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Wood-based products distribution planning with wood returns in a Iberian company

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ABSTRACT: *This paper explores the possibility of combining inbound and outbound planning in a setting where third-party logistics providers have a lower bargain power than usual. This happens to be very often the case with companies manufacturing wood-based products for which there is a fragmented transportation market. Emphasis is put upon establishing the best group of clients of wood-based products to be served by the truck departing from the mill in a way that delivery costs are minimized and further finding the best supplier of wood to be visited by the same truck when it returns to the mill. This problem is similar to other distribution problems with backhauls, but in this fragmented market, route costs are mainly related to the distance of the farthest client visited. Moreover, depending on the duration of the route it may be not possible to perform a pickup of wood in a park to return to the mill. We propose an iterative solution procedure based on mathematical programming that is able to establish distribution plans for rather big instances. Results from its application to a real case of a wood-based panels company are presented. The company has to deal with 4 mills in the Iberian Peninsula, around 135 deliveries per day (330 ton of wood-based panel products) and 80 possible suppliers. The proposed routes were compared against the current daily routes showing significant savings in the transportation costs followed by better utilization rates of the trucks' capacity.*

KEYWORDS: *Distribution planning, mixed-integer programming, forest operations, logistics, backhauling*

1 INTRODUCTION

The transportation of raw materials to the mills is a key activity in forest-based supply chains, as it corresponds to about 45% of the wood procurement costs and has an enormous impact on the efficiency of the entire chain (Audy et al., 2012). Many operations research (OR) models and methods were developed for improving wood transportation planning and decision making particularly at tactical and operational levels. Depending of the application context, the models may focus only in the inbound logistics decisions usually at the initial stage of the supply chain (procurement stage); only at the outbound logistics usually focusing in distribution and sales planning; or may cover the entire supply chain, thus acknowledging the impact of wood transportation planning in the production, distribution and sales decisions downstream. Yet, the joint planning of the inbound and outbound logistics is still uncommon in the literature of wood-based products distribution planning.

In this paper, we focus on the improvement that can be derived by integrating both the outbound and inbound logistics of a company that produces wood-based products. The scope of this work relates to the Iberian market in which the product margins of these products are relatively small, but in which the transportation market is highly fragmented and, therefore, the bargain power of logistics providers is considerably lowered. The wood-based products industry faces ever increasing competition and companies that want to strive have to excel in terms of price, quality and client service. Therefore, distribution efficiency and efficacy has become a major point together with sustainable operations. A clear avenue to pursue such advantage is through supply chain management (Fearne and Hughes, 1999).

In the literature, examples of models to support the inbound logistics decisions taken by the planners of the wood supply at the mill may be found in the (Epstein et al., 2007), (Carlsson and Rönnqvist, 1998) and (Palmgren et al., 2003). The tactical wood transportation problems define the wood flows (i.e. timing, amount, assortments) across the locations that supply, demand and store the wood over the supply chain, in order to meet the demand at the mill. The wood supply is intrinsically dependent on the stands harvest operations, therefore, combined transportation and harvesting planning models are common (Palmgren et al., 2003). The planning horizon in these problems typically range from 1 month to up to 3 years.

Other shorter term models design the vehicle routes as a sequence of daily trips going back and forth between wood sources and sinks, which may or may not account for backhauling possibilities (Bredström and Rönnqvist, 2008). As stated by (Audy et al., 2012), the Vehicle Routing Problem in wood transportation has specificities that differ from the standard vehicle routing problem (VRP) problems found in the literature, including: all pick-ups occur before the deliveries, mills and stands may have particular times to be visited (time-windows), mix of wood assortments that may or may not be transported at once, the route usually start and ends at the drivers home. When the route may be composed by many sources and/or sinks, such models include the former wood flow allocation decisions (Berbeglia et al., 2007).

As transportation services are typically outsourced, the hauliers often carry out the detailed planning of the fleet characteristics and schedules at a monthly, daily or even hourly basis. Examples of models to address routing decisions can be found in (Palmgren et al., 2004), (Gronalt and Hirsch, 2007) and (Murphy, 2003). Decision support systems for transportation planning and routing include ASICAM system (Weintaub et al. 1996) and the Swedish system RuttOpt (Flisberg et al., 2009) and (Andersson et al., 2007). Examples of models to support outbound logistics are found in the review of (D'Amours et al., 2008). Bredstrom et al. (2005) deals with planning the routing and scheduling of transportation means for pulp distribution. When stock management is the major concern, these models may include production planning and/or sales planning decisions. Further examples of supply chain planning using aggregated wood flow decisions may be found in (Gunnarsson et al., 2004).

In this paper, the challenge pertains to a large-scale delivery operation in which the mill assigns the deliveries of trucks while all the scheduling decisions afterwards of both inbound and outbound logistics are at the responsibility of the haulier. The wood-based products producer has a distribution cost that mostly depends on the distance between the mill and the farthest visited client - farthest client based costing. On one hand, this fact eases the distribution problem, but on the other hand, the planner has less visibility over the possible backhaul routes that could fit into the outbound operation.

We show that even without a direct responsibility over the operation plan, it is possible to use OR-based tools to substantially improve the overall distribution operation. Improvements are visible on the cost and sustainability perspectives. By integrating the inbound and outbound planning it is possible to improve the utilization of the transportation resources. The overall transportation capacity is better used and the total distance traveled empty is minimized. The overall goal is that within reasonable boundaries, if transportation services are hired to distribute products to clients served by a mill, it would be desirable to use the same vehicle to bring raw materials from suppliers back to the mill. In this reasoning, it is assumed that the trucks used to transport finished goods can also be used to transport raw-materials. This happens to be the case of several wood-based panel companies that work with trucks that have trailers with reinforced canvas. These trucks may be used to deliver panels and afterwards transport wood chips without the need of major changes in the truck layout. However, this situation is uncommon in other forest-based companies that are supplied predominantly by roundwood materials with a dedicated fleet. Next we detail the problem addressed, the solution approach developed and discuss the potential impact of our methodology in the company. We finish by drawing some concluding remarks and future research developments.

2 PROBLEM STATEMENT

The integrated inbound and outbound distribution problem for wood-based companies with farthest client-based costing may be stated as follows.

Given a set of mills, a set of clients where specific products must be delivered in a day, and a set of suppliers that may have availability of raw materials needed at the mills, the problem consists in finding optimal daily routes as a sequence of one or many deliveries of wood panels (outbound) and one return of wood based raw materials (inbound). This operation is performed by several trucks and the goal is to make the best use of total transportation capacities and assure the fulfillment of all deliveries. The delivery costs are computed based on the farthest visited client and there are earning to be accounted for when returning with raw materials after a final delivery.

We are looking for routes with the following characteristics:

- Routes start at a mill and end at a mill, not necessarily the same.
- Routes are planned in a daily planning horizon that force a maximum of 2 routes per day per truck.
- The fleet for this distribution operation is considered homogeneous and trucks have a capacity that is around 24 ton.
- The outbound routes may include 1, 2 or many deliveries. In most of the cases, 1 delivery will

correspond to satisfying the demand of a preferred client ordering a full-truck load; 2 or more deliveries correspond to smaller scale clients that order a less than full truck load.

- Each delivery corresponds to a bundle of products per each client (i.e. order) and all orders have to be fulfilled.
- All combinations of deliveries are possible.
- No time windows at the clients, but we consider that is necessary to comply with the mill and stockyards working hours.
- Routes may include 1 Return (Inbound) after all deliveries have been performed.
- Suppliers includes stockyards managed by the company or other companies, mills with by-products used to produce wood-based panels such as sawmills. These suppliers have capacity constraints that is hard to measure accurately. Hence, we roughly estimate the availability with an upper bound on the number of trucks that can visit a backhaul.
- The products transported from the supplier to the mill may be transported with trucks that have trailers with reinforced canvas. Most of the times the transported product will be recycled wood chips. Nevertheless, this product may be chosen independently from the product transported in the previous delivery.
- Mills may receive any type of the accepted wood-based raw materials, with preference to recycled; yet storage capacity constraints are not considered;

In Figure 1 there are three examples of possible solutions to the described problem. The full line arrows represent the trips with the vehicles loaded and dashed arrows represent empty trips. Node M represents the mill, node S the supplier and nodes A, B and C denote the clients. Solution (1) is a solution in which backhauls are not privileged. These type of solutions are the typical solutions when inbound and outbound planning is not integrated. Solutions (2) and (3) have different costs for the haulier, but for the company they are just about the same since the cost of the trip is based on farthest client visited. These last solution will be privileged in our solution approach.

3 SOLUTION APPROACH

We propose an iterative solution procedure, based on mathematical programming, that has three integrated modules (cf. Figure 2). First, we have developed a mixed integer formulation that takes an integrated outbound-inbound perspective in order to cluster clients in the same region while searching for possible backhaul routes. The second module routes each of the previously defined clusters. Two cases may happen after the routing: either the solution is feasible in terms of time and we move to module three, or we tighten the clustering and repeat the routing process. The last module assigns the collection of routes to trucks in order to minimize the number of vehicles used in one planning period.

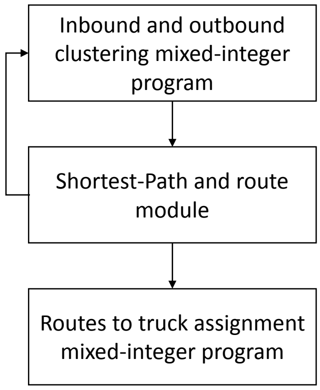

Figure 2: Iterative solution approach.

The first module is the key element of this solution approach. Let us define the mathematical model that has as output the required clusters of customers.

Sets

L - set of line-haul nodes (clients)

B - set of back-haul nodes (suppliers)

O^+ - Initial node (mill)

O^- - end node (used as sink for unused routes)

O - set encompassing the initial and end node $O = \{O^+ \cup O^-\}$

N - set of nodes, $N = L \cup B \cup O$

K - set of routes

Parameters

t_{ij} - time required to travel from location i to location j, $(i, j) \in N$

b_i - upper time limit to visit node $i \in B$

T - adjacency parameter (time between linehaul nodes)

d_i - demand in client $i \in L$

Q - vehicles' capacity (homogeneous fleet)

N_{max} - maximum number of nodes visited by a route

α - objective function weight for the distance to the

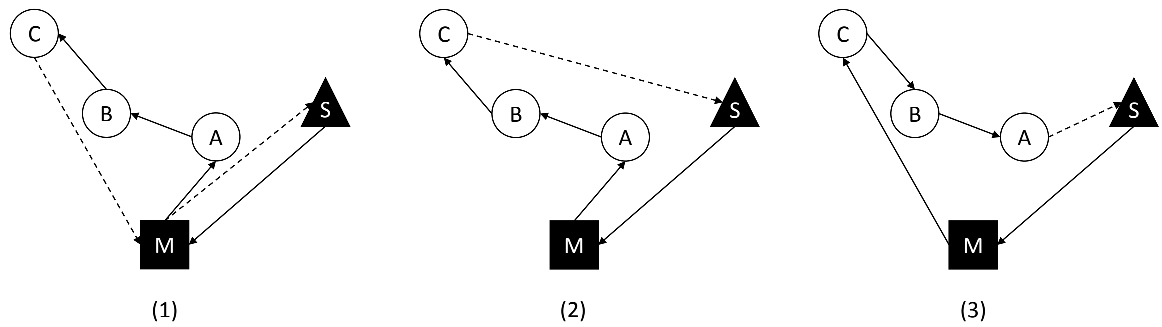

Figure 1: Possible solutions for the integrated inbound and outbound distribution problem for wood-based companies with farthest client-based costing.

last visited client

β - objective function weight for the number of routes used

γ - objective function weight for the number of backhauls visited

Decision variables

$$x_i^k = \begin{cases} 1 & \text{if route } k \in K \text{ visits node } i \in N \\ 0 & \text{otherwise} \end{cases}$$

c_k - maximum time to reach a linehaul node visited by route $k \in K$

The inbound and outbound clustering mixed-integer program reads as follows.

$$\min \alpha \sum_{k \in K} c_k + \beta(|K| - \sum_{k \in K} x_{O^-}^k) - \gamma \sum_{k \in K} \sum_{i \in B} x_i^k \quad (1)$$

subject to:

$$\sum_{k \in K} x_i^k = 1 \qquad \forall i \in L \quad (2)$$

$$\sum_{i \in B} x_i^k \leq 1 \qquad \forall k \in K \quad (3)$$

$$\sum_{k \in K} x_i^k \leq b_i \qquad \forall i \in B \quad (4)$$

$$\sum_{i \in B} x_i^k - \sum_{j \in L} x_j^k \leq 0 \qquad \forall k \in K \quad (5)$$

$$\sum_{i \in N \setminus \{O^+\}} x_i^k \leq x_{O^-}^k N_{max} \qquad \forall k \in K \quad (6)$$

$$x_i^k t_{O^+ i} \leq c_k \qquad \forall i \in L, k \in K \quad (7)$$

$$\sum_{i \in L} d_i x_i^k \leq Q \qquad \forall k \in K \quad (8)$$

$$t_{ij}(x_i^k + x_j^k - 1) \leq T$$
$$\forall i \in L, j \in L \cup B : (i \neq j), k \in K \quad (9)$$

$$t_{O^+,i} + t_{ij} \leq b_j + M(2 - x_i^k - x_j^k)$$
$$\forall i \in L, j \in B, k \in K \quad (10)$$

$$x_i^k \in \{0, 1\} \qquad \forall i \in N, k \in K \quad (11)$$

$$c_k \geq 0 \qquad \forall k \in K \quad (12)$$

Objective function 1 encompasses three different terms. The first aims at reducing the maximum distances from the mill to clients served in a given route. This term has to be seen together with constraint (7) were the value of the farthest client visited is set for each route. The second is used to minimize the number used routes by subtracting the routes that do not initiate $x_{O^-}^k$ to the number of available routes $|K|$. The third term aims at maximizing the visited backhaul nodes. Notice that to balance the trade-off between those terms, weights α, β and γ are used.

Constraints (2) establishes that all clients nodes must be visited and constraints (3) establish that a route may visit at most one backhaul (supplier) node. For a truck to visit a backhaul node, it must have visited a client before (constraints (5)). Constraints (6) establishes that if a route is not used, than it cannot visit any location. Further note that a route may visit at most N_{max} different nodes.

Constraints (8) establish that the sum of the demands of visited clients by a truck cannot exceed its capacity.

The clustering of customers performed with variable x_i^k is tightened by parameter T in constraints

(9). These constraints establish control the proximity range (in terms of time) of the clients visited in each route.

Finally, constraints (10) estimate the possibility of visiting a supplier in a given route, after visiting all clients. Remark that the supplier nodes have a time window defined by the parameter b_i that needs to be respected (4).

Constraints (11) and (12) establish the domain of the variables.

The output of the first module are the nodes to be visited in each route. These clusters are then fed into the shortest-path and route module. In case the best route found is feasible - the backhaul is visited within the time windows, then the route is passed to the last module. In case the best route found is unfeasible, then parameter T is tighten and the first module is solved again. Notice that these parameter T controls the maximum time between clients of a given cluster. The last module, which finds the needed number of trucks for each planning period is described as follows.

The objective is to assign routes to vehicles as to minimize the number of used vehicles given a maximum time limit for the conclusion of the last route. Note that for all routes their completion time regards the total elapsed time for travelling from the mill to all clients, from the last client to the supplier and from there the return back to the mill (depot).

Sets

- R - set of trucks
- K - set of routes

Parameters

- t_i - time needed to complete route $i \in K$
- T_{max} - maximum working hours

Decision variables

- $y_i^k = \begin{cases} 1 & \text{if truck } i \in R \text{ is assigned to route } k \in K \\ 0 & \text{otherwise} \end{cases}$
- $z_i = \begin{cases} 1 & \text{if truck } i \in R \text{ is active} \\ 0 & \text{otherwise} \end{cases}$

$$\min \sum_{i \in R} z_i \qquad (13)$$

subject to:

$$|K| z_i \geq \sum_{k \in K} y_i^k \qquad \forall i \in R \qquad (14)$$

$$\sum_{i \in R} y_i^k = 1 \qquad \forall k \in K \qquad (15)$$

$$\sum_{k \in K} t_k y_i^k \leq T_{max} \qquad \forall i \in R \qquad (16)$$

$$y_i^k \in \{0, 1\} \qquad \forall i \in R, k \in K \qquad (17)$$

Constraints (15) force vehicles to be active whenever a route is assigned to them. Constraints (15) establish that all routes must be completed must be assigned to a vehicle. Constraints (16) establish that a vehicle cannot exceed it's maximum working hours that are more related to driver's constraints. Finally, the domain of the decision variables is set up with constraints (17).

4 CASE STUDY: IBERIAN WOOD-BASED PANELS COMPANY

The proposed methodology for solving this distribution problem was motivated by a case-study performed within one of the world leaders in the wood-based products sector. This manufacturer is present in twelve countries within three continents and has a wide range of products, from simple board to complete construction systems, a large range of wood-based products and materials for furniture, construction and decoration. Our focus is on the Iberian peninsula where they have 4 mills (2 in Portugal and 2 in Spain).

Within one day of deliveries in the total of the 4 wood-panel mills owned by the company in the Iberian peninsula there is an average of 132 delivery orders to 57 distinct clients, corresponding to many thousands of different types of products. These operation amounts to approximately 3354 ton, i.e. 800ton/mil/day. There are 88 potential suppliers of raw materials that can be used as backhauls after delivering all clients, each of these suppliers have a limited availability of different types of raw materials. The suppliers include stockyards owned by the panels producer company, third-party stockyards and mills with by-products that may be incorporated in wood-panels production process, such as sawdust and wood chips. The compatibly between the suppliers and the mills is not complete as the mills are dedicated to produce specific products. Overall, there is around 36933 ton available per week in all suppliers and, therefore, the mills shall not starve due to lack of raw materials. Next to the 4 mills there are several hauliers available to perform inbound and outbound transportation services. The number of homogeneous trucks with trailers with reinforced canvas amount to 141.

The mills and the stockyards/suppliers have similar opening working hours (around 7 a.m.), but they differ in the closing time. The mills close around 9 p.m. and the suppliers around 6 p.m.. Moreover, the drivers are limited in the Iberian peninsula to drive less than 9 hours.

In the current transportation planning process the trucks are routed on a daily basis for deliveries on the same day. At each one of the mills, the outbound planner groups scheduled deliveries that are already available as finished products in stock for that day. The groups include clients in the same district or clients in the route between the mill and the farther district, up to a maximum of 24 ton per truck. If a full truck load is not possible obtain, the planner may delay the delivery one day hoping that a better consolidation will arise in the next day. The outbound planner regularly contacts the suppliers to check if possible returns for the planned deliveries are possible. Afterwards, routes are settled and the hauliers are contacted (1 truck per route in almost all cases). The trucks start loading as soon as possible and the haulier/driver plans the sequence of deliveries, the driving directions and the scheduling for each delivery without visibility to the mill.

Overall, this process results in a low rate of inbound-outbound flux integration. Some of the cases in which this flux happen, the mill does not even notice.

With the proposed solution approach the goal is to improve routing and scheduling performed at the mill by assuring inbound-outbound Integration by planning returns whenever possible, while minimizing costs and keep constraints fulfilled.

5 RESULTS AND DISCUSSION

In this section we compare the real-world results of the distribution plans for one day of activity of two mills with the results obtained by applying the solution approach described in Section 3. This instance is representative of the volumes transported in this case-study per day. Results for a set of key indicators are presented on Table 1. These indicators are number of routes (# Routes), number of trucks (# Trucks), average number of clients per route (Avg. # clients per route), average load of trucks (Avg. Load of trucks), number of backhauls integrated with client deliveries (# Integrated Backhauls), average route duration (Avg. Route Duration), and the number of routes with X clients (# routes X clients). The models and the solution approach were implemented in OPL and solved with the CPLEX solver version 12.5.1. To obtain the integrated distribution plan the overall solution approach took about 30 minutes, which is a reasonable time for plans that have to be obtained once per day.

The results show a clear advantage of the solutions found through the proposed approach compared with the real-word results. Both the number of routes and trucks were lowered. Therefore, the average number of clients per route and the utilization of the vehicles was improved. Having the integrated model to plan both outbound and inbound fluxes resulted in a drastic increase on the number of visits to the suppliers that were possible after an outbound trip. Despite the fact that the route duration is not directly tighten to the potential cost savings, it is worth to point out the visible decrease in the route duration that enables more visits to the suppliers.

Together with the Iberian wood-based panels company, it was estimated the implementation of this solution approach should yield savings of at least 6% on the operational costs of distribution.

6 Conclusions

In this paper, we presented a OR-based solution method for integrating the inbound and outbound transportation planning, driven by the needs of a real case of a wood-based panels producer company in the Iberian Peninsula. This solution approach is based on three linked models. First, the nodes to be visited for each route are found. These nodes are then scheduled and, finally, the best assignment of routes to trucks is obtained. Results show a significant improvement of the solution method when compared against the current plans. From a sustainability point of view the results are even more visible as we are able to shift from 22 visits to suppliers after visiting clients to 90 visits.

Future work shall be devoted to assess the gains that can be obtained with the flexibility of postponing some visits in a given day. Moreover, the integration of the plans of the different mills is also a future avenue of research.

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	Mill 1		Mill 2		Overall	
	Manual	Solution Approach	Manual	Solution Approach	Manual	Solution Approach
# Routes	42	42	51	48	**93**	**90**
# Trucks	40	42	44	37	**84**	**79**
Avg. #clients per route	1.46	1.67	1.37	1.35	**1.41**	**1.51**
Avg. Load of trucks	22.7	22.83	22.26	23.68	**22.48**	**23.26**
# Integrated Backhauls	3	27	19	46	**22**	**90**
Avg. Route Duration	4h15	3h15	2h57	2h06	-	-
# routes 1 client	33	28	38	39	-	-
# routes 2 clients	2	6	8	3	-	-
# routes> 2 clients	7	8	5	6	-	-

Table 1: Real-world results against results obtained through the proposed solution approach.

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