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A case study of combined winter road snow plowing and de-icer spreading

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Abstract

In this article, we address a winter maintenance problem where the streets need to be plowed and gritted in a sequence that depends on the class of the road.The maintenance fleet includes vehicles equipped for plowing, some for spreading, and some for both at once. The objective is to complete the operations as rapidly as possible while considering street hierarchy, turn restrictions, heterogeneous speeds and street/vehicle compatibility. An Adaptive Large Neighborhood Search framework is developed to solve the problem. An analysis of the results obtained can not only provide a good basis for vehicle routing, but help managers plan long-term policies and investments.

Keywords: winter road maintenance, vehicle routing, Adaptive Large Neighborhood Search (ALNS), heuristic algorithm, snow plowing, salt spreading, sand spreading, winter gritting.

Résumé

Cet article traite d'un problème d'entetien hivernal où les rues doivent être déblayées et un traitement d'épandage appliqué dans un ordre donné qui varie selon le type de route. Parmi les véhicules disponibles, certains sont équipés pour déneiger, certains pour épandre et d'autres peuvent réaliser les deux tâches simultanément. L'objectif du problème proposé est de terminer les opérations le plus tôt possible en considérant la hiérarchie du réseau, des restrictions sur les virages autorisés, des vitesses d'opérations variables selon le type de véhicules et la compatibilité entre les rues et les véhicules. Un algorithme de type Adaptive Large Neighborhood Search est développé pour résoudre le problème. Les résultats permettent non seulement d'obtenir des circuits pour les véhicules, mais également une meilleure planification des politiques et des investissements à long terme.

Mots-clés : entretien routier hivernal, viabilité hivernale, tournées de véhicules, Adaptive Large

Neighborhood Search (ALNS), algorithme heuristique, déneigement, déblayage, épandage de fondants, épandage d’abrasifs.

1 Introduction

In winter maintenance, spreading chemicals and abrasives and plowing snow are common operations performed to keep the roads safe and passable. In recent years, the problems related to the routing of the vehicles used for these operations have drawn more attention (Campbell et al. 2014; R. Eglese et al. 2014). However, it appears that in the scientific literature, these operations have been considered either independent either from each other or as being performed concurrently in one passage by a set of homogeneous multitask vehicles. In reality, it often happens that the authorities responsible for winter maintenance operations manage a fleet of heterogeneous vehicles which can be equipped to perform gritting, plowing or both at once thus making the routing problem more complex. This article, two types of maintenance operations are required for each street. The first one, spreading, also known as gritting or salting/sanding, consists in putting chemicals and abrasives on the road surface to improve vehicle traction. The second one, plowing, consists in pushing the snow to the side of the street in order to clear the way for road traffic.

Depending on the type of vehicle servicing the street on the first passage, a second service might be required. The routing of the spreaders and snowplow is related to arc routing problems. One major difference between the two is that spreader routing is generally considered on an undirected graph with limited vehicle capacity while snowplow routing is generally considered on a directed graph with turn restrictions. There are other characteristics that can be similar or different for the two operations as shown in Table 1. The challenge underlying these constraints is that the problems are often site-specific. It is then difficult to develop a methodology that can cope with various situations.

[Table 1 about here.]

In this article, we adapt and test a methodology that considers the interrelation between the spreading and snow plowing operations. This work is motivated by real winter road maintenance in a northern city in the province of Québec.

The rest of the article is organized as follows. Section 2 reviews major works about routing for snow plowing and gritting. Section 3 describes the case study for this work and the methodology used to tackle the problem. Section 4 presents and discusses the tests performed, and concluding remarks are provided in Section 5.

2 Literature Review

Winter snowplow and winter spreader operations present a special case of arc routing problems where a set of links must be serviced. They are very challenging because they involve a large set of constraints which depend largely on local conditions and practices. In the next sections, we review some major works about routing problems for snow plowing and winter spreading. For more information about arc routing problems, we refer the reader to Corberán and Laporte (2014).

2.1 The snowplow routing problem

Thorough literature reviews covering different snowplow routing problems from an operational research perspective have been produced by Perrier et al. (2007b) and Campbell et al. (2014). Cabral et al. (2004) study the general case of the Hierarchical Chinese Postman Problem (HCPP) where the streets are assigned categories indicating the order in which they should be serviced. They also consider the notion of precedence, since vehicles take more time to go along a street that has not been plowed . A graph transformation, a decomposition and a makespan heuristic are used to solve the problem.

Similar constraints are addressed by Perrier et al. (2008) in a case study based on the City of Dieppe, New Brunswick. They consider priority classes based on traffic volume, road/vehicle compatibility, load balance, different service and deadheading speeds, and turn restrictions. A parallel algorithm heuristic and cluster-first, route-second methodology are devised to solve the snowplow routing problem.

Dussault et al. (2013) also take into account precedence together with turn penalties and asymmetrical weights when vehicles are plowing uphill in the context of snow plowing. They devise a local search algorithm, which they subsequently tested using theoretical instances.

Synchronized arc routing is introduced in Salazar-Aguilar et al. (2012). This situation occurs when a multi-lane road must be plowed by several vehicles side by side in one passage. The authors devise a metaheuristic to solve the problem. It is applied to theoretical benchmark instances and to a real case study in the city of Dieppe, New Brunswick.

Liu et al. (2014) use a Memetic Algorithm with Extended Neighborhood Search (MAENS) to create snowplow routing within the city of Edmonton, Alberta. They perform a sensitivity analysis to determine how many vehicles should be used to perform the plowing operation. They also measure the impact of the depot location on the travel distances and travel times of the vehicles.

Another case study was performed on three cities in the province of Québec (Quirion-Blais et al. 2015; Quirion-Blais et al. 2016). In order to solve the snowplow routing problem, the authors devise a metaheuristic that factors in partial area coverage, service hierarchy, balanced workload, street/vehicle compatibility, one-way streets and turn restrictions.

2.2 The spreader routing problem

R. Eglese et al. (2014), Perrier et al. (2012), and Perrier et al. (2007a) review works dealing with winter spreaders. R. W. Eglese (1994) addresses gritter routing while considering salt capacity, network hierarchy and multiple depots. He heuristically solves a case study and concludes that the number of depots can be halved without increasing the number of vehicles and while respecting the constraints.

Muyldermans et al. (2002) focuses on district designs for salt spreading, taking into account vehicle capacity and the workload balance among vehicles. In an attempt to measure the quality of their cluster, they also use a heuristic to build the salting routes.

A dynamic version of the problem is studied by Handa et al. (2005) and Handa et al. (2007). They adjust route planning using a genetic algorithm based on updated information obtained from Next Generation Road Information Systems. They test their algorithm on the road network of South Gloucestershire and achieve a 10% improvement in terms of total distances traveled by the trucks compared with the routing in use.

Tagmouti et al. (2007) address another dynamic version of the problem for which the service cost is a time-dependent piecewise linear function. In further works, they use a Variable Neighborhood Descent heuristic to solve the problem within a reasonable time (Tagmouti et al. 2010; Tagmouti et al. 2011).

More recently, Gudac et al. (2014) also devised two heuristics which are fed using real-time information. Their algorithm considers vehicle capacity, priorities and load balancing.

2.3 The combined snowplowing and winter spreading problem

In Gupta et al. (2010) a routing model is developed to estimate the workforce required to plow the streets. They mention heterogeneous vehicles that could perform plowing, spreading or both; for the model, however, they consider that all streets require only one service where both plowing and spreading is performed simultaneously by uniform vehicles. In their work, they also consider multiple depots, variable speeds, weather input and U-turns penalties and they prioritize roads with high Annual Average Daily Traffic (AADT).

Hajibabai et al. (2014) study the case where plowing and spreading are performed concurrently in Lake County, Illinois. They devise a model and a heuristic that takes into account priorities, turn restrictions, salt and fuel capacity. In a further work, the dynamic version of the problem is also considered (Hajibabai and Ouyang 2016).

Kinable et al. (2016) study a problem where all the vehicles perform both spreading and plowing at the same time in the city of Pittsburgh, Pennsylvania. In their work, the vehicles need to service the complete network while minimizing the makespan. They consider a mixed multigraph since some streets can be serviced in only one passage in either directions and they take into account the following constraints: heterogeneous capacity, limited fuel and salt capacity and several depots. They model the problem with a Mixed Integer Programming (MIP) and a Constraint Programming (CP) models and they propose a constructive heuristic to solve the problem.

3 Case Study and Methodology

In this section, we describe the case study and the solution methodology we use to tackle the problem.

3.1 Case study

The case study for this article is from a small city in Northern Québec, Canada. Figure 1 shows the road network, which is composed of 527 kilometres of roadway. While freeways, arterials and collectors are serviced under the provincial authorities, the city is in charge of the local roads, which account for 347 kilometres. They are divided into a three-class hierarchy: commercial (c-), residential (re-) and rural (ru-) streets. All the local streets need to be gritted and plowed after a major snow event.

[Figure 1 about here.]

Three types of vehicles are available: graders, front-end loaders, and tandem axle trucks. The graders and the front-end loaders can only plow the streets while the tandem axle trucks can plow, spread or do both at once. Commercial streets have to be plowed by graders, which can remove snow more effectively. Back alleys, which are narrower need to be serviced by the front-end loaders and only once in either direction. For the case we are presenting, a total of eight vehicles are available : two graders, three front-end loaders and three tandem axle trucks. The operating and deadheading speeds for each type of vehicle are given in Table 2.

[Table 2 about here.]

Figure 2 shows the steps to be performed during a normal snow event. At the beginning of the snowfall, the tandem axle trucks are sent to grit the commercial streets. The second step starts when a sufficient quantity of snow has accumulated on the ground. Then all the vehicles start to plow the road network in order of priority: commercial streets first, followed by residential streets and finally rural streets as shown in steps 2, 3 and 4. Afterward, the tandem axle trucks are sent out to grit the streets that have not yet been gritted. For this last step, no hierarchical classes are observed.

[Figure 2 about here.]

It should be noted that it is not required to end the previous step before starting a new one. For example, the graders can still be plowing the commercial streets while the other vehicles start plowing residential streets. However, all the higher priority classes must be completed before the lower ones. Therefore if all residential streets are cleaned before the commercial streets then the ending time of the residential streets is extended until all the commercial streets are cleaned. Since some streets are only plowed by vehicles in the second, third or fourth step, they still need to be gritted by another vehicle. Thus, in a fifth step the tandem axle trucks are required to grit the streets not plowed by them previously.

Another operational constraint that should be considered is that heavy vehicles cannot be operated as easily as cars. Therefore U-turns can be dangerous and should be avoided. For most intersections, the danger is so high that U-turns are prohibited; nevertheless, they are mandatory on dead-end streets. In between, some U-turns are allowed if they can save a lot of time.

Another consideration that should be taken into account during plowing is that snow is being pushed to the right side of the truck. Therefore when the vehicle travels straight ahead through an intersection or turns left, the driver needs to take extra care not to leave any snow windrow in the middle of the intersection. Considering this, right turns should be favored as much as possible and the number of left turns kept to a minimum. On the other hand, it is also considered good practice to complete all the segments of one street before starting another.

3.2 Solution methodology

To address these constraints, we opted for a solution based on the Adaptive Large Neighborhood Search (ALNS) metaheuristic. This algorithm is divided into two steps. Initially, a solution, which consists of a set of routes, one for each vehicle, is built using a simple construction heuristic. Then, the initial solution is sent to an improvement step where route sections are removed and reinserted elsewhere, in the same route or in another one. The route sections to be removed are selected following certain rules described by the neighborhood destruction operators. For example, one neighborhood operator can choose to remove the links that incurs the highest costs. This rule can be applied one or several times before the solution is sent to a neighborhood repair operator, which reinserts the links following a certain strategy in order to obtain a feasible solution. An example of a construction operator would be to insert some of the removed links in the position that incurs the least cost in the solution.

The strength of the ALNS lies in the fact that there are different neighborhoods and in the adaptive mechanism which chooses these operators. One operator might behave better in improving solutions that are penalized by hierarchy constraints, while another might behave better for improving routes that have a lot of deadhead. The efficiency of the neighborhood operators varies depending on the characteristics of the network, the constraints and the advancement in the search phase. The adaptive neighborhood selection mechanism helps to choose the best operators at the best moment.

The ALNS used for this work is adapted from the one devised for the snowplow routing problem in Quirion-Blais et al. (2016). The procedure consists in first applying the algorithm iteratively for each hierarchical class and one more time while considering all classes but not changing the arcs from one priority to another. To integrate the spreading phase, we modify this framework as shown in Figure 3. The new methodology is described as follows:

Step 1: The algorithm is used to develop **spreaders** routes for the **commercial** streets. We consider this step independently from the others since the completion time does not have any relationship with the other steps. Therefore, we do not consider this step in the makespan of the operations but rather start to measure the time after the dashed line in Figure 2. Since this step can be taken independently from the rest of the methodology, it is not considered in the rest of this article.

Step 2: The algorithm is used to develop **snowplow** routes problem for the **commercial** streets.

Step 3: The third step of improvement builds the plow routes to **plow** the residential streets. The ending time from the previous step is also used in order to balance the total length of each route.

Step 4: The fourth step of improvement is similar to the third step except that we are improving the **plowing** routes for the **rural** streets.

Step 5: Before starting the fifth improvement phase, the data for the **spreading** step for the **residential** and **rural** streets have to be updated. Indeed, all the streets serviced by the tandem axle trucks in the third and fourth steps can be removed since these trucks can perform both spreading and plowing at the same time. Then the improvement step can be performed using the ending time from the previous step to balance the workload among the trucks.

Step 6: Before starting this improvement step, **all the routes** from the other steps, except the first one, are **merged** for each vehicle. Then the ALNS can pick and insert links in all the routes as long as the priority class and the street/vehicle compatibility are respected. For this part of the improvement phase, an additional step is added before inserting the links in the vehicle routes. If a link in class re or ru is inserted in the route of a tandem axle truck, then all the tandem axle truck routes are inspected to remove this arc from the spreading phase. On the other hand, if a link in class re or ru is inserted in a route of a vehicle that cannot plow, then the tandem axle truck routes are inspected to find the link in their spreading phase. If it is not found, the link is immediately inserted into the tandem axle truck spreading phase using the best insertion procedure.

[Figure 3 about here.]

A few other modifications are brought to the algorithm so that it gives a better representation of reality :

- The objective function to be improved is the following:

$$z = \sum_{p \in P} (t^p M^p) + t^{deadhead} M^{deadhead} \tag{1}$$

where the variables t^p and $t^{deadhead}$ are respectively the ending time for each priority p and the cumulative deadheading time, the constants M^p and $M^{deadheading}$ are weights set by the user to give more or less importance to each priority or the deadheading time, and P is the set of priorities.

- Since turn restrictions are different for the spreading and plowing steps, two matrices of distances between the arcs are built. The plowing distances are used until the vehicle starts spreading, after which the spreading distances are used.

- The turn penalties depend on the angle between the arc entering and the one leaving as shown in Table 3.

- A street/vehicle compatibility constraint is enforced.

- In all cases, the weight $M^{deadhead}$ is set equal to 1. This part of the objective function is used to help the metaheuristic to find improvements.

- The weights affecting the ending time in the objective function are modified by trial and error following the value of the ending time. The goal is to keep the values of each part of the objective function, or each priority, in the same order of value unless otherwise specified.

- The seeds for which the clusters are built in the initial solution are located by an expert based on vehicle type and number.

- We did not consider any capacity.

[Table 3 about here.]

[Figure 4 about here.]

4 Experiment and Results

The algorithm was used first with the fleet of vehicles in current use for the case study. Figure 5 shows the routing obtained for each vehicle. It can be seen that the vehicles that can do both spreading and plowing are sent to the extremities of the network and come back to the centre to grit the streets, which have been plowed by the other vehicles in the first phases.

[Figure 5 about here.]

Then, the algorithm is applied using various fleet configurations to reflect life events. To do so, the number of vehicles is varied by removing or adding one from or to the number in vehicles of the current fleet. The various combinations obtained are shown in Table 4. It should be noted that fleets having fewer than six or more than ten vehicles are not considered since they too different from the current situation. Some tests are also done with the same number of vehicles as in the current fleet, but changing the values of the weights in order to give more importance to each part of the objective function. Four tests are carried out by iteratively doubling the value of each part of the objective function.

[Table 4 about here.]

For each fleet configuration, ten replications are done and the lowest value of the objective function for each set is kept. The ending time, including the turn penalties for each street class and the deadhead time obtained, are shown in Figure 6.

[Figure 6 about here.]

When looking at the ending time of the c-class for all the fleets studied, we can see that it is directly related to the number of graders. This is explained by the fact that c-streets can only be serviced by graders. Since the number of graders seems to be a bottleneck for this fleet, we can measure the effect of adding or removing one such vehicle in terms of time. According to the graphs, the ending time of the c-class is about 12,000 seconds with one grader, 6,000 seconds with two graders and 4,200 seconds with three graders. One can observe that there is a big improvement when upgrading from one grader to two. This is explained by the topology of the networks, when looking at Figure 1 one can see that the c-class can easily be divided into two. Separating the streets into three parts is less evident and the time reduction is much less significant.

On the other hand, graphs (f) in Figure 6 show that the ending time of the c-class seems to be insensitive to moderate variations in the weights of the objective function. Again, this shows that the current number of graders is low considering the actual network and constraints. Even when putting a moderate emphasis on the other parts of the objective function, the ending time of the c-class stays about the same.

The results also tend to show that there is one front-end loader in excess when looking at the 2-2-3 and the 2-3-2 configurations in part (b) of Figure 6. Indeed, ending time for the c- and re-class are about the same and slightly extended for the ru-class slightly extended and the more or less extended for the spreading phase depending on which type of vehicle is removed. This situation can be maintained voluntarily in order to prepare in case one of the vehicle breaks down. The rest of the fleet would still be able to service all the streets in a reasonable time.

Part (d) of Figure 6 can also be used to determine which type of vehicle should be chosen in case the authorities want to expand the fleet. In this case, one should choose between a tandem axle truck, which decreases the ending for the ru-streets and the spreading phase, or a grader, which can reduce the ending time for the c-streets as well. Adding one front-end loader would only reduce the ending time of the ru-class while that of the spreading phase stays about the same.

5 Conclusion

In this article, we have introduced a new problem: dual demand routing. The main difficulty in this problem lies not only in that several routes must be developed within a large-scale network, but also that some vehicles can perform only one operation while others can perform both at the same time. We have developed an ALNS framework that can effectively find a solution to the problem. It takes into account: turn restrictions, network hierarchy and street/vehicle compatibility, and heterogeneous vehicle speeds. This solution is not intended to replace the planners, but rather to provide a starting solution which respects their constraints while taking advantage of the dual functionality of some vehicles.

For this article, we use the hypothesis that the speed of each vehicle is relatively uniform within one snow episode and from one episode to another. The calculation time of the algorithm makes it difficult to use it in a dynamic environment. When the conditions are harsher, one can assume that all the vehicles are going to be slowed down uniformly. Hence, the same routing can be used and the routes will still be balanced. If, for some reason, the speeds of the vehicles do not vary uniformly, then the method can be used to plan different scenarios of snow fall with different speeds on the network. The manager will then be able to select the scenario that fits the best to the current conditions.

More than merely providing some routes, we have shown that the tools can effectively be used for tactical planning. When applied to a case study, we have seen that the current fleet has one excess front-end loader. The algorithm can then be used to help determine how to change the fleet composition or how to change the winter management policies if required.

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References

Cabral, E. A., Gendreau, M., Ghiani, G., and Laporte, G. 2004. Solving the hierarchical Chinese postman problem as a rural postman problem. European Journal of Operational Research **155**(1):44–50. DOI: `http://dx.doi.org/10.1016/S0377-2217(02)00813-5`.

Campbell, J. F., Langevin, A., and Perrier, N. 2014. Advances in Vehicle Routing for Snow Plowing. In Arc Routing: Problems, Methods and Applications. Edited by Á. Corberán and G. Laporte. Society for Applied Mathemtics and the Mathematical Optimization Society, Philadelphia, PA. Chap. 14. pp. 321–350. DOI: `10.1137/1.9781611973679.ch14`. eprint: `http://epubs.siam.org/doi/pdf/10.1137/1.9781611973679.ch14`.

Corberán, Á. and Laporte, G. 2014. Arc Routing. Edited by G. Laporte and Á. Corberán. Society for Industrial and Applied Mathematics, Philadelphia, PA. DOI: `10.1137/1.9781611973679`. eprint: `http://epubs.siam.org/doi/pdf/10.1137/1.9781611973679`.

Dussault, B., Golden, B., Groër, C., and Wasil, E. 2013. Plowing with precedence: A variant of the windy postman problem. Computers & Operations Research **40**(4):1047–1059. DOI: `http://dx.doi.org/10.1016/j.cor.2012.10.013`.

Eglese, R. W. 1994. Routeing winter gritting vehicles. Discrete Applied Mathematics **48**(3):231–244. DOI: `http://dx.doi.org/10.1016/0166-218X(92)00003-5`.

Eglese, R., Golden, B., and Wasil, E. 2014. Route Optimization for Meter Reading and Salt Spreading. In Arc Routing: Problems, Methods and Applications. Edited by Á. Corberán and G. Laporte. Society for Applied Mathemtics and the Mathematical Optimization Society, Philadelphia, PA. Chap. 14. pp. 303–320. DOI: `10.1137/1.9781611973679.ch13`. eprint: `http://epubs.siam.org/doi/pdf/10.1137/1.9781611973679.ch13`.

Gudac, I., Marović, I., and Hanak, T. 2014. Sustainable Optimization of Winter Road Maintenance Services Under Real-time Information. Procedia Engineering **85**:183–192. DOI: `http://dx.doi.org/10.1016/j.proeng.2014.10.543`.

Gupta, D., Tokar-Erdemir, E., Kuchera, D., Mannava, A. K., and Xiong, W. 2010. Optimal workforce planning and shift scheduling for snow and ice removal. Tech. rep. MN/RC 2011-03. St. Paul, Minnesota: Minnesota Department of Transportation.

Hajibabai, L., Nourbakhsh, S., Ouyang, Y., and Peng, F. 2014. Network Routing of Snowplow Trucks with Resource Replenishment and Plowing Priorities. Transportation Research Record: Journal of the Transportation Research Board **2440**:16–25. DOI: `10.3141/2440-03`. eprint: `http://dx.doi.org/10.3141/2440-03`.

Hajibabai, L. and Ouyang, Y. 2016. Dynamic Snow Plow Fleet Management Under Uncertain Demand and Service Disruption. IEEE Transactions on Intelligent Transportation Systems **17**(9):2574–2582. DOI: `10.1109/TITS.2016.2520918`.

Handa, H., Chapman, L., and Yao, X. 2005. Dynamic salting route optimisation using evolutionary computation. In 2005 IEEE Congress on Evolutionary Computation. Vol. 1. Pp. 158–165. DOI: `10.1109/CEC.2005.1554680`.

— 2007. Robust Salting Route Optimization Using Evolutionary Algorithms. In. Evolutionary Computation in Dynamic and Uncertain Environments. Edited by S. Yang, Y.-S. Ong, and Y. Jin. Springer Berlin Heidelberg, Berlin, Heidelberg. Pp. 497–517. DOI: `10.1007/978-3-540-49774-5_22`.

Kinable, J., Hoeve, W.-J. van, and Smith, S. F. 2016. Optimization Models for a Real-World Snow Plow Routing Problem. In. Integration of AI and OR Techniques in Constraint Programming: 13th International Conference, CPAIOR 2016, Banff, AB, Canada, May 29 - June 1, 2016, Proceedings.

Edited by C.-G. Quimper. Springer International Publishing, Cham. Pp. 229–245. DOI: `10.1007/978-3-319-33954-2_17`.

Liu, G., Ge, Y., Qiu, T. Z., and Soleymani, H. R. 2014. Optimization of snow plowing cost and time in an urban environment: A case study for the City of Edmonton. Canadian Journal of Civil Engineering **41**(7):667–675. DOI: `10.1139/cjce-2013-0409`. eprint: `http://dx.doi.org/10.1139/cjce-2013-0409`.

Muyldermans, L., Cattrysse, D., Oudheusden, D. V., and Lotan, T. 2002. Districting for salt spreading operations. European Journal of Operational Research **139**(3):521–532. DOI: `http://dx.doi.org/10.1016/S0377-2217(01)00184-9`.

Perrier, N., Campbell, J. F., Gendreau, M., and Langevin, A. 2011. Vehicle Routing Models and Algorithms for Winter Road Spreading Operations. In Hybrid Algorithms for Service, Computing and Manufacturing Systems: Routing and Scheduling Solutions. Edited by J. R. Montoya-Torres, A. A. Juan, L. H. Huatuco, J. Faulin, and G. L. Rodriguez-Verjan. Information Science Reference, Hershey, PA. pp. 15–46. DOI: `DOI:10.4018/978-1-61350-086-6.ch002`.

Perrier, N., Campbell, J. F., Gendreau, M., and Langevin, A. 2012. Vehicle routing models and algorithms for winter road spreading operations. In Hybrid Algorithms for Service, Computing and Manufacturing Systems: Routing and Scheduling Solutions. Edited by J. R. Montoya-Torres, A. A. Juan, L. H. Huatuco, J. Faulin, and G. L. Rodriguez-Verjan. IGI Global. Chap. 2. pp. 15–45. DOI: `4018/978-1-61350-086-6.ch002`.

Perrier, N., Langevin, A., and Amaya, C.-A. 2008. Vehicle routing for urban snow plowing operations. Transportation Science **42**(1):44–56.

Perrier, N., Langevin, A., and Campbell, J. F. 2007a. A survey of models and algorithms for winter road maintenance. Part III: Vehicle routing and depot location for spreading. Computers and Operations Research **34**(1):211–257.

Perrier, N., Langevin, A., and Campbell, J. F. 2007b. A survey of models and algorithms for winter road maintenance. Part IV: Vehicle routing and fleet sizing for plowing and snow disposal. Computers and Operations Research **34**(1):258–294.

Quirion-Blais, O., Langevin, A., Lehuédé, F., Péton, O., and Trépanier, M. 2016. Solving the Large-Scale Min-Max K-Rural Postman Problem for Snow Plowing. Tech. rep. CIRRETL-2016-56. Interuniversity Research Centre on Entreterprise Networks, Logisitics and Transportation(CIRRELT).

Quirion-Blais, O., Trépanier, M., and Langevin, A. 2015. A case study of snow plow routing using an adaptive large hood search metaheuristic. Transportation Letters-the International Journal of Transportation Research **7**(4):508–525. DOI: `10.1179/1942787514y.0000000042`.

Salazar-Aguilar, M. A., Langevin, A., and Laporte, G. 2012. Synchronized arc routing for snow plowing operations. Computers & Operations Research **39**(7):1432–1440. DOI: `http://dx.doi.org/10.1016/j.cor.2011.08.014`.

Tagmouti, M., Gendreau, M., and Potvin, J.-Y. 2011. A dynamic capacitated arc routing problem with time-dependent service costs. Transportation Research Part C: Emerging Technologies **19**(1):20–28. DOI: `http://dx.doi.org/10.1016/j.trc.2010.02.003`.

— 2010. A variable neighborhood descent heuristic for arc routing problems with time-dependent service costs. Computers & Industrial Engineering **59**(4):954–963. DOI: `http://dx.doi.org/10.1016/j.cie.2010.09.006`.

— 2007. Arc routing problems with time-dependent service costs. European Journal of Operational Research **181**(1):30–39. DOI: `http://dx.doi.org/10.1016/j.ejor.2006.06.028`.

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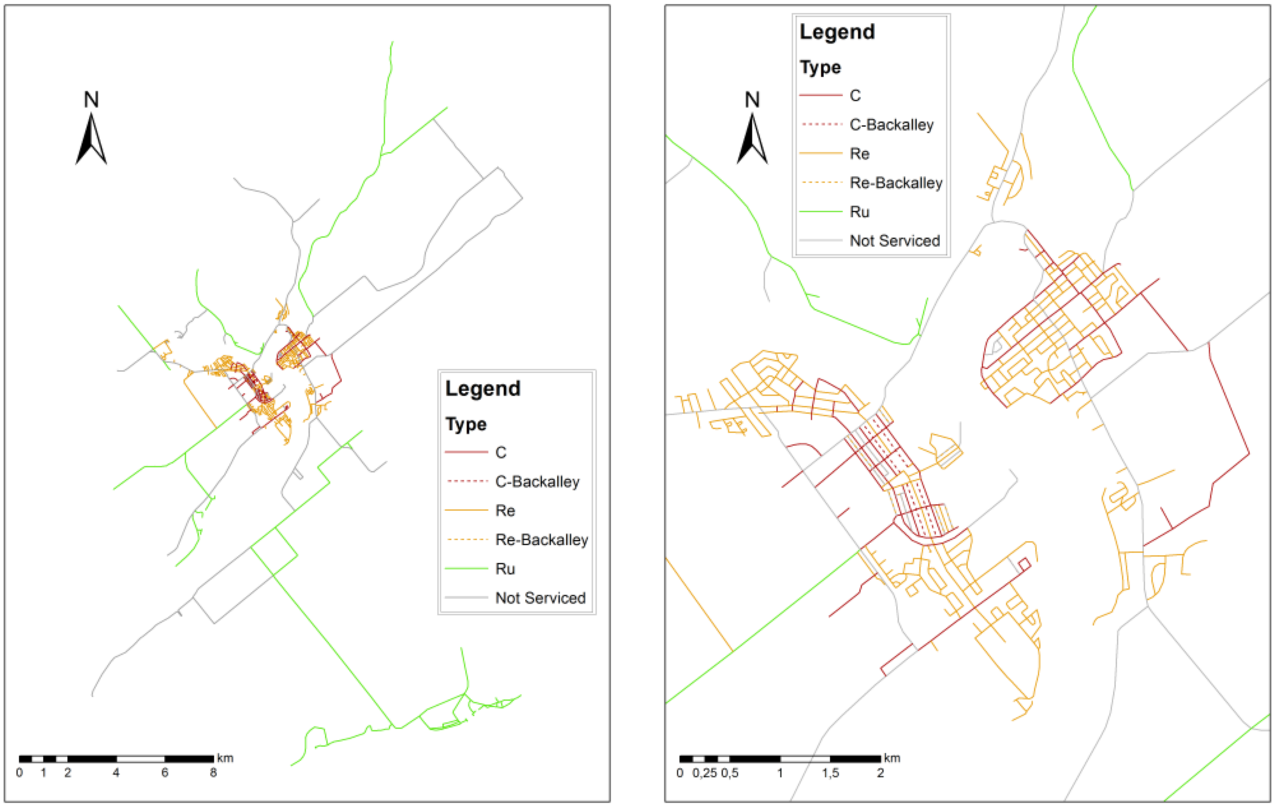
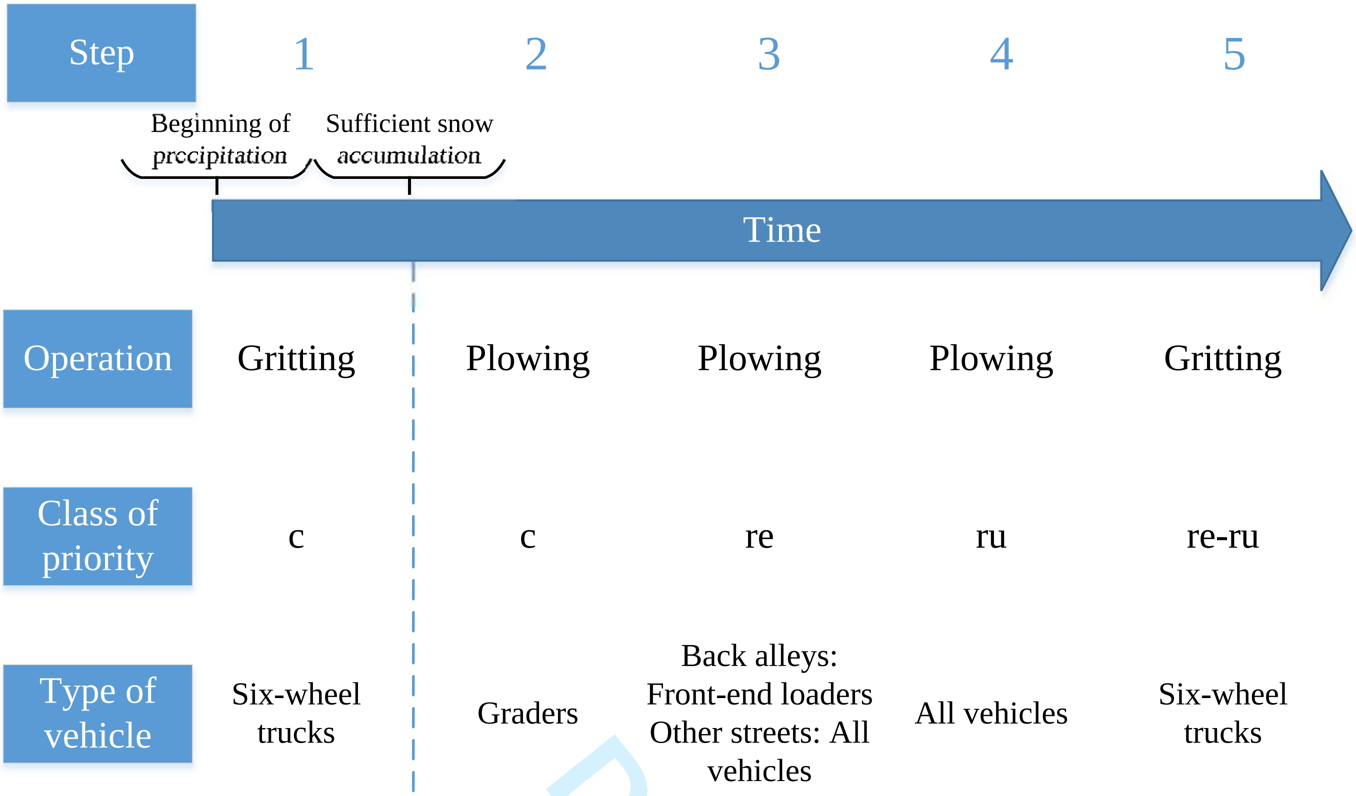


(a) The rural part has long stretches of roads. (b) The urban part has a grid pattern.

Figure 1 – Road network map with a three-level hierarchy (c, re and ru).



Step	1	2	3	4	5
Operation	Gritting	Plowing	Plowing	Plowing	Gritting
Class of priority	c	c	re	ru	re-ru
Type of vehicle	Six-wheel trucks	Graders	Back alleys: Front-end loaders Other streets: All vehicles	All vehicles	Six-wheel trucks

Figure 2 – Order of operations followed after a snowfall.

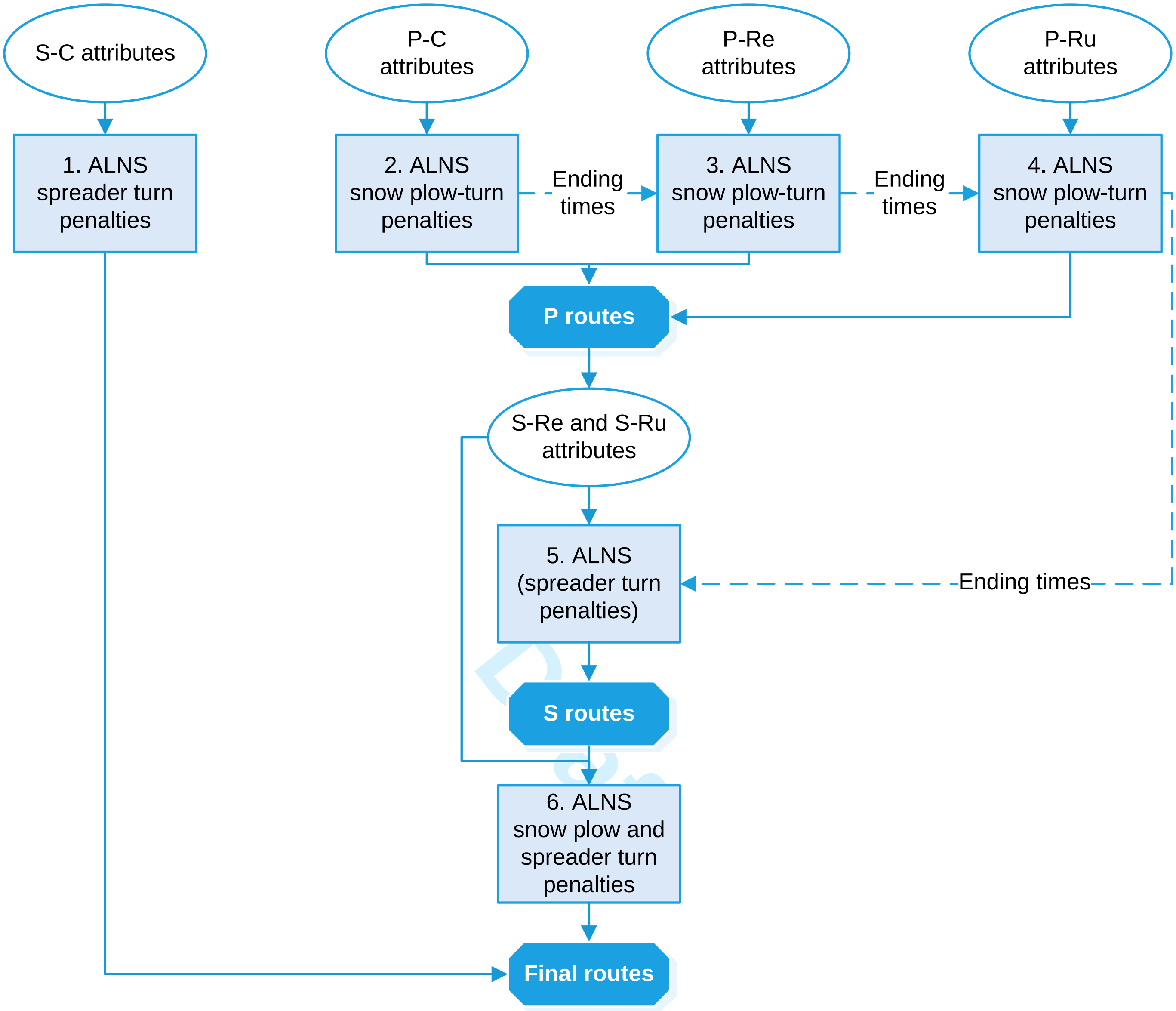


Figure 3 – Scheme of application of the ALNS metaheuristic. S-C, S-Re and S-Ru respectively stand for spreading on commercial, residential and rural streets. Similarly, P-C, P-Re and P-Ru respectively stand for plowing on commercial, residential and rural streets.

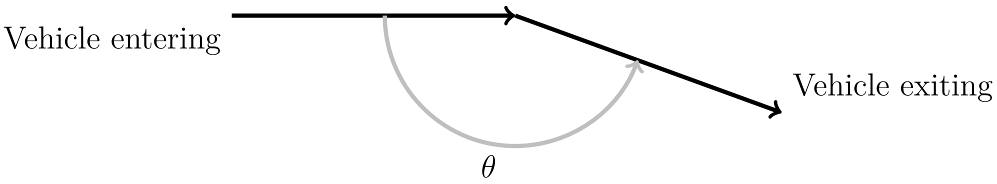


Figure 4 – Measurement of the difference between the input and output angles of a vehicle crossing an intersection.

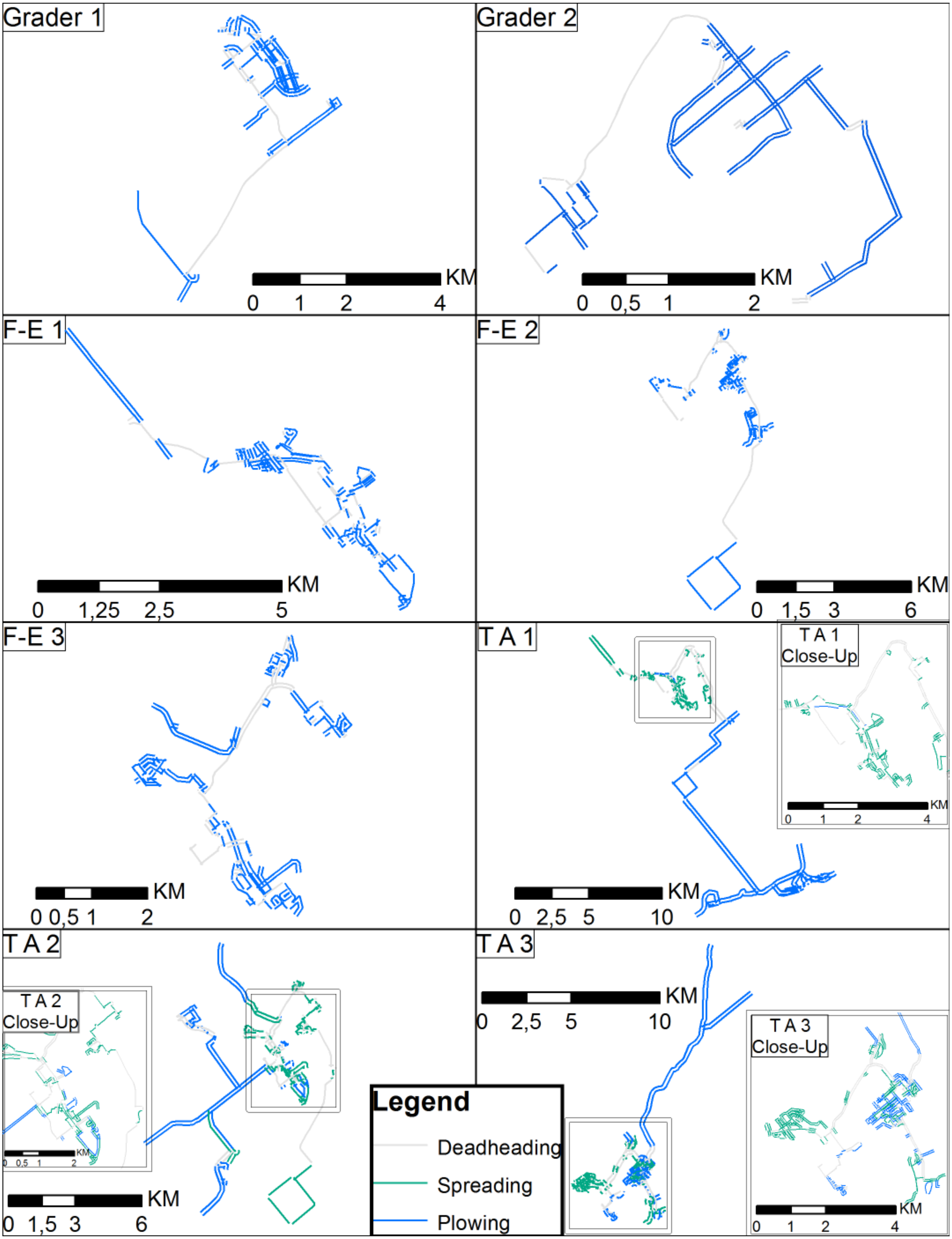
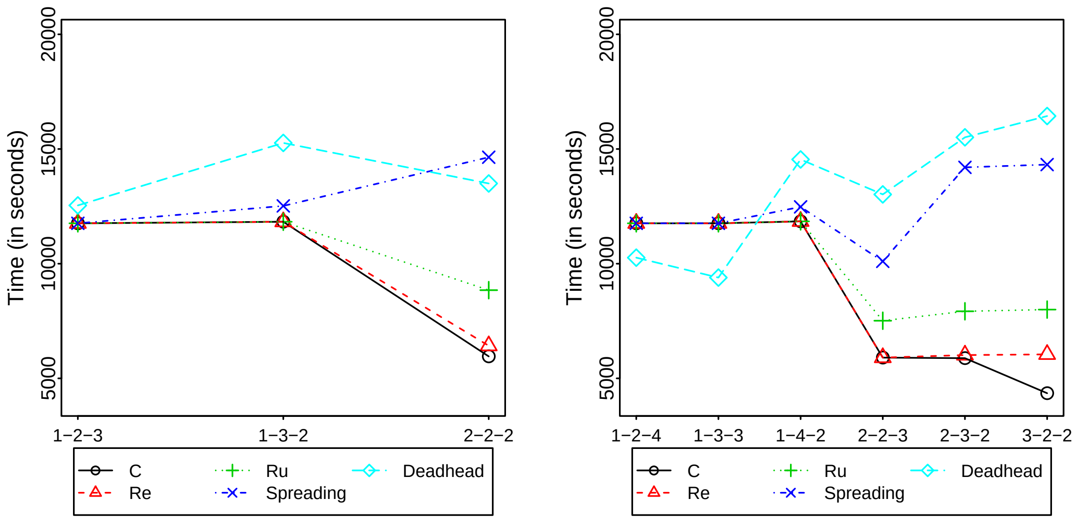
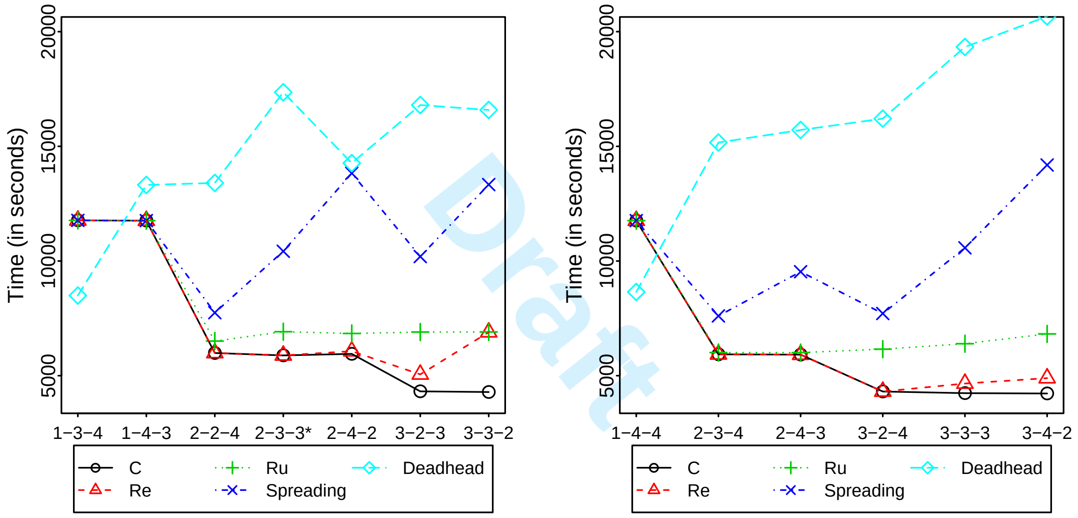


Figure 5 – Routing obtained for each vehicle (F-E: front-end loader, T A: tandem axle truck).



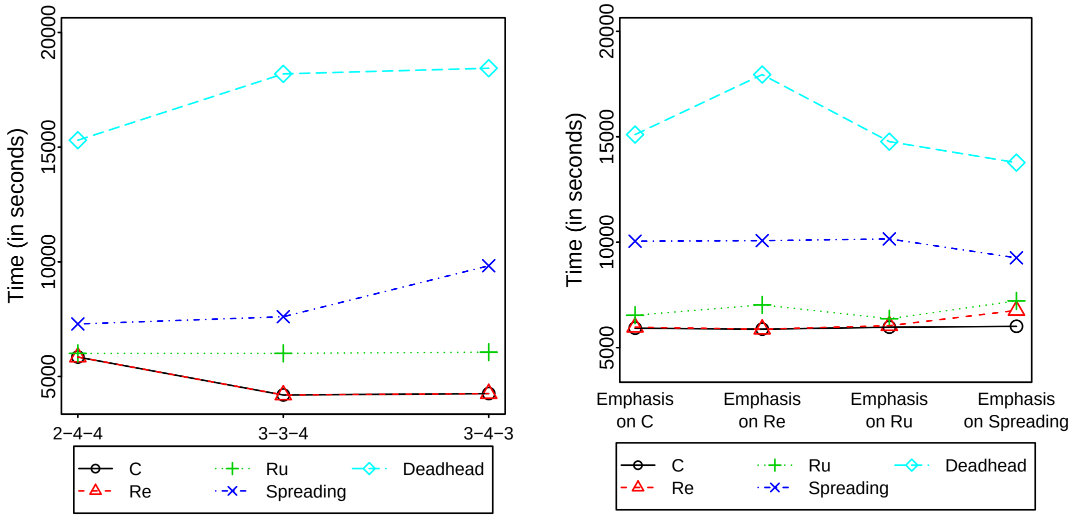
(a) 6 vehicles.

(b) 7 vehicles.



(c) 8 vehicles.

(d) 9 vehicles.



(e) 10 vehicles.

(f) Varying the weights.

Figure 6 – Ending time by priority for each fleet composition. The ending of the c-class and the re-class are often superimposed with vehicle fleets similar to the current situation.

List of Tables

Table 1 – Comparison of the characteristics considered in the literature for two winter maintenance situations (Campbell et al. 2014; Perrier et al. 2011; Perrier et al. 2007a).

	Gritter routing	Snowplow routing
Similar characteristics	Service hierarchy Maximum route duration Load balance Periodic service Time windows	
Different characteristics	Time dependent cost One or two lanes in a single pass One or two lanes in a single pass Working period Multiple vehicle and material depots Sector compactness Level of service policy	Turn restrictions Class continuity Class upgrading General precedence relation Multiple passes per road One or multiple vehicles per route Heterogeneous fleet Different service and deadhead speed Multiple vehicle depots Service continuity Synchronized tandem operations.

	Plowing			Spreading		Deadheading
	c	re	ru	c	re and ru	c, re and ru
Grader	20	20	25	20	25	25
Front-end loader	25	25	25	25	25	25
Tandem axle trucks	35	35	50	35	50	50

Table 2 – Vehicle speed (km/h)

Type of turn	Angle range	Plowing penalty	Spreading penalty
Right turns	$20° \leq \theta < 160°$	0	1
Straight ahead, same street name	$160° \leq \theta < 200°$	0	0
Straight ahead, street name changes	$160° \leq \theta < 200°$	1	1
Left turns	$200° \leq \theta < 340°$	2	1
U-turns	$-20° \leq \theta < 20°$	12	12

Table 3 – Angle range measured according to Figure 4 and penalty given to each type of turn.

	Graders	Front-end loaders	Tandem axle trucks	Total
CF	2	3	3	8
1	1	2	3	6
2	1	3	2	6
3	2	2	2	6
4	1	2	4	7
5	1	3	3	7
6	1	4	2	7
7	2	2	3	7
8	2	3	2	7
9	3	2	2	7
10	1	3	4	8
11	1	4	3	8
12	2	2	4	8
13	2	4	2	8
14	3	2	3	8
15	3	3	2	8
16	1	4	4	9
17	2	3	4	9
18	2	4	3	9
19	3	2	4	9
20	3	4	2	9
21	3	3	3	9
22	2	4	4	10
23	3	3	4	10
24	3	4	3	10

Table 4 – Composition of vehicle fleets used to test the methodology. CF corresponds to the current fleet in the city. Fleets of less than six or more than ten vehicles are not considered in this table.