Collaborative planning in a log truck pickup and delivery problem

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Introduction

The least efficient route which can be planned by a dispatcher is one or a series of 'simple' trips where the vehicle travels loaded from the origin to the delivery site and then returns empty. Half and even more of the hauling distance is traveled empty when the distance from/to a vehicle's depot before/after the trip is considered. Even if a dispatcher tries to avoid 'simple' trips, the actual structure of transportation flows that he is responsible for does not always permit it.

In this situation, pooling these transportation needs with those of another dispatcher may avoid 'simple' trips planning by replacing the empty return part of a 'simple' trip with the loaded part of a transportation request in the responsibility of another dispatcher. Indeed, the new structure of transportation flows generated by the collaboration will allow transportation cost-savings. In Figure 1 we illustrate the effect of pooling, with two different dispatchers having responsibility for the two flows. The empty loaded part of the overall route is smaller (Figure 1-B) when two trips are pooled together compared to making them independently (Figure 1-A).

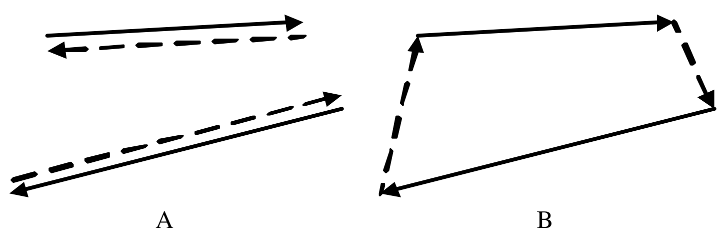


Figure 1
Improvements in unloaded distance (broken line) with pooling

In this paper, we describe the collaborative pickup and delivery problem of a network of business units of wood log supply. Then, a solution methodology for the given vehicle routing problem is proposed and tested in order to demonstrate transportation cost-savings through collaborative planning.

1. Business case study

The case study involves a high-value log specialized supplier, *Groupe Transforêt* (GT), who buys logs from a network of more than 4500 loggers/supplier-mills, classifies them, and finally, resells them in its network of customer-mills. Its business activities take place over a wide territory which is separated into regions each being the responsibility of one coordinator. Each coordinator is responsible for the purchasing and transportation planning within his region. Knowing that there are transportation flows between several regions, collaborative transportation planning could lead to more efficient routes which are not possible in the current governing mode.

GT signs supply contracts with customer-mills based on log species and grades. When a coordinator purchases a log from a supplier, these contracts specify that the log must be classified according to a species-grade pair. Moreover, at purchasing time, the logs are almost always allocated, to the nearest customer-mill which has the corresponding species-grade supply contract. Thus, no customer-mill log reallocation is possible in GT's current organization.

To carry out its transportation planning operations, GT coordinators utilize five types of truck owned by several carriers. The two smallest types have self-handling arm equipment. These self-handling trucks are essential for pickup (delivery) at supply sites (customer-mills) that have no on-site handling equipment available.

2. Vehicle routing problem description

The vehicle routing problem addressed by the coordinators' collaborative transportation planning is a pickup and delivery problem with time windows (PDPTW), a generalization of the pickup and delivery problem (PDP).

In the PDP a set of routes must be generated in order to satisfy a set of transportation requests at total minimum cost (or a similar objective function) and subject to a set of constraints. Each transportation request specifies a quantity, a site of origin and a destination site. Each request must be transported by only one vehicle implying no trans-shipment. For this, a fleet of vehicles is available. The vehicles are spread throughout a set of specific depot sites. This fleet of vehicles may consist of different vehicle-types, each with a unique set of transportation relevant characteristics.

In the PDPTW, time windows constraints are added, usually to the transportation request (i.e. specifying a time interval for pickup and/or delivery) or to the origin/destination sites (i.e. specifying accessible periods) or, more rarely, to both.

In GT's context, the PDPTW involves a set of practical considerations adding other constraints to the classical PDPTW and modifying its cost structure. These are described in the following subsections.

2.1. Vehicle fleet

In contrast with the known fleet by depot context of the classical PDP, GT does not maintain any contracts with carriers. However, regional coordinators have unofficial agreements with regular carriers and maintain business contacts with other carriers. Thus, the available vehicle fleet is represented on a regional basis: each coordinator provides the expected number of available trucks per type, and which defines the consolidated regional transportation capacity.

All these consolidated trucks are linked to the regional 'pseudo-depot', usually located in the middle of the region. However, we don't start and finish a route at the truck depot as we do in classical PDP. Indeed, payment methods used in practice by the industry fix the transportation price on the basis that a route starts and finishes at the first pickup site. However, in our context, when both the first pickup site and the last delivery site on the route are outside the truck's region, we start and finish the route at the truck 'pseudo-depot' to reflect the additional costs in empty traveling distances from and back to the truck's region.

2.2. Time windows

In GT's context, each request has a single time window: an earliest pickup time at origin and a latest delivery time at destination. Furthermore, route generation is also constrained to three other kinds of time windows which are multiple time windows as defined by Xu *et al.* (2003). The first one refers to the consolidated calendar of available truck per type and region. The two others are defined for each origin and destination site. They specify all sites' opening registration periods and on-site handling equipment availability periods.

2.3. Vehicle trailer design

Log trailer can be viewed as a sequence of two to five individual compartments depending on the truck-type, each with loading/unloading access by the top. This design is not constrained by the nested precedence constraints (Xu *et al.* 2003) known in the general freight PDP in which loading/unloading access is restricted by the truck trailer rear door. However, it heightens the routing complexity since the sequence of deliveries is not constrained to be the reverse sequence of pickups. In less-than-truckload context, this will increase the number of route scenarios that can be generated.

In addition, in the classical PDP, when a delivery has been made, no pickup is allowed until the truck is empty. But in our problem's case, when a delivery has been made, we allow pickup even if the truck is not completely empty. This makes routing much more complex than classical PDP, and as far as we know, this has never been studied before in freight PDP.

2.4. Driver regulations and other rules

Transportation legislation which regulates working and driving hours for drivers of commercial carriers must be respected by each generated route. In GT's context, a route is done by a sole driver (i.e. no driver exchange). Thus, these two basic rules need to be observed:

(a) The maximum driving time allowed per working shift is 13 hours, i.e. after 13 hours of driving the driver must take a resting time of at least eight consecutive hours before continuing the route. Of course, the truck may stay loaded during the resting period to allow routes that are otherwise too long to be planned.

(b) The maximum working time allowed per working shift is 15 hours, i.e. after 15 working hours (including driving, waiting and loading/unloading time), the driver must take a resting time of at least eight consecutive hours before continuing the route.

Other rules and possible exceptions in transportation legislation are related to the driver's work cycle (i.e. the number of working hours in a given number of consecutive days). They were not integrated into the planning since our objective is not to manage a specific fleet of vehicles but generate routes which will then be allocated to different carriers.

Finally, due to general practices and industry standards, two customized limits by truck per type and region have been added: a route starting time during the day (i.e. between 6AM to 6PM) and a maximum number of consecutive working shifts for a route (i.e. to allow the truck driver to spend the night at home).

2.5. Transportation requests

The quantity of some GT transportation requests exceeds the capacity of all types of truck. Thus a site within the same route could be visited more than once. Palmgren *et al.* (2004) based the decision on the quantity to be picked up at a site of origin directly in the proposed solution methodology. Their rule was: pickup the minimum quantity between i) the transportation request quantity available at the origin site or ii) the remaining capacity of the vehicle. We customized this rule by restricting the picked up quantity to an integer multiple of a specific quantity value. This quantity value is the higher integer value that minimizes the sum of all types of truck capacities modulus by the quantity value. Thus, all GT transportation requests are converted into loads of size equal to the quantity value and these loads cannot be split during the transportation planning.

2.6. Cost structure

A route is an ordered sequence of segments starting at a site and traveling towards another. There are four potential operations in a segment (waiting, handling, carrying and resting) and each operation involves an hourly cost depending on the type of truck selected. Also, except during the resting operation, fuel expenses are calculated according to three different truck engine fuel consumption functions (idling, handling and on-road). The total cost of a route is the sum of all the segments of the hourly cost of the realized operations, including fuel cost.

3. Solution methodology

GT's PDPTW has been formulated using constraint programming (CP). The choice of CP is explained by its two major features reported by Gendreau (2002): expressivity for problem complexities descriptions and flexibility for problem resolution possibilities. Using OPL Studio 3.7 from ILOG software, we developed a 'greedy & repetitive' solution methodology imbedding heuristics and two consecutive CP models. The general concepts of the solution methodology are: first, a set of 'itineraries' is generated; second, restricted by a Tabu list of transportation requests, a set of 'potential routes' is generated by matching transportation requests with one truck on one pre-identified itinerary taking into account only the capacity issues; third, all operations on each 'potential route' are scheduled to obtain a 'feasible route'. If a 'potential route' becomes unfeasible because of timing constraints, it is eliminated. Finally, the unplanned requests are routed in 'simple' trips.

We use two consecutive CP models to generate routes one by one. The first CP model called *PLAN* generates 'potential routes' relaxing all time constraints. A 'potential route' uses a specific truck (i.e. a type of truck from a specific region) and details what loads are pickup/delivery in what sequenced set of sites. The objective function is to maximize cost-saving obtained through the planning of a 'potential route'.

The second CP model is called *SCHEDULE*. It works with the previous 'potential routes' and schedules the timing of all operations to be conducted for each of them in order to obtain a 'feasible route'. The objective function here is to minimize the total duration of the route and execute the route as early as possible within the planning horizon. If no feasible schedule exists, the 'potential route' is eliminated and no 'feasible route' is generated.

Two different heuristics approaches are used to limit the number of route scenarios in order to solve the model *PLAN*. Both heuristics are described in the following subsections.

3.1. Heuristic 1

Using the algorithm developed by Gingras *et al.* (2006) a set of 'itineraries' is defined. An 'itinerary' is a sequenced order of visiting sites that corresponds to a route obtained by the Gingras *et al.* algorithm. To tackle the less-than-truckload itineraries, a site aggregation/desegregation procedure before/after solving the Gingras *et al.* algorithm has been developed.

Thus, heuristic 1 starts by selecting the largest transportation request to be planned which is not in the Tabu list. A subset of itineraries is then built with all itineraries capable of delivering the selected request. For each itinerary in the subset, all the trucks available to perform the itinerary are identified and testing pairs are created (itinerary; truck). Using the rules adapted from Palmgren *et al.* (2004), the subset of loads which could be planned by each testing pair is selected and the model *PLAN* is solved on each testing pair. If no feasible route can be obtained further in the solution methodology, the transportation request selected in the beginning of the heuristic is added to the Tabu list.

3.2. Heuristic 2

Usually, the itinerary set utilized in Heuristic 1 does not allow the routing of all transportations requests. Therefore, in Heuristic 2 new itineraries are generated in order to meet the remaining transportation requests.

Thus, all origin-destination pairs of remaining transportation requests are created. We create a sequence having the minimum traveling distance and covering a group of three pairs successively (or a group of two if just two pairs are remains). This sequence becomes a new itinerary if its traveling distance is less than the sum of distance over the pairs of the group routed in a 'simple' trip. In the other case, the pairs are added to the Tabu list and no itinerary is created. To tackle the less-than-truckload itineraries, we select the group of three pairs (or two pairs) not previously added in the Tabu list to create other itineraries. However, only the origin and destination site precedence constraint for each pair must be respected rather than travelling pairs successively.

For each new itinerary, testing pairs are created with all trucks available and the model *PLAN* is solved on each of them. If no feasible route can be obtained further in the solution methodology, all the transportation requests are added to the Tabu list and the Heuristic 2 stops.

4. Integrated solution methodology

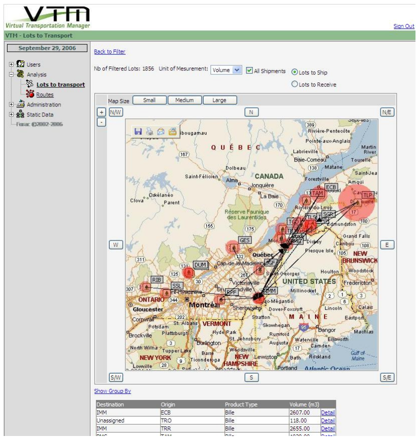
The different CP model and heuristics are used in an integrated way to provide a complete solution methodology to GT's PDPTW. The general framework of the solution methodology is summarized in six steps:

1) Define the itinerary set under the restriction of a Tabu list of transportation requests and for each testing pair (itinerary; truck), solve the model *PLAN* with Heuristic 1 and after, solve the model *SCHEDULE* in order to generate a set *P* of routes;
2) If there is no route in *P*, add specific transportation request(s) to the Tabu list and go to Step 5. Otherwise, select and save the 'best' route in *P* and go to next step;
3) Try to duplicate as many times as possible the 'best' route in taking into account only the capacity issues (i.e. transportation requests quantity and truck availability) and save all 'best' route duplicates;
4) Update transportation requests quantity and truck availability;
5) If no more transportation requests - not in the Tabu list - remain for routing, go to Step 6. Otherwise, empty *P* and go to Step 1.
6) If you use Heuristic 2 to solve model *PLAN*, stop solution methodology and make the routing of all transportation requests inside the Tabu list in 'simple' trips. Otherwise, empty the Tabu list and go to Step 1 but use Heuristic 2 instead of Heuristic 1 to solve the model *PLAN*.

5. Discussion on case study

In order to demonstrate the cost-savings opportunities associated with the coordinators' collaboration in transportation planning, experiments were performed with six weeks' GT transportation requests. Thus, for each week (i.e. 5 days), each coordinator's individual planning was done in order to compare their results with those of a collaborative planning approach. The six-week average improvement in cost-saving through collaboration was 4.55% while the average reduction in traveling distance was 7.25%. The average resolution time of the collaboration planning is 39 minutes.

To obtain GT's transportation data and carry out the collaborative planning in the GT coordinators' network, a Web-based system was developed. This routing system called *Virtual Transportation Manager* (VTM) is a joint development project of the *Forest Engineering Research Institute of Canada* and the *FORAC Research Consortium*. The VTM is composed of three main modules: the transportation data import, the optimizer and the transportation data/route visualization and management functionalities. In Figure 2-A we illustrate the result of an inventory query on transportation requests and in Figure 2-B we show the display of information for a optimized route.



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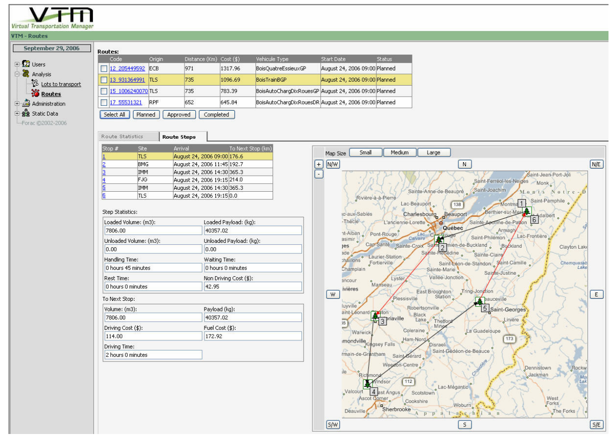

B

Figure 2

Screenshots from VTM on an inventory query result (A) and the display of a route (B)

Some mandatory transportation data do not exist in the GT inventory system and were added to the VTM system through the data management interfaces. Thus, times windows on origin and destination sites were defined using coordinator information. Vehicle fleet available in each coordinator's region was estimated at three trucks from each of the five types (i.e. 13.5, 31.5, 34.5, 37.5 and 41 ton truck-trailer capacities). Also, to respect actual practice, the maximum number of working shifts of the smaller type was constraint to one shift while other type was constraint to three shifts. Finally, the quantity value for pickup in the heuristic rule was set to 3.1 tons.

Conclusion

In this paper, we detailed the collaborative pickup and delivery problem of a business case study in the forest product industry. Then, a solution methodology for the given vehicle routing problem was described and tested. The results in cost-saving and in traveling distance demonstrate the benefits of collaborative transportation planning in the case study.

In order to evaluate opportunities to generate more cost-saving through collaboration on the VTM system, different networks of business units with GT customer-mills must be tested in future work. Also, extensions of the solution methodology must be conducted to evaluate the economic relevance of adding other wood products such as chips, lumber, etc. to these networks. Indeed, routing multi-products trailer-trucks which can haul either logs or other products can allow new routes scenarios that are otherwise impossible with mono-products trailer-trucks.

Acknowledgements

The authors wish to thank other members of the VTM development team from FORAC, FERIC, GT and especially Philippe Marier for their valuable contribution to the solution methodology.

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