</th>
<th>The road length in Square Meter</th>
<th>Lane</th>
<th>No of vehicles</th>
<th>Time in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>34054</td>
<td>249275.28</td>
<td>2</td>
<td>10</td>
<td>8.3092</td>
</tr>
<tr>
<td>43600</td>
<td>319152.00</td>
<td>2</td>
<td>13</td>
<td>8.1833</td>
</tr>
<tr>
<td>44700</td>
<td>327204.00</td>
<td>2</td>
<td>14</td>
<td>7.7905</td>
</tr>
</tbody>
</table>

Table 5.3: Efficient model of the total city area road network information

In the figure 5.3 shows the efficient model total city area snow cleaning information. Efficient model main goal is to clean the whole network within 9 hours. First city used 10 vehicles and 8.3 hours take to clean the snow entire city road network. Second city used 13 vehicles and time spends to clean the whole city network 8.2 hours. Third city it takes 7.8 hours to clean the entire city road network and vehicles used 14.

<table>
<thead>
<tr>
<th>The road length in Meter</th>
<th>The road length in Square Meter</th>
<th>Lane</th>
<th>No of Vehicles</th>
<th>Time in Hours</th>
</tr>
</thead>
<tbody>
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<td>4536</td>
<td>33203.52</td>
<td>2</td>
<td>10</td>
<td>1.1067</td>
</tr>
<tr>
<td>14700</td>
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<td>2</td>
<td>13</td>
<td>2.7587</td>
</tr>
<tr>
<td>11300</td>
<td>82716.00</td>
<td>2</td>
<td>14</td>
<td>1.9694</td>
</tr>
</tbody>
</table>
Table 5.4: Efficient model of shortest city area road network information

Efficient model clean the snow shortest road network first. This model also takes very less amount of time to clean the shortest road network of the city. Shortest road network snow cleaning information shows in table 5.4. Efficient model always work effectively as compare to economic model. In the result analysis section we give more analysis information.

5.6 Results Analysis

In this section we compression both model and find which model provide the best output. We also give some analytical graphical output of the both economical and efficient model.

Shortest City Road Network

<table>
<thead>
<tr>
<th>The road length in Meter</th>
<th>Economic Model</th>
<th>Efficient Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Vehicles</td>
<td>Time (Hours)</td>
</tr>
<tr>
<td>4536</td>
<td>3</td>
<td>3.69</td>
</tr>
<tr>
<td>14700</td>
<td>9</td>
<td>3.99</td>
</tr>
<tr>
<td>11300</td>
<td>7</td>
<td>3.94</td>
</tr>
</tbody>
</table>

Table 5.5 Compression between Economic and Efficient model of shortest road network

In the table 5.5 shows the compression between economic and efficient model of shortest city road network information. In the economic model used less number of vehicles for cleaning the snow of the shortest road network. At the same time efficient used more vehicles as compare to economic model. Again efficient model need less number time to cleaning the shortest road network. But economic model takes much more time as compare to efficient model. Finally we can say that, economic model used less number of vehicles. If we think about the costing then it
better model. At the same time efficient model used more number of vehicles that is more expansive as compare to the economic.

### Entire City Road Network

<table>
<thead>
<tr>
<th>The road length in Meter</th>
<th>Economic Model</th>
<th>Efficient Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Vehicles</td>
<td>Time (Hours)</td>
</tr>
<tr>
<td>34054</td>
<td>3</td>
<td>27.70</td>
</tr>
<tr>
<td>43600</td>
<td>9</td>
<td>11.82</td>
</tr>
<tr>
<td>44700</td>
<td>7</td>
<td>15.58</td>
</tr>
</tbody>
</table>

Table 5.6 Compression between Economic and Efficient model of entire city road network

Now we discuss about the entire city road network. Table 5.6 shows the both economic and efficient model information. In the efficient model take very less amount of time as compare to economic model. We can say, efficient model is best because it takes less amount of time. But according to money concern economic model is best because economic model used less quantity of vehicles.
Figure 5.7: Vehicles comparison between economic and efficient model.

In the figure 5.7 shows the number of vehicles need in both models. Figure clearly shows the economic model use less number of vehicles and efficient model use more vehicles as compare to economic model. For that reason we can easily says the efficient model implement cost much higher than the economic model.
Figure 5.8: Shortest road network snow cleaning time compression of both models.

Figure 5.8 shows the shortest road network snow cleaning time compression between economic and efficient model. In this figure it clearly shows that economic model takes more time as compare to the efficient model.

Figure 5.9: Entire city road network snow cleaning time compression of both models.

Figure 5.9 shows the entire city road network snow cleaning time compression between economic and efficient model. When we use the economic model to clean the entire city road network that time it takes long time as compare to the efficient model. When we consider time we use efficient model.
Chapter 6

Conclusions and Future Work

6.1 Conclusions

Snow cleaning is an important task in winter time. In this thesis we proposed an effective solution to cleaning snow of entire road network of the city. We apply to minimum spanning tree algorithm for finding shortest road network and the greedy heuristic is apply for finding multiple depot positions of the city. Both the algorithms provide very good solution.

When snow is falling vehicles drive to the depots and have to clean the entire road network depending on the importance of the road. In this thesis we propose shortest road network establish first. It means that first importance is shortest road network of the city. After cleaning shortest road network, it cleaning the other road network of the city.

In this thesis paper we proposed two types of solution models. First model is the “Economic Model” and the second model is “Efficient Model”. Both the models provide different types of solutions. According to the money concern “Economic Model” is the best because economic model use less number of vehicles. Most important part of economic model need less amount of money for implement. Second model is efficient model. If we consider time and quality of snow cleaning then we used the “Efficient Model”. Efficient model work very quickly and it use sufficient number of vehicles for cleaning the snow. Finally we can say both the models generate good results.
6.2 Future Work

In future we try to use different method to find the snow cleaning problem. In this thesis paper we apply minimum spanning tree algorithm for generate shortest road network and greedy heuristic for finding the depot position of the road network. In future we will apply different method. Finally we will test it our present solution is optimal solution or not.
References


[13]. From Wikipedia, the free encyclopaedias. www.wikipedia.com