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Winter Gritting in the Province of Antwerp : a Combined Location and Routing Problem

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Abstract

The problem of winter gritting, which involves salt spreading to ensure the safety of road users, is described in detail for the Province of Antwerp. Other than location of main depots, at which all salt spreading tours originate and terminate, the problem also includes location decisions with respect to supplementary depots. Existence of supplementary depots allows trucks to refill during a tour, and thus enables tours to have double-capacity. Location decisions and the subsequent routings are further constrained by partition into districts, and by priorities associated with the roads of the network.

In this paper a two-stage framework for analysis is suggested. It bonds location of main depots with routings on high-priority roads at the first stage, and location of supplementary depots with routings, which can include double-capacity tours, at the second stage. A small example demonstrates the potential savings involved in implementing the new approach.

Keywords : depot location, capacitated arc routing problem, winter gritting, districting

1. Introduction

Street cleaning, snow removal, garbage collection, mail delivery, and school bus routing are some of the most frequently studied real life capacitated arc routing problems (Eiselt et al. 1995a and 1995b). For a comprehensive review see Assad and Golden (1995). Less frequently studied is the similar problem of gritting (Eglese and Li, 1992, Li and Eglese 1995). Gritting is a common practice in winter time in many countries with a moderate climate. Winter gritting involves the spreading of salt ($CaCl_2$ or NaCl) on the roads. There are two kinds of gritting : curative and preventive gritting. Curative gritting is required when frost, ice, or snow have made the roads slippery. Preventive gritting is done when icy conditions are expected to occur. In this paper we focus on curative and not on preventive gritting since it is the more crucial and complex.

In practical contexts, many vehicle routing problems appear in combination with a location problem regarding location of depots or facilities from which the vehicles have to operate. Sometimes the location and routing problems cannot be neatly separated and a combined location-routing approach is required. This often appears to be the case for salt spreading since salt-refilling facilities can be easily relocated.

In this paper we analyse the combined location-routing problem of winter gritting. We describe all the relevant features of this service, its operational difficulties, and the necessary trade-offs. We propose a new modelling approach and pay special attention to its location aspects. Our approach builds on the actual application of organising the salt-spreading operation in the Flemish province of Antwerp. We believe that the Antwerp case is representative of the gritting problem in Belgium and abroad.

2. Winter gritting in the province of Antwerp

Flanders, the northern part of Belgium, is divided into five provinces, Antwerp being one of them. The province of Antwerp has a surface of 2,867 square km, and a population of 1,600,000. Its capital, situated in the western part, is the city of Antwerp, which is an important port with a population of about half a million. The province borders the Netherlands in the north (Figure 1).

While the responsibility for all the "regional" roads in the territory of Flanders lies with the Flemish Government, that for the local roads lies with the communes. Thus salt spreading operations on the regional roads are organised by the Flemish administration, at a cost of approximately 240 million Belgian francs per year. The salt spreading operations on the local roads are organised by the communal authorities. There is no real co-operation between these two authorities. The Flemish administration has its maintenance and salt spreading activities organised per province, where each province is further divided into several districts.

Until recently (end of 1994), the province of Antwerp with 1,084 km of regional roads, was divided into nine districts : Antwerpen, Ruisbroek, Deurne, Wilrijk, Brecht, Vosselaar, Grobbendonk, Turnhout, and Geel (Figure 1). A district is named according to the commune in which its main depot is located. Every district had one main salt depot from which all gritting tours had to start, and at which they had to end. Often a few salt depots of smaller capacity were available for refilling during trips.

The managers of operation in the province were not satisfied with the state of affairs. Division into districts have developed in the past rather haphazardly. Furthermore, districts' borders, routes for gritting, the number of depots and their location, had all evolved accidentally or by rules of thumb.

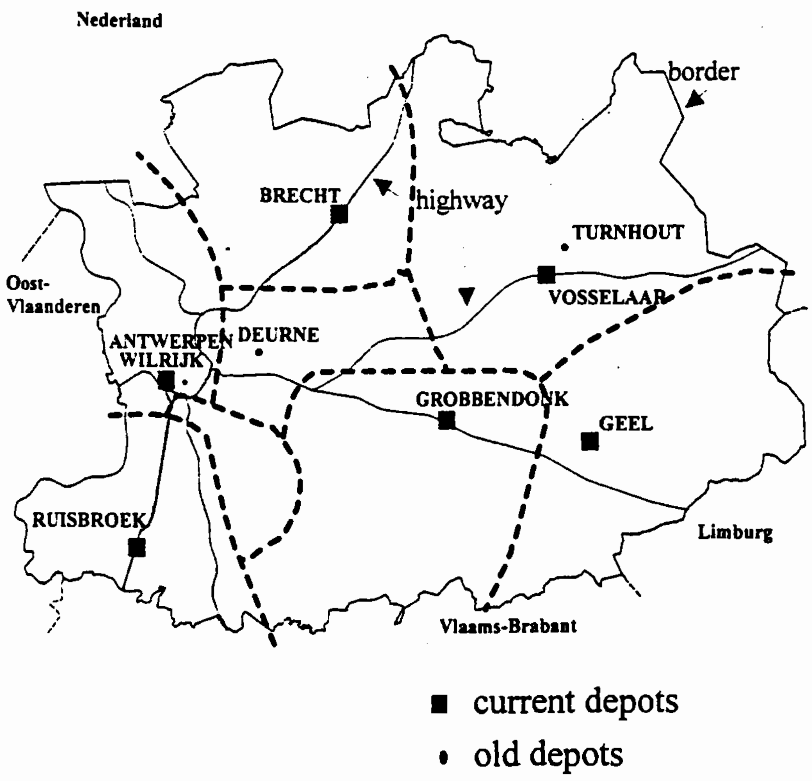

Figure 1: The Province of Antwerp and its salt depots

Given the increasing pressure for cost reduction, management was interested in a more systematic and cheaper organisation, in particular there was an interest in reducing the number of employees at (main) depots. Thus they decided to reduce the number of districts from nine to six (Figures 1 and 2). Antwerpen, Deurne, and Wilrijk were combined into one district because their main depots were geographically close. The new district covers the area of greater Antwerp and the port area, with its main depot being the depot of Antwerpen, located at the Kennedy tunnel under the river Scheldt. Similarly the districts of Vosselaar and Turnhout were combined with the Vosselaar depot serving as the new main depot. Furthermore, small adjustments were made to the definition of district borders, but not based on real analysis. Management did not explicitly consider the impact of districting on the gritting tours.

Following the above described changes, it has become clear that a more rigorous analysis was needed in order to improve the operations of salt-spreading and its management. It was at this stage, in early 1995, that we started our study.

3. Main operational features

We next summarise the main operational aspects of winter gritting in the province of Antwerp.

The Network

The network is composed of 257 nodes and 747 links based on a road map. A priority level is assigned to each link, corresponding to the importance of servicing it. Clearly highways and important motorways are assigned the highest priority level, these links are characterised by facilitating uninterrupted traffic flow, and typically by having 2-3 lanes in each direction with separation between opposite directions. All the other links in the network are defined to be low-priority links. From operational point of view, the rest of the links are considered to have approximately the same priority level. Hence the links of the network can be naturally divided into: high-priority links, and low-priority links. The width of a lane belonging to the high-priority links is 3.75m, and that of the low-priority links ranges from 3.25m to 3.75m.

Districts

The organisational unit for salt spreading activities is the district. A district should not be too small in order to keep fixed costs (e.g. personnel cost) reasonable. On the other hand, districts cannot be very large either, otherwise weather conditions might differ in parts of the district, making the organisation and management more complex. Time constraints further restrict the size of a district. For example, managers would like to ensure that high-priority links are serviced within at most two hours from the start of the gritting operation, and the low-priority links are serviced within at most 2-3 hours. Thus the time restriction constraint is very active in shaping the borders of the districts in Antwerp in which no substantial topographical differences exist, and where the climate is similar throughout the whole province. In general, there is a declared trend to reduce the number of districts.

Depots

There is one main depot in each district. All gritting tours must start from the main depot and end there. This arrangement facilitates the overall organisation, particularly the management of the gritting equipment, trucks and mills.

Secondary depots, which are used for refilling salt in the course of a tour, are of the horizontal or the vertical (silo) type. In the future all secondary depots will be of the vertical type. Silos can easily be located or re-located on small patches of land (often available near the entrances or exits of highways).

They do not require operator attendance, their maintenance cost is minimal, and a driver can refill a truck at a silo without assistance.

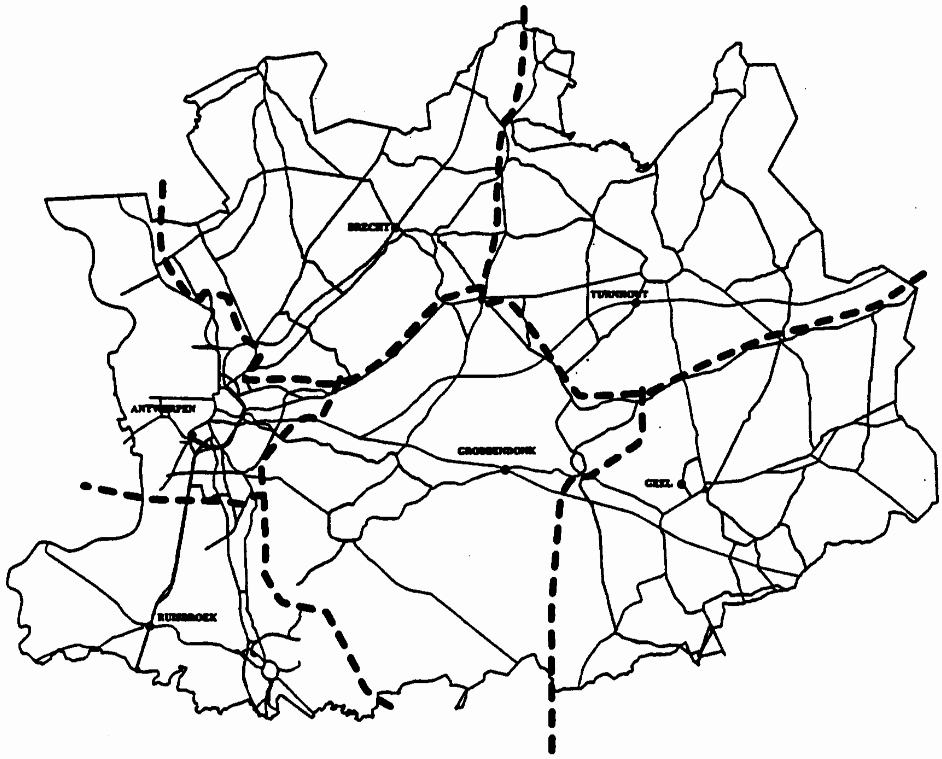

Figure 2: The Province of Antwerp divided in six districts

Trucks

All trucks have an equal capacity of four cubic meters or 5,700 kg of NaCl. Approximately 90 trucks participate in the gritting, out of which about 40% belong to the Flemish administration, and the rest are subcontracted.

Operations

Typically, salt-spreading starts in the early hours of the morning to prevent ice forming. In the province of Antwerp, gritting operations start from 4 a.m. onwards. Not all trucks start from the depot at the same time, thus queuing is minimal and can be ignored. About 25g of salt per square meter is needed for curative gritting, which is required when snowing or the roads are icy already. Thus a truck can spread one lane of approximately 70 km before its capacity is exhausted. The amount of salt that is being spread could be adapted according to circumstances, and truck drivers have the ability to control the quantity of salt spread from within the truck. By adjusting the location of the salt spreader, a truck can spread one or two lanes in one pass. Obviously when spreading two lanes, double the amount of salt is required.

Routings

Each tour must start and end at a main depot. However, a truck can refill salt at a supplementary depot during the trip, and thus tours can be either single capacity tours (without refilling), or up to double-capacity (with refilling). For the high-priority links, two lanes are spread in each direction at one pass. If a third lane exists it is usually not spread with salt. The exits and parking areas that are associated with the high priority links are spread at a second pass. Low priority links can be spread either in two directions (servicing one lane at a time), or in one pass (servicing the two lanes together).

Decisions

Management is confronted with various decision problems concerning location, routings, and their combined operation. With respect to location, it has to decide where to locate depots, when to relocate existing depots, and to where. For a given location of depots, it has then to determine the best routings. Routings are influenced by the desire of management to make them efficient according to desirable performance measures, but also by managerial and operational constraints (e.g. the decision whether a silo should be used exclusively by trucks of one district or not).

Performance Measures

Efficiency of the overall gritting operation is a complex concept and it depends on various measures of performance. Tours are considered efficient if they contain only a small proportion of dead-mileage, where the latter is defined by mileage travelled on roads that are not being serviced. Thus minimising the total amount of dead-mileage travelled is a declared objective. However, routings with minimal dead-mileage can be achieved at the high cost of having many depots. Hence the objective of minimising the number of depots is clearly an underlying guideline. Furthermore, minimisation of the number of trucks (or tours) is also an important goal. And so is compliance with time restrictions for providing a quick service to the high-priority roads. Finally, achieving an operation scheme which is flexible and easy to implement and adapt, both for managers and for drivers, is a natural, yet hard-to-formalise, aim.

4. The combined location-routing problem : a two-stage approach

There are important interactions among definition of districts' boundaries, location of main depots, location of supplementary depots, and the resulting routings. The interactions among districting, location decisions and routings, are demonstrated in Figure 3.

For a given partition into districts, location decisions and the subsequent routings for gritting can be viewed on two levels:

1. location of main depots
2. location of supplementary depots

An appropriate main depot location requires a suitable plot of land which should satisfy logistical and environmental considerations, such as easy access to operations, minimal disturbance to neighbouring facilities, etc. It should also be noted that relocating existing depots is considered feasible but not very practical, and hence should be recommended only if major improvements and savings are involved.

Location of supplementary depots, on the other hand, is much more flexible. Silos, as described in Section 3, need small space, can be easily relocated, and require no man-power for operation.

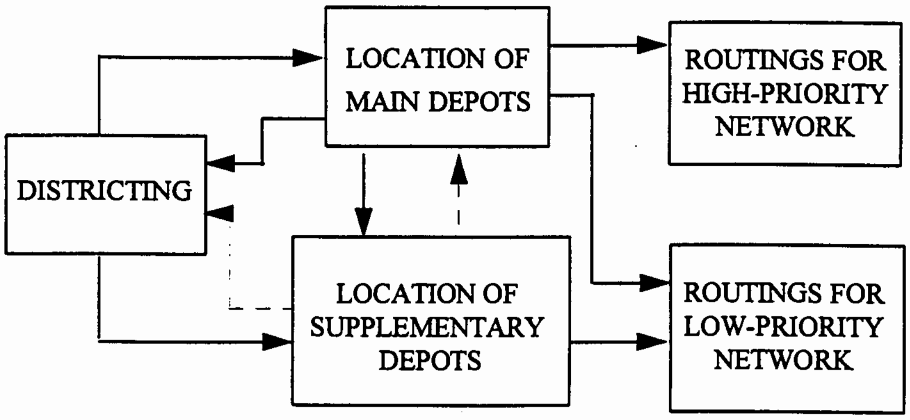

Figure 3: Interactions among main components

Following the inherent differences between main and supplementary depots, we suggest to bond their location decisions with another pivotal feature of the problem: the concept of priorities. Consequently, the suggested framework for analysis bonds location of main depots with routings for service of high-priority links, and location of supplementary depots with routings for service of low-priority links.

Districting

The definition of districts' boundaries strongly affects the overall combined location-routing problem. Moreover, since relocating main depots is operationally very cumbersome and thus not realistic, adjustment of districts' boundaries to support the existing location of main depots could further improve the efficiency of the resulting routings.

Division into districts is strongly compound with location of main depots, since all tours must start and end at the same depot, and spread salt only on roads belonging to the relevant district. Hence it is natural to expect that main depots would not be located near boundaries of districts. Furthermore, in order to avoid dead-mileage and long tours, it is natural to locate main depots close to the centre of districts. However, this is not necessarily the case for the current location of main depots and the new districts' boundaries. This phenomenon could be the result of evolutionary gradual changes which were made to districts' boundaries while keeping the location of main depots fixed.

Next we propose an intuitive and straightforward procedure for districting. It is based on assigning links to the closest depot, and thus avoids location of main depots on boundaries of districts. Furthermore, it tries to create for each district a sub-graph with even degree nodes, and thus to enable tours with less dead-mileage.

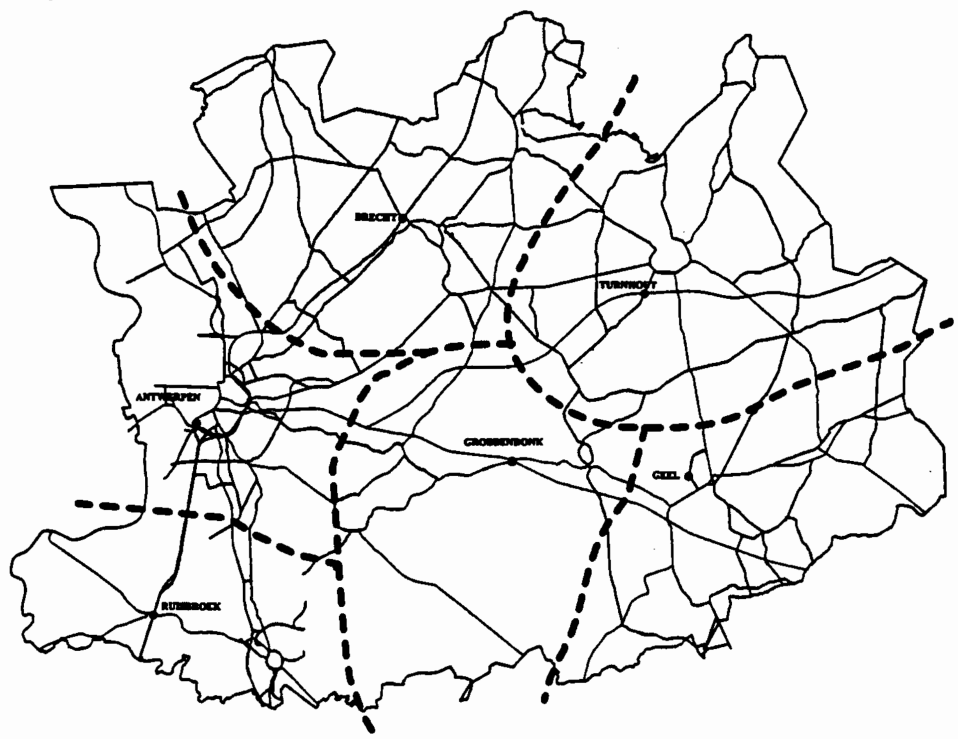

Figure 4: Districting based on shortest distances

Districting Procedure

Initialisation:

Let G be a given network, let (i,j) be a link in the network connecting nodes i and j, let D_k k=1,2,...,K be the network's main depots, and let d(a,b) be the shortest distance from a to b.

Assignment based on short distances:

For all links (i,j) $\in$ G assign link (i,j) to district k if $d(D_k,i) \leq d(D_p,i)$ and $d(D_k,j) \leq d(D_p,j)$ for all $p \neq k$.

Assignment based on node degree:

Otherwise, let D_k be the depot closest to node i, and D_p the depot closest to node j. If the degree of node i, based on links that already have been assigned to D_k, is odd - then assign link (i,j) to D_k. Similarly, if the degree of node j is odd then assign link (i,j) to D_p.

Random Assignment:

Otherwise, assign arbitrarily.

The first phase of assignment based on short distances is demonstrated in Figure 4 for the province of Antwerp. It can be seen that it motivates central location of main depots. The second phase of the assignment is based on the degree of nodes and results in more efficient tours.

4.1 Stage I: Location of main depots and routings on high-priority links

The high-priority links constitute the high-priority network (Figure 1). The motivation for servicing the high priority network separately emanates from the importance that operators associate with providing a good and quick service to it. The separation provides an easy operation scheme both for operators and drivers, and facilitates a faster service to high-priority links, since by definition, no low-priority links exist on tours which serve the high-priority network.

In order to comply with the importance of servicing the high-priority network fast, another guideline is maintained: all tours are single capacity tours. In other words, tours which service the high priority network do not refill at a supplementary depot as this operation would prolong the duration of the tour. Therefore, the location of supplementary depots is irrelevant for servicing the high-priority network.

Given the bonding between main depots and the high-priority network, it is clear that main depots should be located on or very close to the high-priority network. This observation is almost fully validated for the current location of main depots as demonstrated in Figures 1 and 2. All main depots are actually located on high-priority links, except the depot of the district of Geel, which is currently used only by tours which service the low-priority network.

As can be clearly seen in Figure 2, the high-priority network is characterised by having a *tree* type of topology rooted around the ring of Antwerp. This structure is quite typical for areas around big metropolitan centres. The location problem can then be formulated as follows:

(L1) *Determine the minimal number of depots and their location (on a tree structure) such that there exists a feasible routing (for a given truck capacity) with no dead-mileage.*

The problem (L1) always has a feasible solution which guarantees no dead-mileage, however it could include a prohibitive number of depots and tours. Consider, for example, the simple tree in Figure 5a, the figures on the links indicate their length (which needs to be serviced). Assume that truck capacity is such that a single truck can spread a total length of 10 units, and that each link has to be traversed in both directions. In order to construct a feasible solution to (L1) a bottom-up approach is carried on. That is, the tree is traversed from its leaves towards the root, and whenever truck capacity is exhausted (after traversing length that is equivalent to half capacity), a depot is located in order to avoid dead-mileage. Figure 5b presents the result of implementing this approach to the tree in Figure 5a. It includes 3 depots, 5 tours, and no dead-mileage. Obviously the solution suggested in Figure 5b is very expensive both in terms of number of depots and number of tours; it is also characterised by having depots located very close to each other, and tours that do not exploit their full capacity. Clearly the objective of achieving no dead-mileage is not realistic, especially not when weighted against locating additional depots. Hence (L1) is reformulated as follows:

(L2) *Given a fixed number of depots, K, determine their location (on a tree structure) such that there exists a feasible routing (for a given truck capacity) with minimal dead-mileage.*

For the example of Figure 5, an optimal location for the problem (L2) with K=2 is presented in Figure 5c. It includes 2 depots, 4 tours, and a total of 2 units of dead-mileage. It can be easily verified that the location in Figure 5c is optimal since a two-depots solution will always require dead-mileage, and 2 is the lower bound for an integer round-trip routing. Note also that all tours are up to their full capacity. An optimal location for K=1 is presented in Figure 5d and entails 4 tours, and a total of 14 units of dead-mileage.

Obviously the number of depots resulting from (L1) is an upper bound to the potential number of depots for which (L2) should be solved. Thus the combinatorial problem (L2) should be solved a few times for K values smaller than the one obtained in (L1). Finally the proper trade-off between the number of depots and total amount of dead-mileage must be made, and a particular solution should be selected. In practice, districting and capacity constraints will entail small sized instances of (L2).

With respect to the high priority network, it can be verified that for the province of Antwerp a 5-depots solution (without the depot of Geel) satisfies the no-dead-mileage requirements. Furthermore, even a 4-depots solution without dead-mileage exists. It consists of eliminating the depots of Geel and Ruisbroek, and relocating the depot of Brecht 16 km south-west closer to the city of Antwerp. Clearly this 4-depots scheme is operationally not feasible since it involves relocation of an existing main depot.

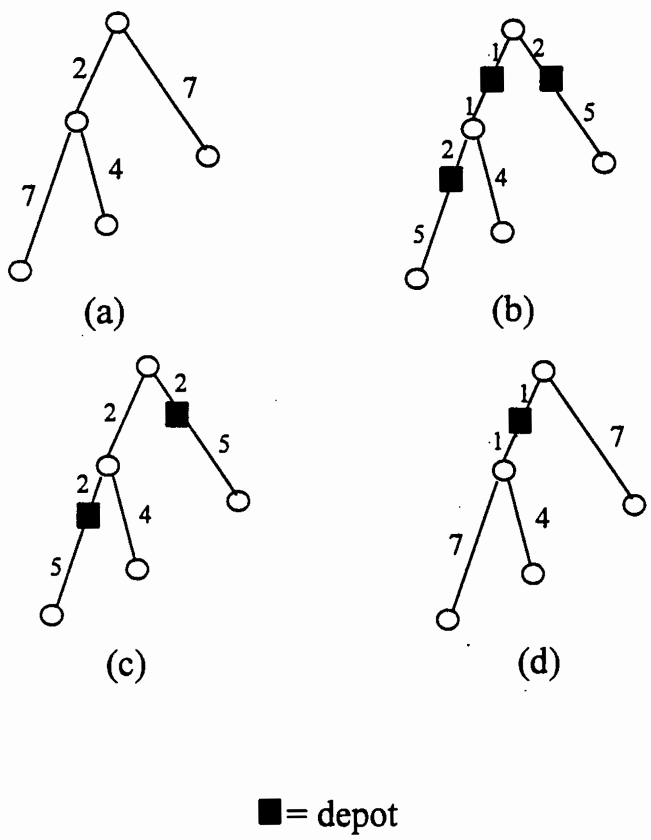

Figure 5: Depot location on a tree

4.2 Stage II: Location of supplementary depots and routings on low-priority links

The low-priority links constitute the secondary network which is naturally more dense than the high priority network. Routings on the secondary network can be viewed as a capacitated arc-routing problem (CARP) which is known to be NP-hard (Golden and Wong, 1981), with the additional following features:

- Existence of districts. Salt can be spread only on links belonging to the district from which the tour was originated. Other links can be traversed but not serviced.
- Existence of supplementary depots. Routes can pass through supplementary depots for refilling, thus some tours can have up to double capacity.
- Links can be serviced twice (once in each direction) spreading one lane each time, or once spreading two lanes in one pass.

As was discussed in Section 3, location of supplementary depots (denoted by silos from here on) is flexible and their maintenance is considered inexpensive, thus management is willing to consider suggestions for relocation of existing silos and recommendations for locating new ones.

Location of silos and the associated routing problem is one of the subjects we are further studying. At least to our knowledge almost no references exist yet to outline clear guidelines for location of silos and their use for routings. Bouliane and Laporte (1992) address the problem of locating relay boxes for refilling during tours of mail delivery. They assume that the routings are given, and formulate the problem as a set covering problem which minimises the number of relay boxes location. Li and Eglese (1995) consider the possibility of having the option to refill the gritting truck at a refilling centre (silo), however they assume that the location of the refill centres is given. While constructing their tours, refilling a truck at a silo is considered if truck capacity has been exhausted, or if the salt left is less than half of truck capacity and the distance the truck can grit is less than the distance to the nearest salt-refill location. Existing CARP-heuristics can be updated to accommodate the location of silos. Consider, for example, the heuristic suggested by Pearn (1991) for the capacitated arc-routing problem on sparse networks with large arc demands. Assume that we want to locate silos such that overall performance is improved. Pearn's algorithm progresses in two phases. At the first phase tours are constructed to include expensive links (links that are far away from the depot). The links within a tour are then serviced (according their cost) until truck capacity is exhausted. Based on the logic of this phase, a silo can be considered for insertion if the tour's required capacity is close to twice (or more) the truck capacity. At the second phase of the algorithm, tours are constructed to include isolated arcs that were not serviced at the first stage. Clearly servicing isolated arcs in different parts of the network can be very expensive. Hence silos should be considered whenever existence of isolated arcs can be avoided.

Current practice assumes that silos are district-related and thus can be used only by tours originating from the district's main depot. Since there is no operational justification for this practice and no real capacity constraint associated with the capability of a silo to be used by tours belonging to different districts, we strongly recommend to abort this practice and allow silos to be free from district association.

Furthermore, the current partition into districts in the province of Antwerp, is such that for each main depot D_k (belonging to district k) and every link (i,j) belonging to district k, it is almost always possible to construct a tour which includes link (i,j) and has no dead-mileage. In other words, the districts are relatively small, and thus capacity does not impose serious constraints on servicing links which are far away from the depots. Thus, silos should be located on the borders of districts, in order to serve more than one district, and allow the augmentation of two single capacity tours into one double capacity tour. Figure 6 demonstrates this idea. Locating a single silo on the border of the three districts can be as effective as locating three district-specific silos, one for each district. Currently there are several silos which are located on borders of districts, such as the one in Poederlee (on the border of Turnhout and Grobbendonk), however, it is used only by the district of Grobbendonk eliminating the ability of the district of Turnhout to make its routings more efficient.

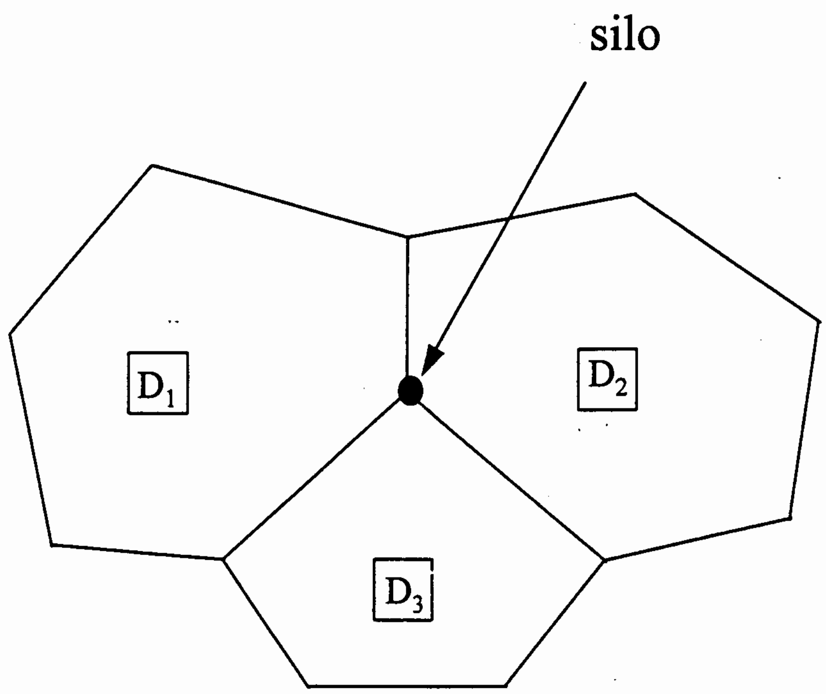

Figure 6: Central location of silo

5. Numerical Example

As an example, we consider the district of Brecht (with its borders as defined by the end of 1994) as illustrated in Figure 7. Salt spreading on the highways of the district is not considered since it is straightforward and is performed by separate tours.

Table 1 presents detailed information on the network of Brecht. The links are indicated by start and end nodes, the type of the link corresponds to its width (type 1 = 3.75 m and type 2 = 3.25 m), and the length of the links is indicated in the last column of the Table. The distance matrix is assumed to be symmetric.

The actual routing that was performed at the end of 1994, included six tours, a total of salt spreading on 318 km of lanes, and a total of 64.3 km of dead-mileage. The total distance travelled was hence 382.3 km. Van de Locht (1995) improved the routing by reducing the number of tours to five and the amount of dead-mileage to 29.7 km. The total distance travelled thus became 347.9 km. The increase in travel time was negligible, and the longest tour took less than 2h30min.

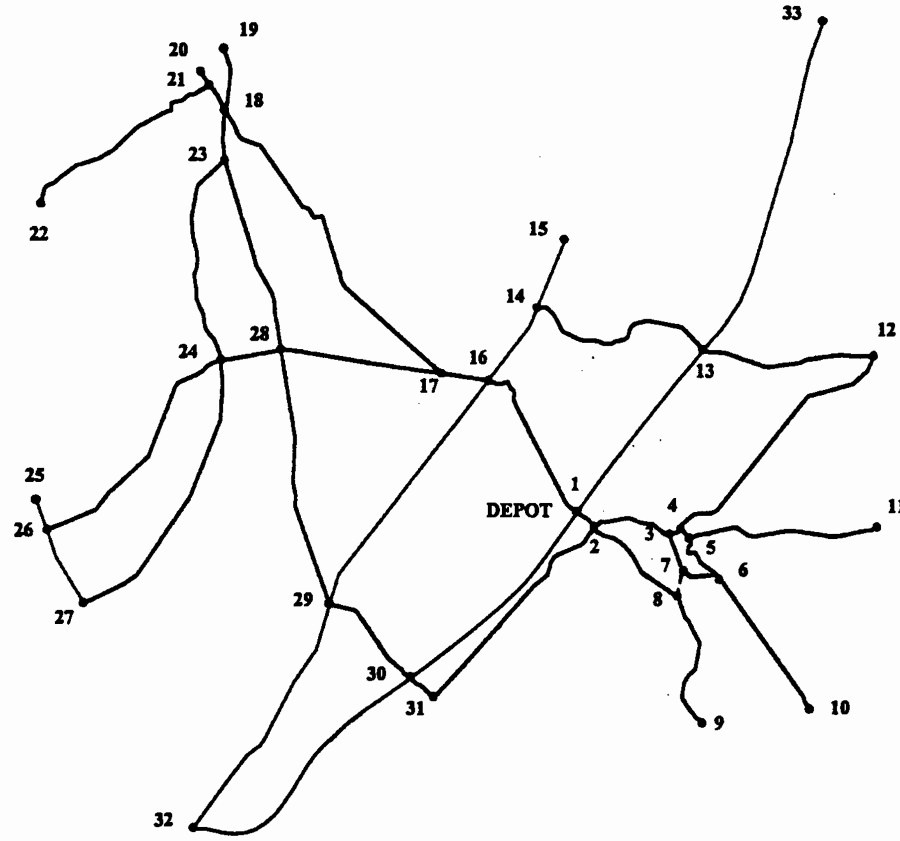

Figure 7: The district of Brecht

When two lanes are spread in one pass, the total distance travelled decreases although the amount of dead-mileage increases. The result is 159 km of salt spreading and 114.4 km of dead-mileage, or a total distance of 273.4 km. A possible addition of a silo allows routes 1 and 2 to be combined, and results in a total distance of 250.5 km. Table 2 summarises these results. The last column in the Table indicates the relative decrease in the total distance travelled compared to the actual routing performed. Thus, the total distance travelled can be reduced by 28% by allowing two lanes to be spread in one pass, and by 34% by including a silo. Obviously, present planning practices are not "optimal" and more careful design and routing could produce further improvements.

Table 3 provides a detailed description of the various tours, note that all tours originate and end at the main depot marked by node 1. Underlined links indicate dead-mileage and italic links indicate travelling on the highway (also considered as dead-mileage). The location of the silo is not unique and feasible locations are indicated by bold node numbers. The Table also provides information on the spreading distance and the dead-mileage (X/Y), and the total travel time for each route. Calculation of travel time is based on the following assumptions (Van de Locht, 1995) :

- speed while spreading on type 1 road : 50km/h, type 2 road : 30 km/h
- deadheading speed : varying between 30 and 50 km/h depending on whether the roads have been serviced before.

link	type	length (km)
1-2	2	0.80
1-16	2	5.09
2-3	2	2.43
2-8	2	3.30
2-31	2	7.18
3-4	2	0.47
3-7	2	1.43
4-5	2	0.50
4-12	2	7.64
5-6	2	1.80
5-11	2	5.79
6-7	2	1.15
6-10	2	4.51
7-8	2	0.81
8-9	2	4.40
12-13	2	5.67
13-14	2	5.71
14-15	1	2.11
14-16	1	2.70
16-17	2	1.45
16-29	1	8.30
17-18	2	10.26
17-28	2	4.92
18-19	2	3.84

link	type	length (km)
18-21	2	1.20
18-23	2	1.58
20-21	2	0.57
21-22	2	6.53
23-24	2	6.59
23-28	2	5.90
24-26	2	7.69
24-27	2	8.80
24-28	2	1.86
25-26	1	0.91
26-27	1	2.49
28-29	2	7.77
29-30	2	3.33
29-32	1	10.49
30-31	2	1.00
highway		
1-13		6.28
1-30		7.37
13-33		10.48
30-32		8.10

Table 1: Characteristics of the road network

	salt - spreading (km)	dead - mileage (km)	total distance (km)	relative decrease in total distance %
one lane in one pass				
situation end 1994	318	64.3	382.3	100
Van de Locht	318	29.7	347.7	91
two lanes in one pass				
without silo	159	114.4	273.4	72
with silo	159	91.5	250.5	66

Table 2: Comparison of routing strategies

It can be seen that servicing two lanes at once reduces total travel distance, especially the spreading distance. This results in shorter overall travel times, and hence increases the level of service. The introduction of a silo reduces the number of tours to four and decreases the total dead-mileage travelled, but naturally increases the travel time of the tour that utilises a silo, as can be seen in the last section of Table 3. Hence, management has to consider trade-offs between level of service (i.e. time duration of tours) and cost (i.e. costs of silos, trucks, and dead-mileage).

Tour description		distance spread / deadhead (km)	time hours & minutes
end 1994			
route 1	1-16-14-15-14-13-12-13-14-16-17-18-21-20-21-18-17-16-1	56.4/12.1	2h05
route 2	1-16-29-32-29-30-31-30-29-16-1	46.2/10.2	1h19
route 3	1-16-17-28-29-28-23-18-19-18-21-22-21-18-23-28-17-16-1	64.0/12.6	2h27
route 4	1-16-17-28-24-27-24-26-25-26-27-26-24-23-24-28-17-16-1	56.7/22.9	2h25
route 5	1-2-31-2-3-7-6-7-8-9-8-2-8-7-3-2-1	50.4/1.6	1h43
route 6	1-16-1-2-3-4-12-4-5-11-5-6-5-4-3-2-1	44.8/4.9	1h35
Van de Locht			
route 1	1-16-29-32-29-16-14-15-14-16-1	57.38/0	1h17
route 2	1-16-17-18-19-18-21-20-21-22-21-18-23-28-23-18-17-16-1	62.7/10.2	2h22
route 3	1-16-17-28-24-26-25-26-27-26-24-27-24-23-24-28-17-16-1	66.5/13.1	2h29
route 4	1-2-3-4-12-13-14-13-12-4-5-11-5-6-10-6-5-4-3-2-1	67.4/3.2	2h19
route 5	1-2-31-30-29-28-29-30-31-2-3-7-6-7-8-7-3-2-8-9-8-2-1	64.0/3.2	2h12
without silo			
route 1	1-16-17-18-19-18-21-20-21-22-21-18-23-28-17-16-1	31.3/28.7	1h41
route 2	1-16-17-28-24-27-26-25-26-24-23-28-17-16-1	33.3/24.8	1h39
route 3	1-2-3-7-6-7-8-9-8-2-31-30-29-28-17-16-1	31.2/19.4	1h28
route 4	1-2-3-4-5-6-10-6-5-11-5-4-12-13-14-16-1	34.5/21.2	1h35
route 5	1-16-14-15-14-16-29-32-30-1	28.7/20.3	1h03
with silo			
route 1	1-16-17-28-24-27-26-25-26-24-23-28-23-18-21-22-21-20-21-18-19-18-17-16-1	64.6/30.6	2h47
route 2	1-2-3-7-6-7-8-9-8-2-31-30-29-28-17-16-1	31.2/19.4	1h28
route 3	1-2-3-4-5-6-10-6-5-11-5-4-12-13-14-16-1	34.5/21.2	1h35
route 4	1-16-14-15-14-16-29-32-30-1	28.7/20.3	1h03

Table 3: Tour description under various strategies

6. Conclusions

The problem of winter gritting was described in detail for the Province of Antwerp. The problem was presented as a combined location-routing problem which is also strongly related to the partitioning into districts. The problem includes unique features such as existence of supplementary depots for refilling, and priorities among the links that need to be gritted.

A two-stage framework for analysis was suggested. It bonds location of main depots with routings on high-priority roads at the first stage, and location of supplementary depots with routings, which can include double-capacity tours, at the second stage.
A small example demonstrated the potential savings involved in implementing the new approach.

It appears that a systematic analysis, as presented in this paper, is a prerequisite for better design, decision making, management and operation. A thorough analysis leads to a more cost-effective organisation and routing of trucks in the short-run. More important however, are the insights produced for application of operations in the long-run. Particularly relevant are the ideas for districting and location of silos.

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