DEMAND DRIVEN-HARVEST SCHEDULING

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ABSTRACT

The forest sector is at the heart of the debate on globalization and sustainable development. For many countries like Canada, Sweden and Chile, the objective is to maintain a flourishing sector without damaging the environment. It is important to be competitive and to operate effectively, from harvesting to manufacturing products, in a context where costs increase rapidly. Our project belongs to the area of value chain optimization. We develop tactical/operational models to plan the annual harvesting activities in order to meet demands at the mills, while integrating transportation and inventory management. Our mixed-integer programming (MIP) models address the assignment of harvest teams to forest areas over a one-year period, as well as the quantities transported from the forest to the mills and the levels of inventory to maintain in the forest and at the mills. We present and compare different MIP formulations, which are solved through a rolling-horizon method that decomposes the models by time periods, each of the resulting submodel being solved by heuristic branch-and-bound. We present computational results on actual large-scale instances derived from the context of the Eastern Canadian forest.

Keywords: Forestry, harvest planning, value chain, mixed integer programming, rolling horizon approach

PROBLEM DESCRIPTION

First, we describe the supply chain between the forest and the mills. The supply chain is defined by five activities: building roads, harvesting, storing wood in dedicated areas, transporting wood from the forest to the mills, storing wood at the mills.

Context

Forest field. The forest field is divided into two levels. The smallest unit is an area. And the largest one is called a sector which is constituted by a set of adjacent areas. Every harvest area includes volumes of different wood assortments, and has specific access restrictions. At the beginning of the annual planning, the set of areas available for harvesting for the year is already known. For an annual planning, moving between two areas in the same sector, witch takes about 10 minutes, is considered instantaneous, as every period of the planning horizon corresponds to 140 hours (2 weeks of work). Moves between sectors require other expensive engines, and need 3 hours in the worst case to be done. Hence, we have to limit the moves between sectors especially when the sectors are very far away from each other.

Road network. Road network is already designed. Each harvesting area needs a single access road. The only decisions we have to take about roads are when they are built, and by which team of workers. Roads are regarded as "harvesting areas " which must be built prior to the harvesting areas served by these roads.

Harvesting teams. Harvesting is done by teams of workers divided into two types: short woods and long woods. For each team type *h* and for each area *b* a capacity of production p_{bh} is defined. This quantity is the volume a team of type *h* can harvest on area *b* during a period of two weeks. We note that, on average, an area can be harvested in three periods of two weeks. But, there are small areas that can be harvested in less than two weeks. Thus, a team can harvest more than one area in a single period. Also some areas can only be harvested by one type of team.

Transportation. Transportation is associated to flow volumes between the forest and the mills. Our project does not include fleet scheduling, or routing problem, or triage in yards. There is no explicit destination in our problem, as each product has a single destination corresponding to the mill requiring this product.

The problem in details

For each activity, there is a set of constraints, which we summarize next.

Harvesting. Team assignment has to verify different access conditions as a area can be harvested only if the road which serves has been built. Some areas are not available for every period during the year, since various restrictions due to hunting, thaw, environmental protection, must be respected. For every forest unit (area and sector), an upper bound has been introduced to prevent situations where too many teams are in the same place. Only one team can work in an area at each period, and five teams can be in the same sector at each period. As soon as a team is assigned to an area, it has to work continuously on it, until there is no more wood to harvest in this area. Obviously, an area can only be harvested once. Following the assignment of a team to an area there are two cases:

- the size (volumes of all assortments) in the area on which the team is working is superior to the team's capacity of production per period, this team cannot work anywhere else during this period;
- if this team's capacity of production is superior to the size of the area, this team can work an another area.

We illustrate these situations with a small example. An area *b* has 100 m^3; the capacity of production of a team during a period of two weeks is 200 m^3this team has to work only half a period to entirely harvest area *b* But if the capacity of production of that team was 50 m^3per period of two weeks, as soon as this team is working in this area, it cannot be in another area during this same period. The team stays in this area until there is no more wood to harvest in this area.

Periods of two weeks allow situations where the harvesting of an area can start anytime during a period of two weeks. The ending time harvest period is the first period when there is no more wood to harvest in the area. T_{bq} is the number of periods of two weeks needed by team q to entirely harvest the area b. If q starts harvesting b at period t the ending time period can be $t + T_{bq} - 1$ or $t + T_{bq}$ according to the proportion of the starting period t the team q is working. If the harvesting of area b starts soon enough, the ending time period is $t + T_{bq} - 1$, it is $t + T_{bq}$ otherwise. A short example to illustrate these possibilities follows. If the harvest of b starts soon enough in the period t (Case A), the ending time period is $t + T_{bq} - 1$ Otherwise it is $t + T_{bq}$. Colored zone in the figure indicates working proportion time period (Figure 1).

Consider a team q starts harvesting b at period t. Real harvesting time is 2,8. $T_{bq} = \lceil 2,8 \rceil$

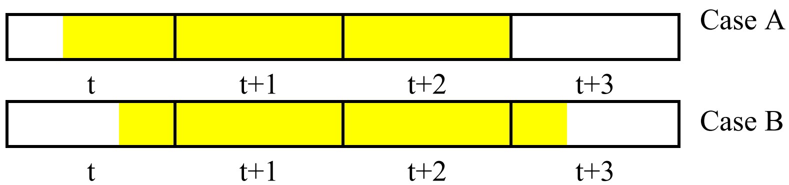

Figure 1: Determination of the ending harvest period of an area

We direct the harvesting effort according to the demands d_{kt} of the mills. By $\tilde{d}_{kt}$ we evaluate the effort that has to be done at each period to satisfy demands at the current period and at the next ones. This way, we manage harvesting effort according to variation of future demands. If the harvesting effort $\tilde{d}_{kt}$ is not reached, lacking volumes are penalized. This penalty is called « delayed production cost » .

Storage in forest areas. Harvested volumes are left on the roadside. Some are for transportation, others stay in storage areas. However, we want to prevent situations when too many products stay on the roadside, losing value.

Transportation. All transported volumes are first delivered to the main mill, before their final destination. An upper bound ξ_b on the total volume transported from each area b to the main mill is introduced, to represent the distance between the area and the main mill. More an area is far away from the main mill, smaller is the upper bound associated to this area. In the contrary, the closer the area, larger is the upper bound.

Storage at mills. A part of the transported volumes are required to satisfy mills demands, remaining volumes stay in storage. For some product k, at each period, a minimum volume m_{kt} is required for safety purposes, but this minimum is not rigid. If needed, this quantity can be used for consumption. If demands cannot be met, we introduce slack variables l_{kt} which are very penalized in the objective function. These quantities will be called « orders » .

Goal Project. For on year planning horizon, divided into 26 periods of two weeks each, we look for a near-optimal harvest scheduling, which minimizes harvesting, inventory, transportation cost.

LITERATURE REVIEW

We do not intend to present an exhaustive review of operations research (OR) applications in forestry, but give a short indication where our projects stands.

Value chain optimization and forestry

Shapiro et *al.* [9] maintain that the optimization of the value chain of a company starts with a quantitative analysis to optimize the bonds between activities, and continues with the development of tools for sharing informations and making decisions. He also justifies why mathematical programming is appropriate for integrating planning problems, emphasizing that most integrating planning processes can be formulated as linear or mixed integer problems. The article by D'Amours et *al.* [1] proposes an overall picture of OR uses for forest value chain planning. In the introduction, the challenges for OR researchers in forestry are listed, one of the major and undoubtedly more complex one being the integration of a broad forest chain activities where the different and many agents have divergent ends (« many to many processes »). The importance to integrating decisions from distinct planning levels is also emphasized as well as in [10].

Optimization in forestry

For a field as wide as the forestry, it is interesting to know the contexts and the degrees of OR involvement. Many forest activities like green up, road network design, cutting strategies, harvesting, vehicle routing etc, have been the subject of scientific research. Within this section, a quick overview of different OR tools used in forest activities is given. Rönnqvist [8] describes the wood flow within a forest planning and a variety of problems associated to planning at different hierarchical level. Each element of the supply chain has a detailed description. The author presents examples of real problems for each planning level, the type of model used and the common solution method.

Epstein et *al.* [2] present several decision-making systems established in the Chilean forest sector. They insist on their effectiveness, the savings obtained and the practical use of the systems. We mention the tool OPTICORT, which is a decision-making system for short-term harvesting (three months), because it is similar to our context. In OPTICORT, planning is based on harvesting and transportation decisions. We specify that the management of the inventories is not included. OPTICORT is based on a linear model which is solved by column generation.

Harvest planning

Karlsonn et *al.* [4] deal with a problem of annual harvest planning from the point of view of Swedish companies. These article objectives are very close to our project. If the objectives are alike, mathematical formulations are clearly distinct. A major difference is the harvesting duration of an area. Every area needs one period to be harvested. In our models, the harvesting duration varies not only with the surface of the areas, but also with the team productivity and can last more than two periods. Moreover, even if the forest territory partition is also on two levels (areas, sectors), the problem applies only to areas from the same sector. We note however the largest number of areas (approximately 400 compared to 184 in our case) in their project. They propose heuristics whose behavior is similar to Branch-and-Bound, where branching rules are based on harvesting. Lacroix's master thesis [5] provides important details about the context of our problem, and presents operational issues considering environmental protection of the forest in Québec.

Very short-term planning

Finally, Karlsonn et *al.* [3] provide a project of operational planning which binds this level of planning to tactical planning. For one period of 3 to 6 weeks, the objective is to choose among a whole of calendars, one for each team. A cost is associated to each calendar, including harvest, displacements between sectors, transport and the inventories. To the usual constraints of transport and inventory, those are added representing the maintenance and the management of the roads. Mitchell [7] gives a very detailed definition of operational harvest scheduling, applied in New-Zealand and Australia companies.

SOLUTION APPROACH

We developped two MIP models. The first one (M1) considers every harvest team. This formulation is intuitive but we notice symmetry between team of same type. Because most of parameters are defined according to type, not team individually, we could develop another model (M2) to break this symmetry. But we had to introduce other constraints to ensure the consistence between a type team scheduling and the team scheduling. Most of the constraints in M1 remain with a light modification, but some as to be reformulated. *A priori* it is not obvious which model will be more efficient. Even if there is less symmetry in M2, the additional constraints could slow down the solution time.

We solve the models on an actual instance, provided by FPInnovations. All computations are performed on a Dual Core AMD Opteron(tm)Processor 285. We chose to use some options of CPLEX12 for large scale MIP, as priorities branching [11] and polishing. After the first or second feasible solution, the « polishing » of this solution starts. Polishing is MIP heuristic provided by CPLEX.

Even with these user options in CPLEX, a direct solution of our models for 26 periods cannot be done in a reasonable time and consume a lot of memory.

Rolling horizon approach

Only short horizons can be solved easily. The rolling horizons approach is about solving a short horizon, save variables associated to some periods. After that, a longer horizon is solved, there are fixed variables. The process goes on until there is fixed variables for 26 periods. For our tests, we use 3 periods horizons, and fix variables associated to the first period.

nFix = number of fixed periods at each horizon
nLg = number of periods at each horizon
nBTours = number of horizons
iT =0
s(iT) = best solution from iTth horizon
Step 1 : Problem for NT = nLg + iT.nFix
Fix variables for periods $t < \text{iT.nFix}$
Solve problem for NT = nLg + nFix.iT periods with variables associated to iT.nFix first periods are fixed
    Save the best solution found in s(iT)
iT←iT+1
Step 2 : Si iT< nBTours
    Go to Step 1
Step 3 : Fin de la résolution
Output is harvest planning for nBTours.nFix+nLg.

Figure 2: Rolling horizons resolution pseudocode

We define 2 stopping criteria:

- time limit of 3 hours by horizon
- acceptable gap of 5\%

Rolling horizon on the whole model or on some constraints. Our models can be divided in two subproblems. The first one is a MIP problem. All harvesting constraints are in it. Remained constraints constitute un LP subproblem. Rolling horizons can only be done on the MIP subproblem. After 26 iterations, the LP problem associated to transport and storage management can be solved for 26 periods. It is not obvious what constitutes the best strategy to gain a good annual schedule. *A priori* solving an annual transport-storage problem, can give a better management of volumes, and reduce orders. So, for each model, we will compare witch strategy is more efficient: rolling horizons on the whole model, or only on harvesting constraints then a 26 LP subproblem to solve. Every strategy is summarised:

M1_C1: Rolling horizon on whole model 1, Polishing after finding 1 feasible solution
M1_R1: Rolling horizon on harvesting constraints from model 1, transport-storage LP suproblem resolution for 26 periods, Polishing after finding 1 feasible solution
M1_C2: Rolling horizon on whole model 1, Polishing after finding 2 feasible solutions
M1_R2: Rolling horizon on harvesting constraints from model 1, transport-storage LP suproblem resolution for 26 periods, Polishing after finding 2 feasible solutions
M2_C1: Rolling horizon on whole model 2, Polishing after finding 1 feasible solution
M2_R1: Rolling horizon on harvesting constraints from model 2, transport-storage LP suproblem resolution for 26 periods, Polishing after finding 1 feasible solution
M2_C2: Rolling horizon on whole model 2, Polishing after finding 2 feasible solutions
M2_R2: Rolling horizon on harvesting constraints from model 2, transport-storage LP suproblem resolution for 26 periods, Polishing after finding 2 feasible solutions

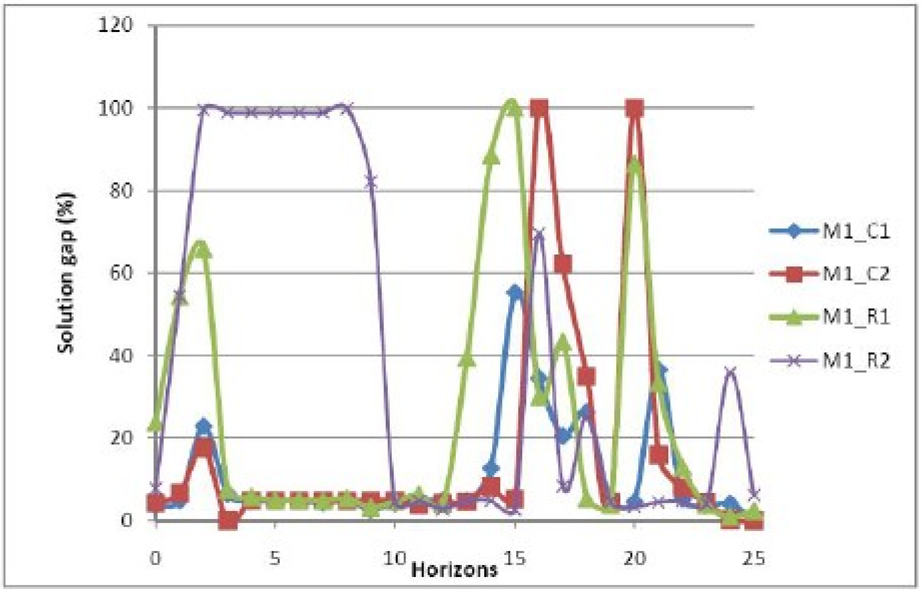

Figure 3: M1 Solutions gap per horizon

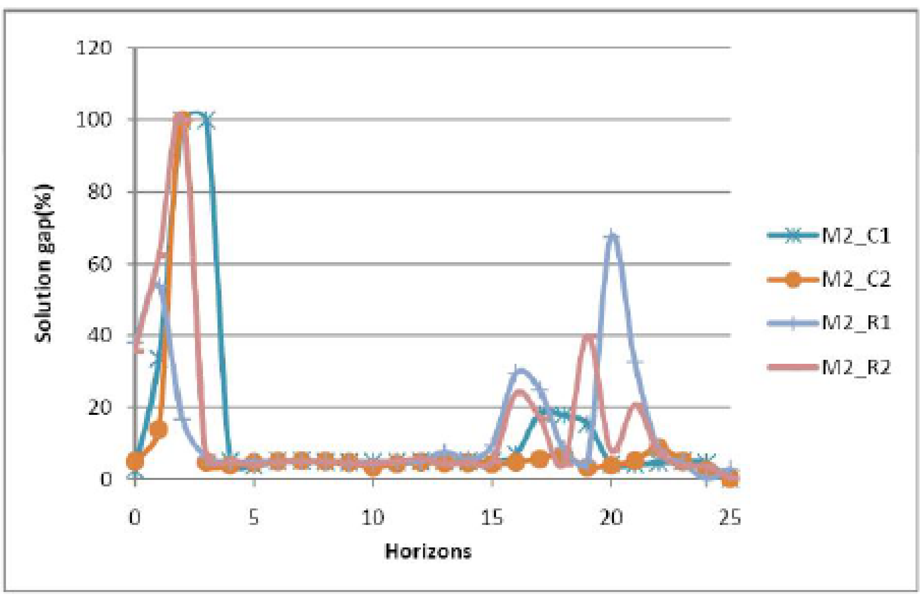

Figure 4: M2 Solution gap per horizon

CONCLUSIONS

Thus we developed two models in order to establish an annual harvest calendar for each team with an aim of satisfying the mills requests. This calendar can be obtained in less than one day. By analyzing our results, the best choice between the two models is not absolute. However M2 solutions are at the top of the strategies. Even if such a calendar is viable in reality, various points should be improved in particular the reduction of the ordered quantities, and thus to approach optimality. However it seems that the use of compact methods has reached its limits. It would be also interesting to know the influence of a greater number of areas on the resolution. The orders relate to only one product. If the forest field is larger, other choices of areas can be made in order to increase the harvest of this product which misses, without inflating the inventory of the other products less required. Thus, the annual planning could be different, maybe faster, even if the number of generated constraints explodes. Indeed larger is the number of stands, larger will be the offer by product. Thus the availabilities and the conditions of access could play in favour of a faster resolution. For next work, we will exploit a column generation approach. It will then be a question of determining schedules for each team over the year. These schedules will have to be feasible and will have to observe the various harvesting conditions. Harvesting production will always be guided by the demands, without forgetting the minimization of the costs of harvest, of inventories and transport.

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