PLANNING OF ROAD NETWORK MONITORING USING GPS AND GIS

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Abstract

Road network monitoring is an activity conducted daily by the Ministry of Transport of Quebec. The complete network must be monitored every two weeks. In this setting, the usual objective in arc routing of minimizing the total travel distance is irrelevant. The vehicles are equipped with GPS locating devices to monitor events and trace routes. Since most planned route are not completed because of events on the network, there is a need to continuously re-plan and re-schedule routes. We developed a methodology to achieve this task by gathering data from the GPS trace, matching it to the planned routes within a GIS and then use mathematical algorithms to propose a new schedule with new routes. The interurban road network studied consists in a hierarchy of three classes of roads that have different monitoring standards. We tested three different methods using different objectives depending on the operators' needs. Results show that the method that implies rescheduling based on assignment and reconstruction of routes with an arc-adding method gives the best coverage for each class of road. Nowadays, more transport operators have devices like GPS to locate and manage their fleet of vehicles. The integration of such technologies to GIS and to OR models for arc routing in day to day operations is however a challenging task. This article addresses both the data processing issues and the optimization issues in order to design an efficient decision support system appropriate for the highly dynamic nature of the problem.

Keywords: Arc routing; Global positioning system; Geographical information system; Optimization; Public works
Topic Area: D4 Applied Geographical Information Systems

1 Introduction

Road network monitoring is a day-to-day operation done by patrollers on rural road networks. They report road damages, call for maintenance activities and respond to different incidents over the network. Because of the randomness of the incident time and location, it is not a trivial task to plan the routes for road network monitoring. Even though planned routes are established for the monitoring operations, they are seldom respected because of road incidents. In addition, it is hard for the network operator to effectively know what has been monitored and what could be done to balance the work by covering areas that were not visited by the patrollers.

Nowadays, the use of Global Positioning Systems (GPS) coupled with Geographic Information Systems (GIS) technologies helps to evaluate the coverage of the network. The monitoring vehicle is equipped with a real-time capturing device that store GPS-type trace and can precisely locate incidents. Unfortunately, there exist no specific arc routing algorithms that can integrate this operational data in order to reschedule and adapt the planned route regarding to what has "really" been done. But numerous valuable operations research works (Cristofides et al. 1986, Hertz et al. 2000, Gendreau et al. 1995) can be integrated if the underlying data is validated and modified to fit the needs of these algorithms.

This paper presents a methodology that addresses the integration of "live" data into daily planning of road monitoring and is aimed to build a bridge between two distant fields: geographical information systems and operations research. It is the fruit of a research project conducted with the road monitoring team of the Ministry of Transport of Quebec.

The paper presents the background, the methodology, the implementation and the results in sections 2 to 5. Section 2 is a review of literature about the use of GIS/GPS in transport and mathematical developments related to oriented arc-routing. Section 3 presents the Transport Object-Oriented Modelling (TOOM) that is used for data modelling and exposes the foreseen methods for route construction and planning. Section 4 describes the implementation phases: geographical information system assembly, integration of global positioning system data, choice of adequate performance indicators, and development of a dedicated decision support tool. In section 5, the actual results from experimentations applied to the monitoring of the road network in the region of Estrie in Quebec are reported. The conclusion focuses on the findings of this project and lists the operational constraints that were encountered.

2 Background

This section reviews the literature about the two main elements that feed our methodology: use of GIS and GPS in the field of transport, and works on the capacitated arc routing problem (CARP), which is related to road monitoring routes.

2.1 GIS and GPS in transport

Although their enormous capabilities to analyze, render, and store data, geographic information systems (GIS) are mostly employed today in operations research as one-way data feeder for mathematical models. Erkut et al. (2001) have successfully used GIS to provide distance and time data for their emergency services districting and location problems. Derekenaris et al. (2001) have presented an application combining GIS, Global Positioning System (GPS) and mobile communication technologies to manage a fleet of ambulances. The complexity of arc routing problems should benefit from a better integration of the mathematical formulation and resolution into the available GIS data model.

The increase of GIS utilization in transport (GIS-T) has brought new paradigms in transport planning, such as the desegregation of the spatial locations, but some challenges remain about the storage of temporal data within applications (Goodchild 2000). At the operational level (day-to-day), the improvement of location devices such as GPS receivers has strengthened the role of GIS for vehicle location and traceability. Some problems arise when there is a need to couple planned data with operational data, such as matching GPS "trace" to predefined route (White et al. 2000). In that case, a GIS data model is needed to take into account the uncertainty of GPS signal, data errors or other events of the daily operations. Dueker and Butler (2000) have proposed a GIS framework to store and share transport data. Their model is compatible but different from the recommended NCHRP 20-27 data model (2001) because it integrates cartography objects to basic transport features. Trepanier and Chapleau (2001) have also work on the integration between road and transit network within GIS-based applications. The figure 1 shows the process of integrating a transit network into a road network. There is a significant difference between the analytic trace (at left) and the related paths on the road network (at right).

Figure 1. Transit network object melted into road network object

2.2 Capacitated arc routing problem (CARP)

CARPs are a generalization of the Chinese Postman Problem and of the Rural Postman Problem problems with a vehicle capacity constraint. A demand is defined on each «required» arc. The demand is usually specified by a service duration for each arc. Most of the works on the CARP consider undirected graphs. As the CARP is NP-hard, solution methods are heuristics that can be classified in three categories:

- Simple constructive methods. Those methods consist in constructing feasible routes using various decision rules: e.g., a greedy algorithm or the « *path-scanning algorithm* » (Golden et al. 1983), or an adaptation of the Clarke & Wright algorithm (Golden and Wong 1981). There are also insertion algorithms (Chapleau et al., 1984).
- Two-phase constructive methods. Those procedures can be classified in two groups: 1. *Route-First*, *Cluster-Second*, which consists in constructing a large route that is then split into multiple routes satisfying the capacity constraint (Ulusoy, 1985), 2. *Cluster-First, Route-Second* where the arcs are first partitioned in clusters satisfying the capacity constraint and then a route is constructed for each cluster (Benavent et al., 1990).
- Adaptation of meta-heuristics. Local search methods (tabu, simulated annealing) used for node routing problems are adapted to arc routing problems (Eglese, 1994 and Hertz et al., 2000).

Directed CARPs have been modeled as an integer programming problem (Dror and Leung, 1998 and Dror and Langevin, 2000), However, due to the complexity of the problems, works on the directed CARPS have been limited to adaptations of methods designed for the undirected cases (Mittaz, 1999). The specificity of unidirectional covering of the arcs leads to difficulties to adapt these methods.

3 Methodology

This section will report on the methodological developments to achieve the desired goals of this project.

3.1 Transport object-oriented modelling

An object-oriented (OO) approach is well suited to integrate GIS technologies to mathematical models, because of its openness and its flexibility. Based on traditional OO approaches (computer science), the Transport Object-Oriented Modelling (TOOM) is characterised by its special metaclasses of objects, which are used to describe every transportation system (Trépanier and Chapleau 2001):

- Dynamic objects are elements that move in the system and are at the base of transportation activities. Most common dynamic objects are people, cars, or goods. They have properties that express social, demographic or economic features.
- Kinetic objects describe the movement itself. For instance, transit routes, trip chains and individual trips are kinetic objects. A road is a kinetic object when seen as a car link between two locations. These objects are characterised by length, capacity, service level, etc.
- Static objects refer to all the supporting elements of the transportation system that do not move during large amount of time. Home places, trip generators, transit stops, subways stations, and depots are all static objects. These objects are related to spatial properties and network connectivity.
- System objects are groups of objects embedded in the general transportation system. A transit network, for example, contains dynamic, kinetic and static in relation between themselves. No transportation activity can exist without one of these metaclasses.

The TOOM always tries to create a wide view of every system, even thought the data for each object is not available. A special structure called "object-model" is needed for the database structure, for object-oriented programming, to model the behavior (role) of the objects in the whole system and to interface data from information systems (GIS, GPS readings) to mathematical models.

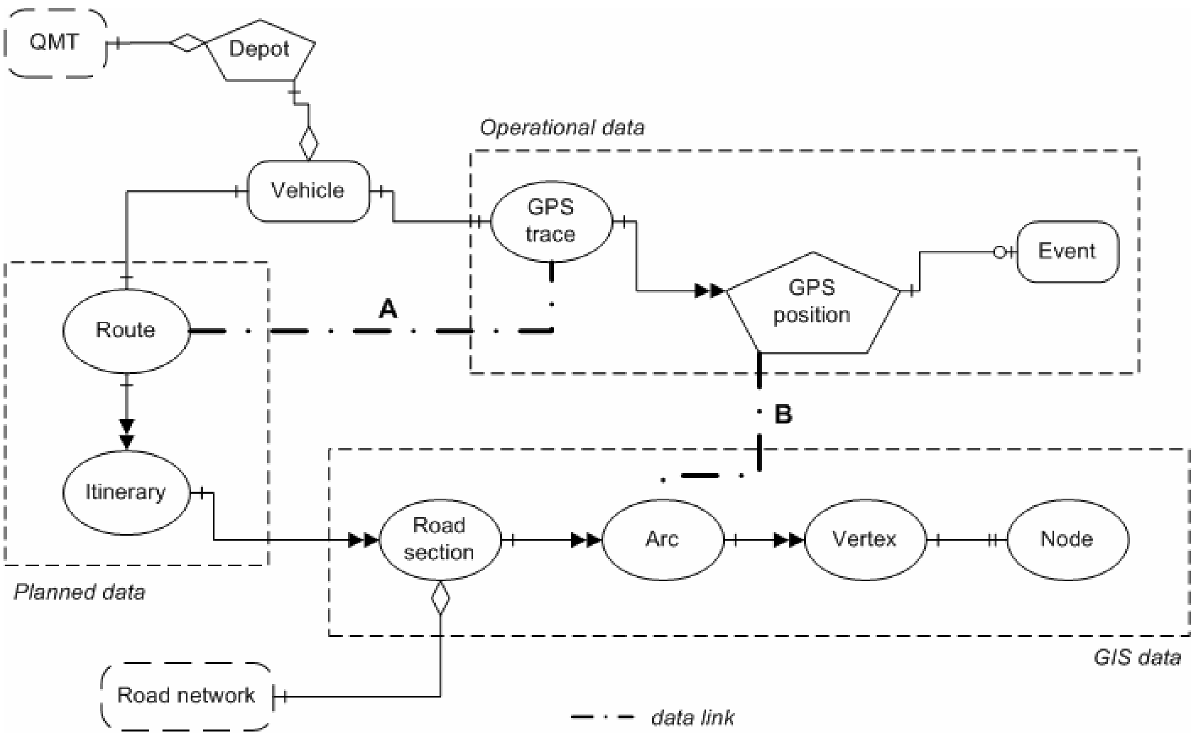

Figure 2. Object-model for the road monitoring problem.

Figure 2 illustrates the object-model of the road monitoring problem as observed in this project. The model identifies three categories of data:

- GIS data, composed of kinetics classes that support the vehicle routing (road, arc, nodes, vertex);
- Planned data, regrouping the monitoring routes, which are defined by itineraries (sequence of road sections);
- Operational data, gathered through daily work of the road maintenance monitoring team, and composed of GPS traces (one for each route), GPS locations and special events such as accidents, road hazards, dead animals, etc.

Among the data integration challenges, the link between operational planned data can be done through the matching of GPS trace to planned route (A), or by linking GPS positions to GIS arcs (B). Once the link is done, it is possible to precisely know what part of the network has been covered and then apply the algorithms to plan the routes again. The model also serves to visualize the routes and the scenario results on the GIS interface.

3.2 The monitoring problem

The routing problem for monitoring can be defined as a Capacitated Arc Routing Problem (CARP) with additional constraints. Each side of the roads must be monitored separately, so the set of roads is modeled as a directed network. The objective is to cover with one vehicle the entire network over a two-week horizon with the following constraints:

- The set of 'autoroute' (freeway) arcs must be covered once every week-end and once every 5-day week.
- The set of 'national road' arcs must be covered once every seven days.
- The other arcs must be covered once every 14 days.
- There are 20 working shifts (each shift corresponds to one monitoring route) of 7,5 hours per 7-day period.
- Some road segments can be individually identified as mandatory or highly important by the operator because of accidents, construction sites or public complaints.

During a shift, the vehicle may have to leave the planned route to respond to an 'emergency' call. When it accesses the site of the emergency, the vehicle does not perform monitoring. As it travels back from the emergency site, the vehicle usually monitor the roads. It then gets back to the point where it had left the route to resume its itinerary which it may not be able to complete during its shift. Hence the following shifts of the horizon have to be replanned according to what was covered (both planned and unplanned) during that shift. The exact itinerary of the vehicle is transmitted by the GPS and the network used for route planning is updated following the TOOM formalism. One then knows each arc that has been monitored during the shift.

Two set of methods are foreseen. The first one is to use a set of predefined routes in order to find a schedule that is compatible with the operator coverage needs. The second method (Cluster First & Route Second), is to build routes from nothing with a 3-step approach:

1) Assign oriented arcs to "n" routes using an assignment algorithm (like Fisher & Jaikumar). This assignment take into account operational constraint that are coded in the GIS, plus usually monitoring procedures and road priority management.
2) Build a "rough" route on these arcs using Chinese postman heuristics.
3) Improve the set of routes by exchanging arcs in order to harmonize their length and duration. A Tabu-like search is used.

3.3 Proposed methods

We propose three methods differing by the degree of dynamism considered but also by the difficulties of development, processing and integration of data. The methods are made to fit the information system architecture and the business processes of our research partner. They are quite simple mathematically, but they are built in such a way that they can handle missing or erroneous data that come especially from processing GPS trace of the patrols.

3.3.1 Method 1: Assignment of predetermined routes

This approach consists in defining a sequence of predetermined routes, one route for each shift of the two-week horizon, which satisfy the frequency of passage requirements for all types of roads. The set of shifts is partitioned into four sub-sets, WE1, W1, WE2,W2 corresponding respectively to the first week-end (2 days), the first week (5 days), the second week-end (2 days) and the second week (5 days). There are three shifts each day. Figure 3 illustrates this partition. It also shows that a same route can be performed several times in the planning horizon.

Day of week	*S*	*S*	*M*	*T*	*W*	*T*	*F*	*S*	*S*	*M*	*T*	*W*	*T*	*F*
Shift	WE1		W1					WE2		W2				
1 - day	8	7	15	21	2	18	17	8	12	9	17	35	8	19
2 - evening	1	23	8	4	7	11	31	21	1	2	13	16	14	12
3 - night	4		10	27	12	22	6	10		24	25	2	24	7

Figure 3. Route planning for a two-week period (method 1)

The following model (see next page) aims at maximizing the number of passages on class 1 arcs (autoroutes).

The objective (1) is to maximize the number of passages on class 1 arcs. Constraints set (2) ensure that at most one route is assigned to each shift. Contrary to the «classical» assignment problem, a given route may be assigned to several shifts. Constraints (3) specify the requirements of covering frequencies for the 3 classes (C_1, C_2, and C_3) of arcs. Hence each class 1 arc must be covered at least once each week-end and each week (3a). Each class 2 arc must be covered at least once every 7 days (3b), and each class 3 arc must be covered at least once every 14 days (3c). Constraints (4) define the binary variables.

3.3.2 Method 2: Re-planning

The preceding method is not adapted to the case where some of the arcs in a planned route are not covered because the routes planned towards the end of the horizon may not be adequate to cover the remaining arcs. To circumvent this difficulty, the preceding method can be used after each shift or each day to replan the remaining shifts. One has to modify the arc sets C1, C2, and C3 according to what has been actually covered at that time.

Let $S = WE_1 \cup W_1 \cup WE_2 \cup W_2$ be the set of shifts.
Let K be the set of predetermined routes.
Let A be the set of arcs.
Let C_1, C_2, C_3 be the 3 classes of arcs.

$$\partial_{ik} = \begin{cases} 1 \text{ if arc } i \text{ is included in route } k, \\ 0 \text{ otherwise}. \end{cases}$$

The decision variables are:

$$y_{kj} = \begin{cases} 1 \text{ if route k is assigned to shift j}, \\ 0 \text{ otherwise}. \end{cases}$$

$$\max \sum_{k \in K} \sum_{j \in Q} \sum_{i \in C_1} \partial_{ik} y_{kj} \qquad (1)$$

s.t.

$$\sum_{k \in K} y_{kj} \le 1 \qquad \forall j \in S \qquad (2)$$

$$\sum_{j \in \alpha} \sum_{k \in K} \partial_{ik} y_{kj} \ge 1 \, \forall i \in C_1 \text{ and for } \alpha = WE_1, W_1, WE_2, W_2 \qquad (3a)$$

$$\sum_{j \in \alpha} \sum_{k \in K} \partial_{ik} y_{kj} \ge 1 \qquad \forall i \in C_2 \text{ and for } \alpha = WE_1 \cup W_1, WE_2 \cup W_2 \qquad (3b)$$

$$\sum_{j \in \alpha} \sum_{k \in K} \partial_{ik} y_{kj} \ge 1 \qquad \forall i \in C_3 \text{ and for } \alpha = WE_1 \cup W_1 \cup WE_2 \cup W_2 \qquad (3c)$$

$$y_{kj} \in \{0;1\} \qquad (4)$$

Figure 4 illustrates this approach (here WE1 = ϕ).

Day of week	*S*	*S*	*M*	*T*	*W*	*T*	*F*	*S*	*S*	*M*	*T*	*W*	*T*	*F*
Shift	WE1		W1					WE2		W2				
1 - day	8	7	15	21	2	18	17	8	12*	9	17	35	8*	19
2 - evening	1	23	8	4	7	11	31	21*	1	2*	13*	16	14	12
3 - night	4		10	27	12	22	6	10		24	25	2	24*	7*

* modified route (method 3)

route done

replanning

Figure 4. Route re-planning (method 2 & 3)

3.3.3 Method 3: Re-planning with partial integration

This approach builds on method 2 by integrating the arcs of the preceding shifts that have not been covered to the routes already assigned (by Method 1) to the remaining shifts. These new routes are added to the set of pre-defined routes and can be used for scheduling the following shifts. The integration of the non-covered arcs to the assigned routes must be based on decision rules about the selection of the routes to which integrate those arcs and about the place where to insert the arc within the routes. This integration should be done after each shift or each day and should take into account both the «urgency» to cover a given arc and the route «load» balancing. The integration should minimize the additional distance needed to cover those arcs. There have been several methods developed for the integration of new «customers» to existing routes (Mittaz, 1999). In this case, the least distance to route method has been used.

3.3.4 Alternate objectives

The main difficulties of these methods are in the choice of the objective (1), which depends on the vision of the manager. It should be noted that in this context the usual objective of minimizing the total distance is irrelevant, because the monitoring truck must patrol anyway. Moreover, the real objective is to find feasible solutions that maximize the ability to patrol the road network as most as possible, in order to better serve population and road safety. Objectives more relevant to the operational constraints are:

- *Minimization of the assignment costs.* This approach requires defining a cost c_{kj} to assign route k to work shift j. The mathematical objective becomes: $\min \sum_{k\in K}\sum_{j\in Q} c_{kj} y_{kj}$. This cost does not represent a real cost but rather a penalty to assign a route to a shift. The costs are initialized at 1 and are incremented by 1 after each solution in order to obtain different solutions while satisfying all the constraints. That is, if $y_{kj} = 1$ in a solution, then the corresponding c_{kj} is incremented by 1 in the next problem to solve.
- *Maximization of the covering of a priority class.* The network hierarchy defines tighter operational constraints on class 1 (autoroutes) arcs. Those arcs correspond to priority arcs and the solution favors the assignment of routes covering those arcs. the objective becomes: $\max \sum_{k\in K}\sum_{j\in Q}\sum_{i\in C_1} \partial_{ik} y_{kj}$ where $\partial_{ik} = 1$ if arc i is in route k.
- *Class weighted maximization.* This objective corresponds to assign different weights to each class. The objective becomes: $\max \sum_{k\in K}\sum_{j\in Q}\sum_{i\in A} \alpha_i \partial_{ik} y_{kj}$ where α_i is the corresponding weight. In a simple version, the weights used are 4-2-1 for classes 1-2-3. In an advanced version, each weight is proportional to the cardinal of each class subset (still in 4-2-1 proportion).
- *Arc weighted maximization.* The disaggregated approach allows to assign an individual weight w_i to each arc i according to a given criterion. This criterion can correspond to the daily traffic or the frequency of incidents. The objective is then: $\max \sum_{k\in K}\sum_{j\in Q}\sum_{i\in A} \partial_{ik} y_{kj} \omega_i$.

4 Implementation

Designing a decision support tool needs a rigorous modeling of the process in order to provide architecture well adapted to the operational constraints, especially when many components of different nature must communicate.

4.1 GIS assembly

The planning of the monitoring of road network requires the use of a geographical information system (GIS). The GIS is aimed to:

- support route planning by providing a mathematical graph for arc routing;
- gather and validate GPS data collected during monitoring activities;
- display monitoring route information on map.

In this project, the Quebec ministry of transport provided us a GIS road network (polylines). Going from the GIS network to the analytical graph is more a practical problem than a fully automated data processing. Indeed, the operational partitioning of the GIS networks is often not adapted for the routing algorithms. For example, such partitioning fails to split the road segments at every crossroads or at points allowing U-turns (on freeways) which leads to a mathematical graph that is incoherent and unusable. However, the disaggregated approach used in this work aims at assigning to each arc the real characteristics of the road network and thus provides a specific structure to the graph. Hence, unlike the traditional graphs used in routing, the graph used here may have several arcs for a given road segment in order to take into account possible events all along the segment. A more aggregated graph would result in an important loss of information. Table 1 shows the main statistics for the network and identifies the classes of arcs.

Table 1. Analytical road network statistics

	Number	Length (km)	Min length (km)	Max Length (km)
Nodes	140			
Arcs	374	7.9 (average)	2.3	40.8
Class 1 arcs (freeways)	40	244.3	2.7	13.8
Class 2 arcs (main roads)	146	1126.4	2.3	37.4
Class 3 arcs (secondary roads)	188	1574.2	2.4	40.8

Figure 5 illustrates the GIS network and its corresponding analytical network. The area covers the southern part of the province of Quebec. A simplified analytical network has been used for this study. For example, freeway ramps have been removed because they are taken in charge by a special monitoring team.

4.2 Data flow

Figure 6 illustrates the flow of information in the system. The various planning methods (scheduling & arc routing) use in the first place the operational parameters and the characteristics of the network. One of the contributions of this work is to integrate the follow-up of the actual operations to the planning. This follow-up is build around the GIS which links the mathematical optimization and the completed monitoring activities located by the GPS.

The data flow is structured around three core processes: schedule planning, monitoring activities and arc routing. Schedule planning is made using mathematical concepts (herein our method) and parameters that depends on the patrolling objectives. Then, route sequence is transmitted to the operation, where patrollers follow the routes. During the shifts, routes are usually disturbed by events on the network. Special situations (snowstorm, accidents, flooding) will feedback the planner to make him change the parameters for the next sequence. Finally, the arc routing and route construction phase integrates data from GPS traces within the GIS to 1) store the road sections that have been patrolled and 2) to identify road section that were not patrolled for the next iteration.

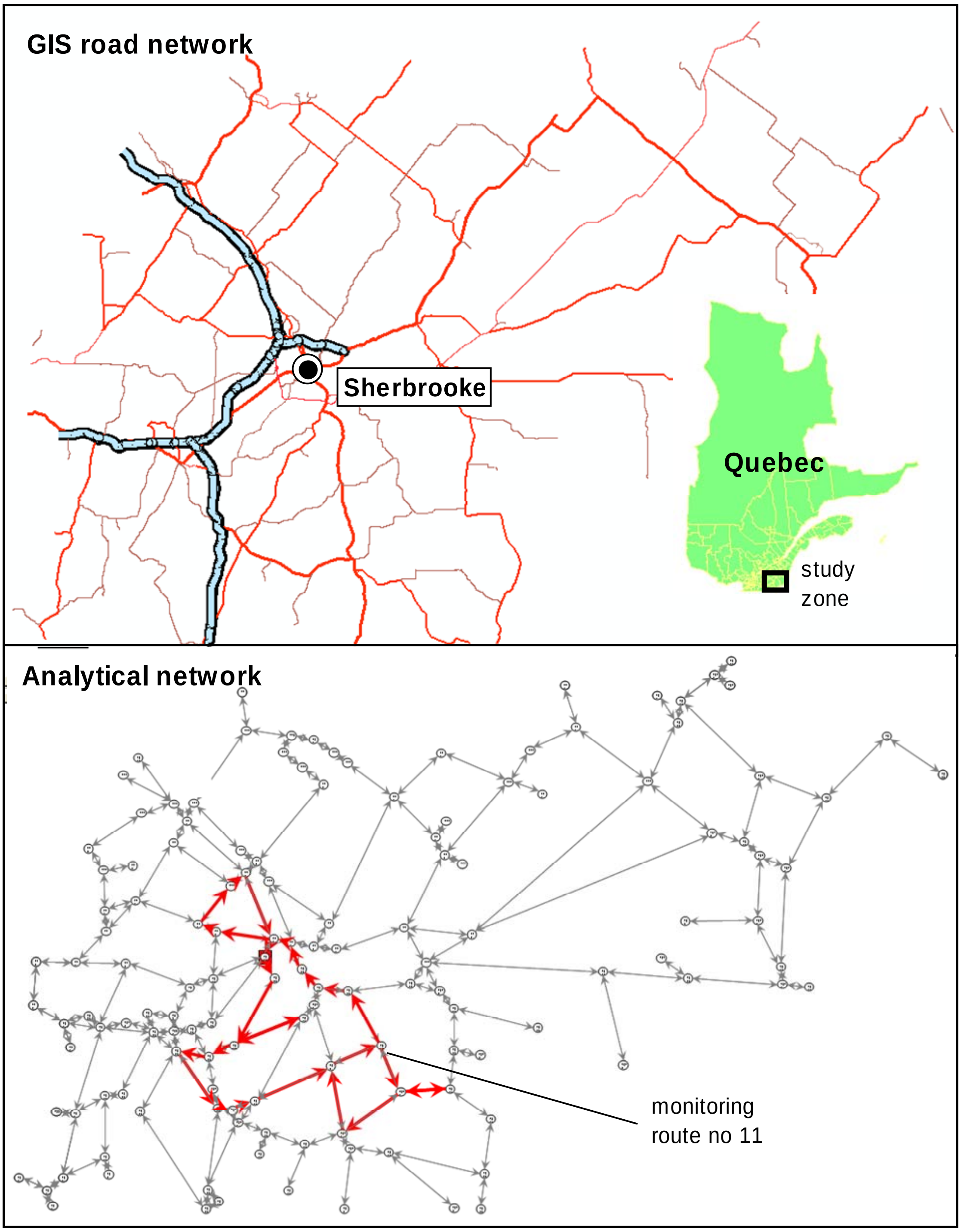

Figure 5. Before and after: GIS and analytical road network, with example of a monitoring route

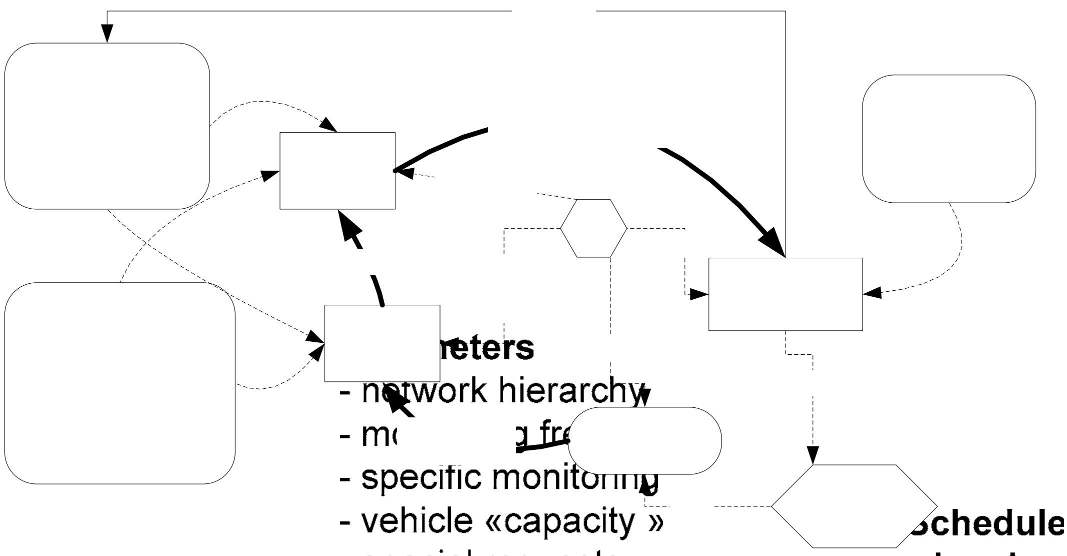

Figure 6. Implementation of the proposed methodology

4.3 Decision support tool

A decision support tool has been developed to test the three routing methods defined in Section 3. The tool uses an Excel spreadsheet interface to display results (Figure 7), an Access database to store data and CPLEX solver with AMPL language for optimization. Visual Basic for Application (VBA) is used for data handling and to automate the tests. This section will focus on the main steps required to solve each method.

The first method corresponds to a single planning over the full horizon. It does not ask for any a priori processing of the data but requires a precise and coherent definition of pre-determined routes. This definition is used to do the operations follow-up in order to compare the actual vs. the planned covering and hence update the performance measures. (This is true for the three methods.).

Method 2 integrates the follow-up into the monitoring planning. It is then necessary to identify the uncovered arcs of the previous shifts routes and to remove them from the set of arcs to cover. This task is not as obvious as it may seem, because of the overlapping periods of the arc classes. Thus, arcs of class 1 have an overlapping period of one week-end or one 5-day week, arcs of class 2 an overlapping period of 7 days (week-end + 5-day week), and arcs of class 3 an overlapping period of 14 days. The information update must take into account this feature. For example, if the replanning is done after the first week-end, all arcs of class 1 have to be covered again. However, arcs of class 2 covered during the week-end must be removed from the set of arcs to cover. This variation implies updating the parameters δ_{ik} (inclusion of an arc within a route) each time the model is re-solved.

The third method inserts the uncovered arcs of the previous shifts routes into the predefined routes. The first difficulty of implementation concerns the choice of the route for inserting a given arc. A priori, any pre-determined routes is eligible for the insertion. However, in order to reduce the size of the mathematical model and of the data processing, we used a reassignment of the left-over arcs to the already scheduled routes. The eligible routes are those in the overlapping period.

The objective of the mathematical model is to minimize the arcs to routes assignment cost. This cost is defined in this case as the additional distance due to the insertion of the arc (using the shortest paths). However, this definition prevents the integration of a capacity constraint to the model. Indeed, the insertion of two arcs in the same area does not necessarily imply an additional distance equal to the sum of the two additional distances generated by the two arcs as there respective shortest paths may share some common arcs. Hence, the notion of vehicle capacity has been introduced in the selection of an eligible route, which must satisfy the overlapping period and not exceed the vehicle capacity (or a little bit more). We have also limited the number of arcs to insert in a given route to favor more diversity in the routes.

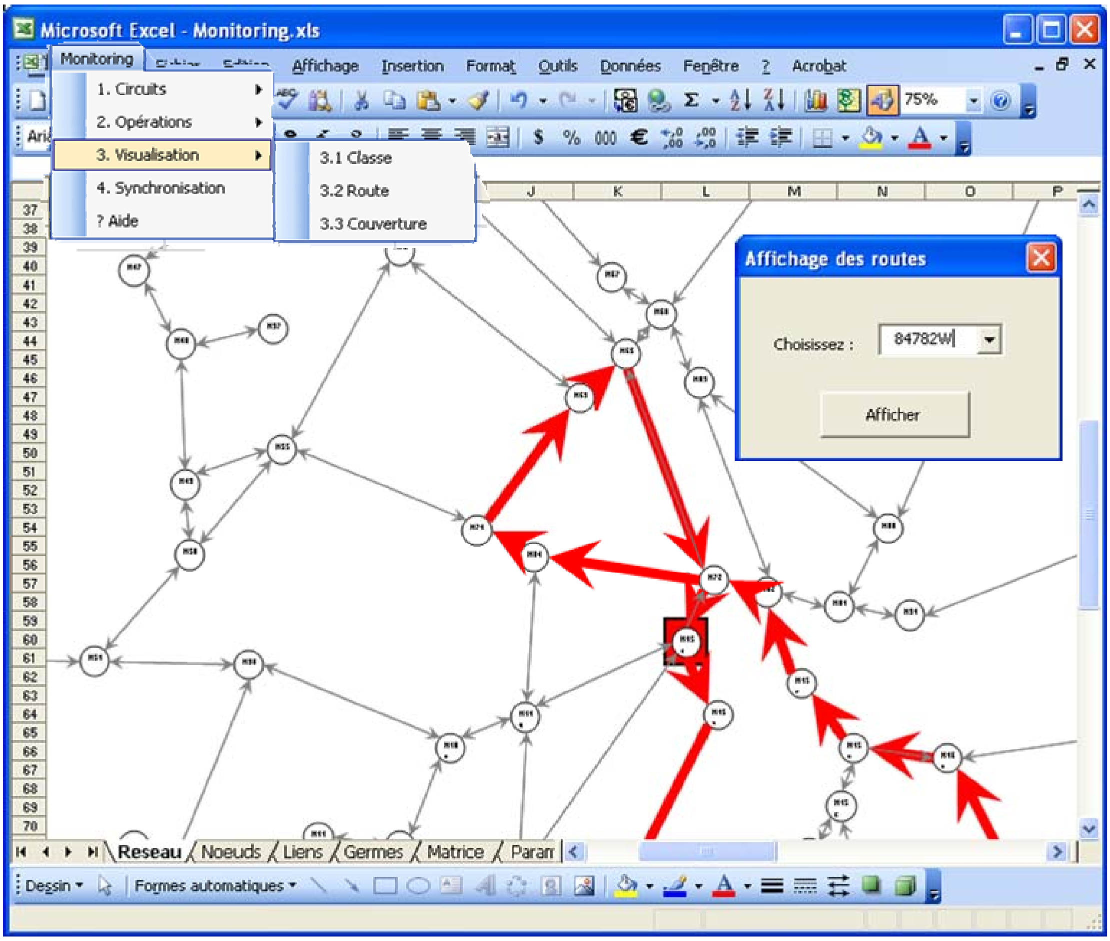

Figure 7. Decision support tool interface

Such an approach requires to calculate the added distance and to determine where to insert the left-over arcs in all eligible routes, at each re-scheduling. Solving the mathematical model is not problematic and is done very quickly. The new routes are then added to the set of pre-determined routes for the remaining part of the horizon.

5 Results

The different results were based on the reference network presented at Table 1 (year 2002 data). There were 32 monitoring routes prepared by the Ministry of transportation, plus 12 routes that were generated by a preliminary study showing that re-planning required more routes. A cross-analysis of the following elements was conducted in order to find the best results:

- The planning methods 1, 2 and 3.
- Two scenarios of route coverage completion to take non-patrolled arcs into account. First, there is a rigid 50% completion (which means that each route has been serviced 50% of its length). Second, a 50-75% random completion is calculated for each route in order to reproduce the best the operating context.

- Several objectives as presented in section 3.3.1 (maximize class 1 freeways, simple class weighted, advanced class weighted).

Results are displayed in Table 2 and 3, using two performance measures:

1. The network hierarchical coverage (NHC)

$$C_{ct} = \sum_{i \in C} \frac{\partial_{it} l_i}{L_c}$$

C_{ct} is the NHC for class C at period t, l_i is the length of the arc i, ∂_{it} =1 if arc *i* has been covered at period *t* and L_c the total network length of class *c*. The measure is equal to 1 if all arcs of class *c* have been visited. The measures expresses the capability to cover all arcs at least once.

2. The network hierarchical capability coverage (NHCC)

$$K_{ct} = \sum_{i \in C} \frac{n_{it} l_i}{L_c}$$

K_{ct} is the NHCC for class c *at period t, l_i is the length of the arc i,* n_{it} is the number of time the arc *i* has been visited at period t and L_c the total network length of class *c*. The measure expresses the capability to cover the hierarchical network.

Table 2. Result for advanced class weighted maximization (random 50% to 75% route completion).

	C_{ct} WE1	C_{ct} W1	C_{ct} WE2	C_{ct} W2	K_{ct} 2 weeks	C_{ct} 2 weeks
Method 1: assignment of predetermined routes						
Class 1	1.00	1.00	1.00	1.00	15.51	1.00
Class 2	0.94		0.93		2.67	1.00
Class 3	0.95				1.60	0.95
Method 2: re-planning						
Class 1	1.00	1.00	1.00	1.00	10.26	1.00
Class 2	0.92		0.98		3.55	0.99
Class 3	0.69				1.50	0.69
Method 3: re-planning with partial integration						
Class 1	1.00	1.00	1.00	0.93	9.72	1.00
Class 2	0.99		1.00		3.35	1.00
Class 3	1.00				1.95	1.00

Table 2 shows that method 3 is globally better than method 1 and balance the coverage of the three classes of arcs. Method 2 is too rigid and has poor results for third class roads. In fact, the constraint (3c) on class 3 arc has to be relaxed to obtain feasible solutions. Only the method 3 assures that each arc is covered within the weeks horizon, but method 1 offers a better coverage of the freeway (each arc is visited about 15 times over the two weeks).

Table 3 presents results for various percentages of coverage and weighting methods. The method 3 is used for comparison. It shows that the advanced class weighted maximization brings the best results for overall coverage. For a 50% route completion, both class weighted maximization have acceptable results.

Table 3. Result for different weighted maximization

	C_{ct} WE1	C_{ct} W1	C_{ct} WE2	C_{ct} W2	K_{ct} 2 weeks	C_{ct} 2 weeks
Method 3 – Objective: MAX simple class weighted – 50% route completion						
Class 1	1.00	0.77	0.72	0.90	6.85	1.00
Class 2	0.93		0.75		2.96	0.95
Class 3	0.85				1.58	0.85
Method 3 – Objective: MAX advanced class weighted – 50% route completion						
Class 1	1.00	0.99	1.00	1.00	8.73	1.00
Class 2	0.93		0.88		2.94	0.95
Class 3	0.83				1.33	0.85
Method 3 – Objective: MAX class 1 – random route completion (50 to 75%)						
Class 1	1.00	1.00	1.00	0.89	10.87	1.00
Class 2	0.97		1.00		3.74	1.00
Class 3	1.00				1.76	1.00
Method 3 – Objective: MAX advanced class weighted – random route completion (50 to 75%)						
Class 1	1.00	1.00	1.00	0.93	9.72	1.00
Class 2	0.99		1.00		3.35	1.00
Class 3	1.00				1.95	1.00

6 Conclusion

Even though numerous mathematical algorithms are developed to address transport problems, they are sometimes hard to implement in a "real-life" situation implying GPS and GIS because:

- Some use parameters that are not well defined or needs data impossible to gather effectively.
- Some necessitate “perfect” analytical graphs and therefore, will suffer from geographical errors within GIS layers (which are common, because GIS layers are evolving constantly).
- Some are not robust to erroneous or missing data, which is a reality in day-to-day planning. Sometimes, one missing attribute on a single arc can completely transform a solution.

In this project, we had to address the road network monitoring route planning with the help of operational data coming from GPS. The major problems were related to the variability of monitoring route completion rate, which forced us to develop re-planning methods that would take into account the effective coverage, even with missing or incomplete data. The choice of a maximization objective is also an issue because it depends on the operator's point of view and influences the results accordingly. Finally, there is a need to have a decision support tool to visualize and manage the routes, because the operator will not understand and implement them.

This paper demonstrated the success of a combined methodology integrating Transport Object-Oriented Modelling, which links technologies to network modeling, and heuristics, which achieve optimization. Among the further works to be achieved in this aim, there is the full construction of new monitoring routes with the help of a fully dynamic approach. A method is under development for this task, but several modeling issues have to be addressed: seeding methods, route shape, operational constraint, route acceptance by operator, etc. We also examine road marking and snow removal routes problems assisted with GPS, which could use similar methods.

Acknowledgements

The authors wish to thank the Ministry of Transport of Quebec and especially M. Serge Hamel from Estrie region for their faithful help and grant for this project. The project was also supported by the National Science and Engineering Research Council of Canada and the "Fonds de recherche sur la nature et les technologies" of Quebec.

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