A Tactical Transportation-Driven Harvest Planning Problem

Greg Rix
Department of Mathematics and Industrial Engineering,
École Polytechnique de Montréal, Montréal, Canada

Louis-Martin Rousseau
Department of Mathematics and Industrial Engineering,
École Polytechnique de Montréal, Montréal, Canada

Gilles Pesant
Department of Computer and Software Engineering,
École Polytechnique de Montréal, Montréal, Canada
Email: greg.rix@cirrelt.ca

1 Introduction

The forestry industry defines a significant proportion of the economy of many countries; including Canada, the United States, Chile, Sweden and Finland. These forests, most notably in Canada, can cover very large areas of land which makes transportation costs very significant: often up to 30% of the gross cost of the wood supply chain. Thus it is a necessity to organize these activities as significantly as possible for both economic and environmental reasons.

Supply chain planning in the forestry industry includes a wide range of decisions, with time horizons ranging from real-time operational problems to long-term strategic problems. A recent survey can be found in (D'Amours et al., 2008). When forest companies plan over a length of approximately one year, referred to as the tactical stage of planning, the decisions commonly made are the schedules of forest sites to be visited by harvest teams in order to produce enough volume to meet all demands over the horizon, and also the allocation of this volume to the different demand points. This allocation allows for an estimation of transportation costs, with more detailed routing and scheduling decisions left for operational planning.

The problem presented in this abstract will generalize a common tactical problem to include routing decisions, and was motivated by the specific needs of several Canadian forestry companies. A critical component of their operations is to ensure that they have a reliable source of permanent fleet drivers. In order to do this, they must be able to guarantee a variety of different schedules to several trucking contractors whom they hire drivers from, and harvest team scheduling has been identified as more flexible in order to accomodate this requirement. This resulting problem generalizes the well studied location and inventory routing problems, and is thus NP-hard.

We model this problem as a mixed integer program (MIP), which we solve via a branch-and-price based algorithm with columns representing driver schedules. These columns are generated at each node by solving a shortest path problem. We then give results on an industrial case study.

2 Problem Formulation

We assume a multi-period problem formulation: a horizon of approximately one year partitioned into periods of two weeks to a month in length. The geographical planning region consists of forest sites (supply points) and mills (demand points). Each forest site contains a known standing volume of several different products, and each mill has a known demand per period of these products. Additionally, mills must hold a minimum inventory of each product per period in order to protect the company against potential unforeseen fluctuations in supply or demand.

The company hires a set of harvest teams, each of which has a given capacity of volume per period. This capacity, along with the periods in which the team is available to work, determines the total target of volume for each team. Each team is also given a priority, which determines the penalty associated with any shortage in volume harvested over the horizon. When a team is assigned to a forest site, it must remain at that forest site until all standing volume is harvested. It must also cut each product in the forest site into a single length, which must be determined in order to synchronize with transportation decisions.

A set of trucking contractors is employed, each of whom have a set of driver schedules they wish to have filled. Each driver schedule is defined in terms of a number of shift length in hours, a number of shifts desired per period, the minimum and maximum number of drivers they wish to have on this schedule, and the type of truck used on this schedule. This last requirement implies that the formulation must take into account a heterogeneous vehicle fleet, with each vehicle differing in terms of capacity of each product and length. Every schedule is given a priority, which determines the penalty associated with violating any shortage of shifts for this schedule.

We formulate the problem as a MIP, with decision variables as follows:

- The volume of each product harvested at each forest site each period;
- The location of each harvest team each period (binary);

- The flow from each forest to each mill each period;
- The number of each feasible route traversed on every driver schedule each period (integer);
- The storage at each forest and mill each period.

The objective is to minimize total cost, which is a combination of transportation costs, storage costs, and penalties associated with less-than-desired workload for harvest teams and trucking contractors.

3 Methodology

The biggest obstacle in formulating the model in this matter is the exponential number of variables representing log-truck routes. Hence we use a branch-and-price based methodology in which we start with an empty pool of routes and generate improving ones a priori using a methodology similar to that used on the tactical/operational problem in (Rix et al., 2012). First, we relax the constraints linking the flow variables to the routing variables and penalize any violation in the objective function in order to start with an initial feasible solution. Then, we relax the integrality restrictions on all variables to yield a linear program (LP).

We then iterate between this master problem and a set of subproblems (one for each period and for each driver schedule) to generate negative reduced cost routes. These subproblems can be formulated as shortest path problems with resource constraints. Due to the nature of forestry industry with total transported volumes being much larger than a single truck capacity, this is not an elementary shortest path problem as is common in standard vehicle routing problems, and hence the subproblems are solved in polynomial time via a dynamic programming algorithm. Any routes that have a negative reduced cost are added as variables to the master problem, and the process is repeated until either no negative reduced cost routes remain, a time or iteration limit is reached, or a given number of iterations have passed with minimal objective value improvement.

It is possible that columns that are generated early in the algorithm will later become non-basic and remain that way indefinitely. As managing the column pool can require a significant amount of computation time when the pool is very large, we limit this pool size. Upon passing a predetermined upper limit, columns are eliminated randomly until a lower limit is achieved (set to 70% of the upper limit).

In order to quickly generate integer-feasible solutions, we use an effective heuristic branching method by traversing the search tree in a depth-first strategy without backtracking. We impose branching decisions on the harvest team assignment and harvest length variables by fixing the one with the largest fractional value to 1 upon the resolution of an LP. We do not allow backtracking: branching decisions can not be reversed. When no more binary variables can be fixed in this manner, we enforce integrality on all routing variables and solve the resulting problem as a MIP.

4 Results

This algorithm has been implemented on an industrial case study provided by FPInnovations, a Canadian not-for-profit research organization whose goal is to improve forestry operations. This data set contains 50 forest sites, 2 mills, 2 log assortments, 6 harvest contractors, and 3 different trucking schedules using 2 classes of truck. The gross forest supply is approximately 4 million cubic meters, while gross demand is 2 million cubic meters: half of the total forest management area must be harvested over 12 periods of 30 days. After accounting for truck capacities, approximately $20,000$ pickups and deliveries must be scheduled to deliver the demand.

Under a total time limit of 40 minutes, the root relaxed LP could be solved to optimality through column generation in 160 seconds, and the best integer solution found by termination was within 29.6% of this lower bound. As expected, the solution generated has all high priority harvest teams and trucking contractors working at full capacity, while the low priority ones are scheduled so as to satisfy the remainder of the demand.

5 Conclusion

We presented a problem that arises in the Canadian forestry industry in annual planning. This problem generalizes the location and inventory routing problems to account for harvest team scheduling, driver scheduling, and storage decisions. We modeled this problem as a mixed integer program and developed a branch-and-price heuristic for resolution of the problem. This heuristic has been shown capable of generating quality solutions to a medium-sized industrial case study in a reasonable time limit.

References

S. D'Amours, M. Rönnqvist, and A. Weintraub. Using operational research for supply chain planning in the forest products industry. *INFOR: Information Systems and Operational Research*, 46(4):47–64, 2008.

G. Rix, L.-M. Rousseau, and G. Pesant. A column generation algorithm to solve a synchronized log-truck scheduling problem. Paper presented at Odysseus 2012: the 5th International Workshop on Freight Transportation and Logistics, 2012.