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MODELLING THE FOREST HARVESTING TOUR PROBLEM

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Abstract. In a globalized market, forest management plans play an important role in the sustainability of forest enterprises. Several optimization processes have therefore been developed to support decision-making in forestry operations. However, important issues remain to be addressed, such as planning the allocation of harvesting areas and scheduling the harvesting teams that are contracted for these purposes. Harvesting schedules include different time scales and natural constraints, so that finding optimal or even good quality ones constitutes a highly complex combinatorial optimization problem. Efficient planning of harvesting operations can significantly reduce the costs associated with logistics and improve the economic performance of companies in the sector. In Uruguay, almost 75% of total forest harvesting operations for pulp production are carried out by contractor companies, so they are an important player in the supply chain. This study aims to optimize the allocation and routing of the harvesting equipment of forest contractors, which must be located at the sites to be harvested during the year. Numerical experiments over a case study based on realistic data have shown that realistic-sized instances can be resolved by standard mathematical programming software in a reasonable time. The mathematical programming model can also be useful to evaluate potential gains in joint planning by several contractors with respect to the costs incurred by separate planning; as illustrated also with numerical examples over the same case study. This model can be used to support annual forest harvest scheduling and equipment allocation for corporate contractors, leading to better quality plans and improvement opportunities.

Mathematics Subject Classification. 90C11, 90C35, 90B06 .

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1. Introduction

In the forestry industry, innovation is essential for the success of forestry companies, especially in developing countries [19], especially when making cost-effective use of harvesting operations [4]. Harvesting and transport account for a large part of the costs in the forest supply chain [14]. Therefore all these logistics must be well managed [9].

Keywords. Optimisation, mathematical, programming, planning forestry.

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Optimization models related to forestry operations planning have been used in recent years in several academic works, such as case studies in log transportation [3,15], harvesting and transportation [8] and strategic planning problem [6,7,12,16].

The concept of sustainability in forestry is increasingly seen as important, mainly in a diversified approach to sustainable timber production [18]. Therefore, optimization models are already largely able to take into account sustainability aspects using multi-criteria [2] and multi-objective approaches [10].

Reducing costs for contractors is important for their viability. The contributions of this study are related to the proposal of an optimization model for the transfer of forest harvesting equipment to solve a complex logistic problem, where different technical constraints in this industry are considered. This planning problem integrates allocation and routing problems. As the problem generalizes the Travelling Salesman Problem, it is known to be difficult to solve, even for small instances.

Although our current knowledge does not encompass any existing research concerning forest harvesting scheduling, certain authors have explored analogous issues within the context of sugar cane harvesting, which exhibits both resemblances and distinctions. In particular, [17] proposed the Route Planning Problem for Mechanized Harvesting (RPPMH), which aims to minimize the time the harvest machine takes to maneuver, in order to reduce fuel and labor costs, among others. Another work, [13], discusses sugarcane harvest front scheduling focusing on balancing harvest and transport capacities. That work presents a MIP problem to tackle complexity and scalability issues. Finally, [1] discussed a bi-objective mixed-integer non-linear programming model for finding variants of plans that can minimize the total cost incurred. In particular, the formulation takes into account both the total cost incurred by the harvesting and transport operations and the total harvesting time.

1.1. Description of the problem

In planning harvesting operations, many objectives and constraints must be considered. The planner has information on the sites to be harvested during the year. These sites have different properties, such as their geographical location, the estimated timber volume, the tree species, the distance to a certain industrialization destination, and the accessibility of the terrain.

A **harvesting front** is defined as the operations in a particular place with specific equipment for the felling, debarking, and cutting of trees, for their subsequent loading and transport to a timber industrialization destination. The special equipment consists of *harvesting* machines and *forwarders*.

The forestry establishments or forests where these operations are carried out may have more than one tree planted. In the case of Uruguayan forests, it is usual to have some of the following Eucalyptus species: *grandis*, *dunnii*, *maidenii*, *benthamii*, and *globulus*. For each establishment, there is a production index, which measures the volume harvested by a harvester in a period, for example, $m^3/month/harvester$; there is also information on the volume of existing wood according to the species. This information establishes the time required for each team to complete a harvest at a given site.

On some sites, there is a time limit (usually a certain month of the year) for forest harvesting, and all operations must be completed before that date. Each forestry contractor will be in charge of a harvesting front, depending on whether it has the necessary machinery for harvesting and whether the harvesting front is located within its working region. Once the harvesting of a facility begins, the front cannot be moved until the harvest is completed.

Forestry contractors have a base of operations, usually in a city or town where the company is based. To limit large movements, each contractor has a maximum operating radius, measured as the distance from the base of operations to the harvesting area.

Contractors with a certain operating range must stay in that region. Other contractors have freedom of movement and may be assigned to other harvesting sites far away from where they were at the beginning of the season. Care should always be taken to ensure that contractors' teams move as little as possible.

The annual harvesting plan determines which harvesting fronts at different times of the year are to be established, and therefore the forestry contractors should be informed of this planning so that they can travel to each site to carry out the operation. Each contractor may eventually be able to work simultaneously on

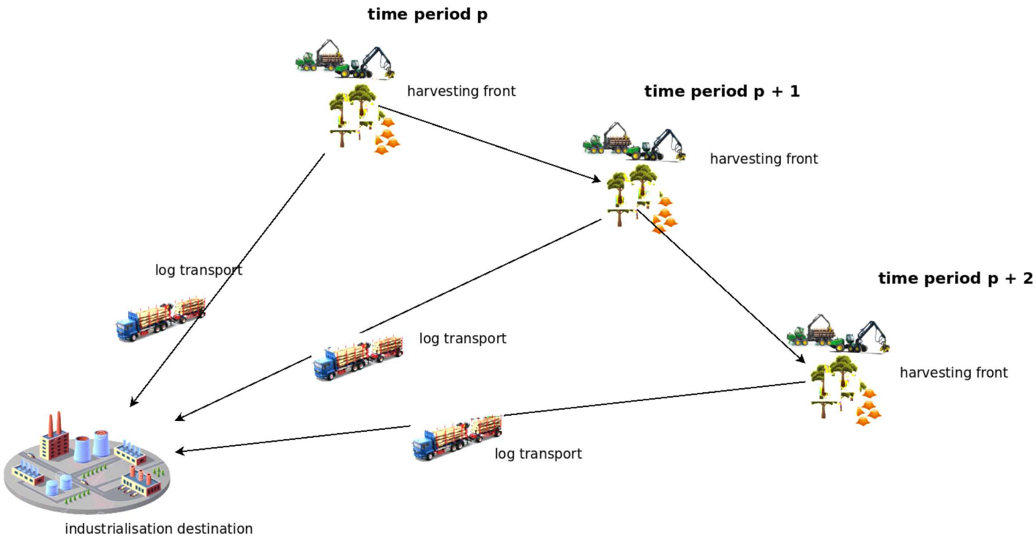

FIGURE 1. Outline of forest harvesting and transport operations to be carried out within a given planning horizon.

more than one harvesting front as long as it has the necessary machinery. Consideration should be given to ensuring that the distance to the industrialization destination remains relatively constant from period to time to avoid fluctuations in the number of trucks needed to transport the timber. The scheme describing the complete planning is shown in Figure 1.

In the following section, we develop an optimization model for the annual planning of the harvest,including the installation of harvesting fronts in the different available forests and the movement of the equipment between these fronts. The aim is to satisfy in each period of the planning horizon for timber the demand of the industrialization centers, considering the distance between the different fronts to be covered by the equipment. The optimization objective is to minimize the total cost of moving the equipment between the different fronts to be operated. In this way, optimal equipment planning can be found in terms of where to allocate each harvesting front in each period of the planning horizon to increase the economic efficiency of forest harvesting and log transport.

The problem has an underlying graph structure, with a non-empty set of vertices and a non-empty set of edges. In this structure, the harvesting sites (forests), the base of operations of the contractors and the timber industrialization sites are associated with the vertices, and consequently, the edges are assigned with the distances between them (with the smallest road distance between two points). However, the forest logistics system has some particular characteristics that preclude using directly the routing approaches commonly found in the literature.

In this forestry problem, we posit that harvesting teams consisting of one or more harvesters belonging to a forestry contractor tour the different fronts over a planning horizon. They start this annual tour at the forestry contractor base, from where they go to one of the harvesting points and move on to the different sites until the given allocation is completed. One important particularity of this problem also lies in the fact that the time needed to complete a harvest by one contractor on a given front is not necessarily the same as that of another team (because they have different machinery capacities). This also can lead to a team being at a harvesting front for several periods.

2. Mathematical model

This section describes a mathematical programming model to optimise the allocation of harvesting fronts to each contractor, trying to minimise the transfer of equipment.

2.1. Set of indices

As a set of indices we will have:

- $P = \{p_1, p_2, \ldots, p_{|P|}\}$, planning horizon, set of time periods in the year to perform harvesting (for instance the weeks of the year).
- $K = \{k_1, k_2, \ldots, k_{|K|}\}$, forestry contractors.
- $B = \{b_1, b_2, \ldots, b_{|B|}\}$, forest contractors' bases of operations.
- $I = \{i_1, i_2, \ldots, i_{|I|}\}$, harvesting sites, where fronts will be installed.

2.2. Model parameters

The following are the parameters of the model:

- v_i, volume of timber at harvesting site i, $i \in I$.
- r_{ik}, harvesting capacity (in m^3 of wood) of each harvesting equipment at location i, $i \in I$ and $k \in K$.
- t_{ik}, time it would take contractor k to harvest all the timber available at the front installed at site i. This parameter can be calculated according to the following equation:

$$t_{ik} = \frac{v_i}{r_{ik}}, \forall i \in I, k \in K \tag{1}$$

- d_{ij}, distance between harvesting locations or bases of operations, with $i, j \in B \cup I$.
- f_i, distance between a harvesting location i and the industrialisation destination, $i \in I$.
- D^p, demand for timber in period p by industrialisation destination, $p \in P$.
- t_i^{MAX}, latest feasible period for harvesting location i, $i \in I$.
- $a_{ik} = 1$ if the harvesting site i is in the contractor's operating area k, $a_{ik} = 0$ in the other case, $i \in I, k \in K$.
- var_{MAX}, maximum variation of the distance to the industrialisation destination for consecutive fronts to be assigned to a harvesting team.
- C_i^{HARV}, cost of operation per harvester at each harvesting front, with $i \in I$. This cost depends on the number of harvesters operating at the harvesting front, and is calculated per m of timber harvested [5].
- C_{ij}^{TRANS}, cost of moving harvesting machinery from i to j, with $i, j \in B \cup I$. This cost is calculated on the basis of the weight of the forestry machinery to be transported. For this work, the reference rates in Uruguay for the transport of machinery weighing approximately 20 tonnes are used.

2.3. Variables of the model

The following decision variables are defined for the problem statement:

- x_{ijk}, this binary variable indicates whether contractor k harvester machines move to location j after being at location i, i and $j \in B \cup I, k \in K$.
- y_{ik}^p, this binary variable indicates whether the contractor's harvesting equipment k operates at harvesting site i in period p, $k \in K$, $i \in I$, $p \in P$.
- $s_{ik} \geq 0$, this integer variable indicates in which period contractor k starts to operate on a harvesting front at site i , $k \in K$, $i \in I$.
- $w_i^p \geq 0$, volume harvested in period p at the front installed at i, with $p \in P, i \in I$.
- u_{ik}, represents the number of harvest sites visited by contractor k before installing the harvesting front at site i, $k \in K, i \in I$.

2.4. Objective and constraints

The objective function and constraints of the mathematical model are described below:

$$\min \sum_{i\in B\cup I}\sum_{j\in B\cup I}\sum_{k\in K} C_{ij}^{TRANS} d_{ij} x_{ijk} + \sum_{i\in I}\sum_{k\in K}\sum_{p\in P} C_i^{HARV} y_{ik}^p. \tag{2}$$

The objective of the problem is to minimise the cost of moving harvesting equipment between locations and the cost of operating the equipment at each installed front (2).

$$w_i^p = \sum_{k\in K} r_{ik} y_{ik}^p \, \forall i \in I, \forall p \in P. \tag{3}$$

The amount harvested during each period at the harvesting front installed at location i, by the contractors' teams installed there, is defined in Constraints (3).

$$\sum_{i\in I} w_i^p \geq D^p, \forall p \in P. \tag{4}$$

Constraints (4) state that the harvested volume must meet the total wood demand of the industrialisation destination.

$$\sum_{p\leq t_i^{MAX}} w_i^p \leq v_i, \forall i \in I. \tag{5}$$

Constraints (5) ensure that the number of machines allocated during all the enabled periods is sufficient to harvest the existing timber volume at harvest site i.

$$s_{ik} \leq p y_{ik}^p, \forall i \in I, k \in K, p \in P. \tag{6}$$

Constraints (6) ensure that each contractor's harvesting equipment will operate on the respective fronts once the start period (s_{ik}) has been established.

$$\sum_{p\in P: p\leq t_i^{MAX}} y_{ik}^p \leq t_{ik}, \forall i \in I, k \in K. \tag{7}$$

Constraints (7) state that the stay of a contractor's harvesting equipment at a given location may not exceed the estimated time of operation for that location (i.e, that after completing the harvest at a given front, the equipment must moved on to another location).

$$\sum_{i\in I} y_{i,k}^p \leq 1, \forall k \in K, p \in P \tag{8}$$

$$\sum_{k\in K} y_{i,k}^p \leq 1, \forall i \in I, p \in P. \tag{9}$$

Constraints (8) and (9) make sure that a harvesting team is only present at one location at any given time.

$$s_{ik} + t_{ik} \leq t_i^{MAX}, \forall i \in I, k \in K. \tag{10}$$

In Constraints (10) it is established that the period for the start of operations of a contractor plus the estimated time it would take to complete the harvest cannot exceed the maximum period of stay of contractors at a given location,

$$s_{ik} + t_{ik} - M * (1 - x_{ijk}) \leq s_{jk}, \forall i \in I, j \in I, k \in K. \tag{11}$$

The sequence of operations from one site to the next is determined by Constraints (11).

$$\sum_{i\in B\cup I}\sum_{k\in K} x_{ijk} = 1, \forall j \in B\cup I. \tag{12}$$

Constraints (12) guarantee that exactly one harvesting equipment shall be installed at each site (i.e, that all sites will be harvested in the planning period).

$$\sum_{i\in B\cup I} x_{ilk} = \sum_{j\in B\cup I} x_{ljk}, \forall l \in B\cup I, k\in K. \tag{13}$$

The continuity of the transfer of contractors to other harvesting fronts is ensured by Constraints (13).

$$x_{ijk} + x_{jik} \leq 1, \forall i \neq j \in B\cup I, \forall k \in K. \tag{14}$$

The model ensures that there is only one transfer of harvesting equipment between two different locations, with Constraints (14).

$$\sum_{i\in B\cup I} x_{iik} = 0, \forall k \in K. \tag{15}$$

With Constraints (15), a harvesting equipment is prevented from returning to a place where it has already been.

$$\sum_{b\in B}\sum_{j\in B\cup I} x_{bjk} = 1, \forall k \in K. \tag{16}$$

Constraints (16) specify that harvesting teams must always start from a base of operations.

$$u_i - u_j + N x_{ijc} \leq N - 1, \forall i \neq j \in I, \forall k \in K. \tag{17}$$

Constraints (17) preclude the existence of sub-tours of harvesting teams within the overall tour.

$$y_{ik}^{p} \leq a_{ik}, \forall i \in I, \forall k \in K, p \in P. \tag{18}$$

Constraints (18) specify that a contractor installs a harvesting front only in locations corresponding to its area of operation.

$$f_j \leq (1 + var_{MAX}) f_i x_{ijk}, \forall k \in K, \forall i \neq j \in I. \tag{19}$$

In order to ensure that there are no large differences between the distance to the factory at a harvesting front in a certain period with the harvesting front in the following period, Constraints (19) limit this difference to be no greater than a certain ratio (see Fig. 2).

3. Illustrative example

The following example is given for illustrative purposes. Tables 1 and 2 show the data for a case where two contractors (with one "harvester") have to plan the harvesting of 7 sites.

The result of applying the model described above is shown in Figure 3. The contractors are identified by the orange and green colours. The graph shows how many periods the contractor will work at each installed collection front.

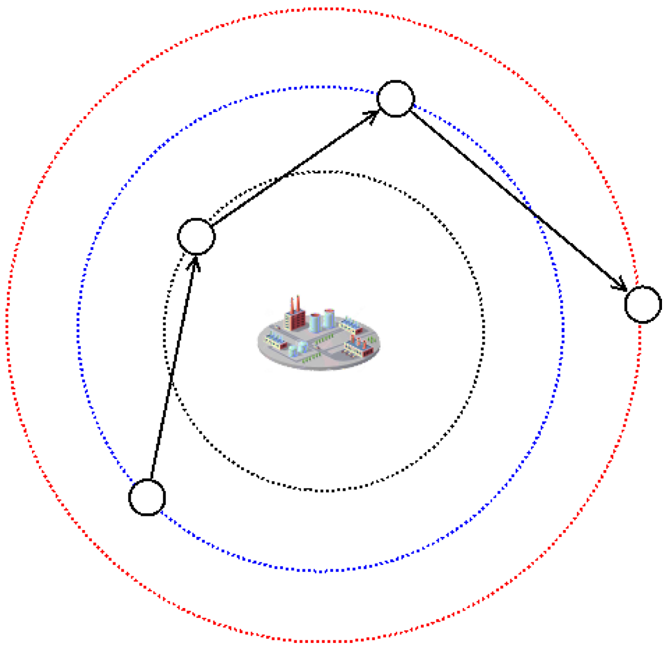

Figure 2. A harvesting team moves to another front, the distance to the industrialization plant of this one must maintain a certain margin with respect to the previous front.

Table 1. Distance matrix for the example. Location 0 corresponds to a contractor's home base.

	0	1	2	3	4	5	6	7
0	0	10	20	10	20	30	30	30
1	10	0	16	39	4	71	81	123
2	20	16	0	22	24	54	64	107
3	10	39	22	0	12	32	42	84
4	20	4	24	12	0	3	4	83
5	30	71	54	32	3	0	22	65
6	30	81	64	42	4	22	0	43
7	30	123	107	84	83	65	43	0

Table 2. For each harvest site, there is a record of the volume to be harvested, the yield per harvester and the harvest time limit. In this case, the harvest yield is the same for both contractors.

i	v_i	r_i	t_i^{MAX}
1	10000	5000	10
2	5000	5000	10
3	10000	2500	10
4	5000	5000	5
5	10000	5000	10
6	5000	5000	10
7	5000	5000	10

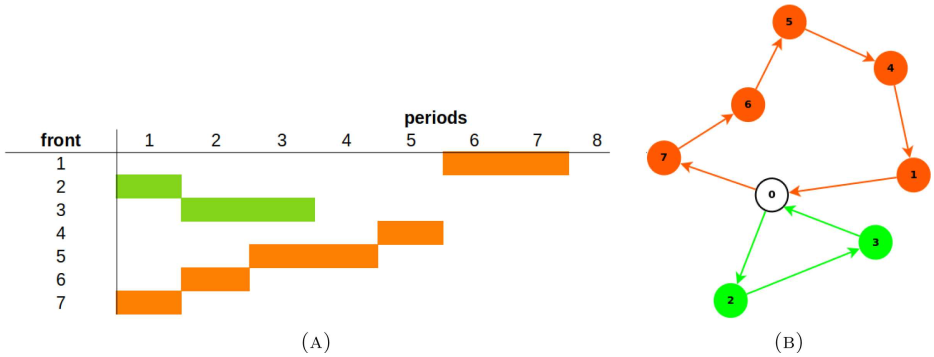

FIGURE 3. Example of the resulting planning for two contractors (orange and green). (A) Timeline for each contractor, (B) Transfer of each contractor between the different fronts.

TABLE 3. Description of initial assignment. Each contractor with a certain number of harvesters is assigned a number of harvest fronts to set up and a volume of timber to harvest.

K	#Harvesters	$\|I\|$	Harvest volume (m^3)
A	3	5	228000
B	2	6	121000
C	3	11	263000
D	4	3	432000
E	5	10	404000
F	5	7	421000
G	4	5	316000
H	2	10	196000
I	2	2	116000
J	4	6	370000
K	3	9	333700
L	3	3	238000

4. Computational experiments

The model was implemented using AMPL[11] and CPLEX solver version 20.1.0.0, and it was executed in a computer with operating system Ubuntu Linux 20.04 of 64 bit, with one processor Intel®Core™i5 and 12 GB of RAM. For the computational experiments, data provided by an Uruguayan forestry company was used, which consists of planning the forest harvest of 12 contractors and 77 harvesting sites. In Table 3, the description of the original assignment can be seen. This information was used to create the different test instances of the mathematical model. For each contractor listed in Column 1, the table shows in Column 2 the number of available harvesters, in Column 3 the number of places to harvest and in Column 4 the volume of wood to extract. The planning horizon considered is one year, divided in 12 periods of one month (the model itself is independent of the duration of the periods; so that it would also have been used for planning at the week level; this would lead to considering 52 periods during the year, with the consequent increase in computational effort).

These contractors have distributed their operations in different areas of the country. In Figure 4 we see the zones of operation of each contractor. For each contractor, all harvest fronts in set I are located within its zone of operation; and there is a single operation base, also located within this zone.

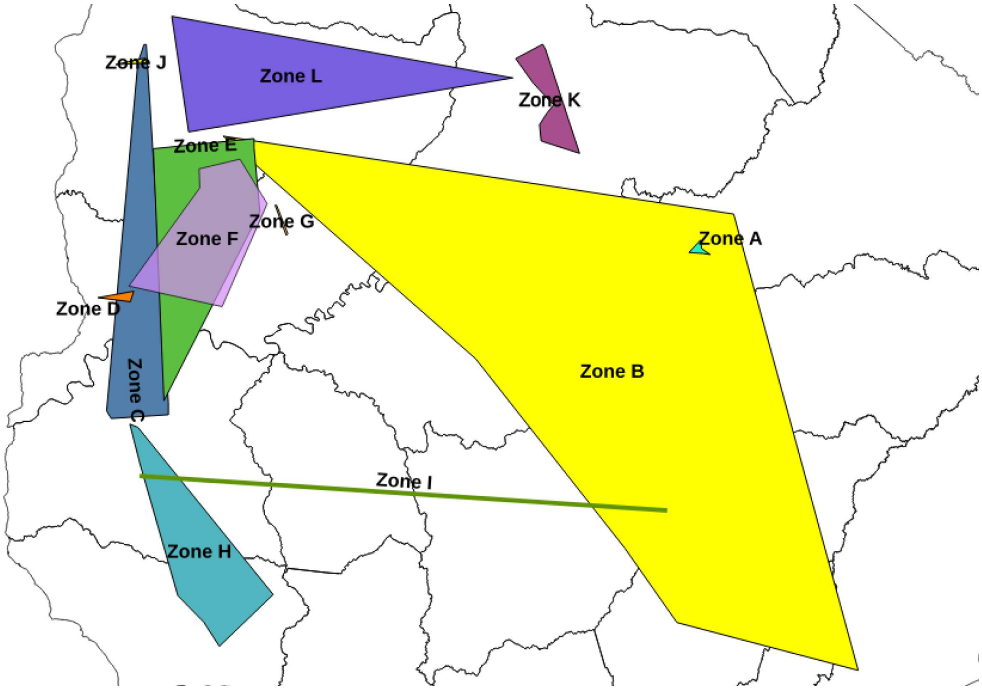

FIGURE 4. Zones of operation of each contractor.

To test the proposed model, 28 problem instances of increasing complexity are constructed (see Tab. 4). The table shows how the different experiments were structured. The data to be highlighted in each case includes the number of contractors involved (which also corresponds to the number of operational bases), the number of harvesting fronts to be installed, and the total cost (the cost of transporting the equipment plus the cost of operating at each site) of optimal solutions. For each case, the number of variables and constraints generated and the time taken to solve the linear problem are also shown, it can be seen that they increase significantly as instance size increases. All instances could be solved to optimality, with gap 0.

4.1. Collaboration

For the experiments, different scenarios were considered.

In the first scenario, the model was executed for each contractor, (instances 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13 and 15 in Tab. 4), thus obtaining the optimal route through the different harvesting places for each one. In a second scenario, the model was executed for groups of two contractors, (instances 9, 16, 17, 18, 19, 21, 22 and 23 in Table 4), thus obtaining the total distance traveled by that group, to compare with the sum of the individual performances.

In Table 5 we can appreciate the cost (length in km) of the optimum tours computed for each contractor, these results from an experiment sequence will be identified by Scenario 1.

In Table 6, you can see that for Scenario 2 of the computational experiments, the model is executed by groups of two contractors. These pairs have been chosen by proximity, as can be seen in Figure 4.

Additional experiments were performed for a third configuration, whose details are shown in Table 7. The results of the application of the mathematical model to three groups of four contractors are shown (instances 20, 21 and 22 in Tab. 4); the groups were chosen according to their proximity (similar to Scenario 2).

Table 4. Results of the mathematical model run for instances with each contractor and for groupings of contractors.

Inst.	Contractors	$\|I\|$	$\|K\|$	#Var.	#Const.	Time(s)	Harvest($)	Transport($)	Total($)
1	I	2	1	49	91	0,05	868.840	9.235	878.075
2	D	3	1	94	157	0,06	3.235.680	2.201	3.237.881
3	L	3	1	40	76	0,05	1.782.620	7.175	1.789.795
4	A	5	1	166	265	0,06	1.707.720	3.314	1.711.034
5	G	5	1	166	265	0,06	2.389.310	11.039	2.400.349
6	B	6	1	205	328	0,06	906.290	18.009	924.299
7	J	6	2	650	818	0,06	2.771.300	14.959	2.786.259
8	F	7	1	246	397	0,08	3.153.290	10.465	3.163.755
9	B I	8	2	616	872	0,15	1.775.130	21.973	1.797.103
10	K	9	1	280	490	0,07	2.499.413	2.463	2.501.876
11	B L	9	2	710	1.027	1,14	2.688.910	33.140	2.722.050
12	E	10	1	381	640	0,11	3.025.960	16.688	3.042.648
13	H	10	1	381	640	1,05	1.468.040	5.497	1.473.537
14	D F	10	2	808	1.194	0,15	6.388.970	10.868	6.399.838
15	C	11	1	430	733	0,95	1.969.870	9.924	1.979.794
16	B G	11	2	910	1.373	0,97	3.295.600	57.613	3.353.213
17	A B	11	2	910	1.373	1,12	2.614.010	41.855	2.655.865
18	K L	12	2	1.016	1.564	1,31	4.282.033	18.470	4.300.503
19	H I	12	2	1.016	1.564	4,03	2.336.880	25.144	2.362.024
20	D E	13	2	1.126	1.767	0,24	6.261.640	25.542	6.287.182
21	C D	14	2	1.240	1.982	1,15	5.205.550	20.643	5.226.193
22	C J	17	2	1.606	2.699	5,26	4.741.170	23.781	4.764.951
23	E F	17	2	1.606	2.699	1,06	6.179.250	38.904	6.218.154
24	A B H I	23	4	5.308	9.061	279,40	4.950.890	96.900	5.047.790
25	G J K L	23	4	5.308	9.061	955,63	9.442.643	87.535	9.530.178
26	C D E F	31	4	8.124	15.133	227,77	11.384.800	91.577	11.476.377
27	A B H I C D E F	54	8	42.848	86.042	2.472,08	16.335.690	407.702	16.743.392
28	(all contractors)	75	12	114.228	242.289	2.871,95	38.743.523	2.443.469	41.186.992

Table 5. Scenario 1 – optimal tour costs (in km) for single contractors.

K	Distance travelled (km)	$\|I\|$
A	172,36	5
B	1.404,73	6
C	516,06	11
D	85,85	3
E	520,67	10
F	326,52	7
G	430,53	5
H	428,81	10
I	720,33	2
J	583,43	6
K	128,06	9
L	373,13	3

TABLE 6. Scenario 2 – optimal tour costs (in km) for groups of two contractors.

K	Distance travelled (km)	Savings (%)
A - B	1.305,94	17,19
B - G	1498,00	18,38
B - I	857,00	59,67
C - D	460,07	23,57
C - J	530,00	51,80
E - F	606,93	28,36
H - I	980,67	14,66
K - L	480,23	4,18

TABLE 7. Scenario 3 – optimal tour costs (in km) for groups of four contractors.

K	Distance travelled (km)	Savings (%)
A - B - H - I	1.679,66	38,39
C - D - E - F	840,39	42,01
G - J - K - L	975,42	35,62

As can be seen in the different executions of the model in the different scenarios, the more grouped the contractors are, the larger savings in the distance traveled by the equipment are produced. In the different configurations, the application of the model in an integrated way with the contractors, results in important savings in distances traveled, compared to the individual executions. For example, in Scenario 2, with the association of Contractors B and I, there is a 59% saving; in this case, the beneficiary would be Contractor I, as it has routes of a similar length to B, but 3 times fewer harvesters. Another significant saving in this scenario is seen in the combination of contractors C and J (51.80%). Although Contractor J has fewer journeys than Contractor C, the latter benefits from Contractor J is larger number of harvesters. Similar observations can be made for Scenario 3, where savings of up to 42.01% are achieved.

5. Conclusions

In this paper, a forest harvesting planning method is presented. It takes into account the demand constraints imposed by industrialization centers and aims to minimize the total cost of harvesting operations, including the cost of operating, handling, and transporting the timber. This model allows an optimal allocation of harvesting fronts for each time within the planning horizon, providing forest planners with valuable information to improve the efficiency of these operations and improve the profitability of the business. The results obtained show that the model can be successfully applied in many forest conditions.

This problem is particularly relevant in the Uruguayan context, as contractor companies work on demand from the pulp industries and must reduce their operational costs to improve their efficiency when planning the harvest of wood from the assigned plantations.

The operational aspects of forest harvesting are fundamental to the profitability of this part of the industry and are critical to maintaining timber supply chains. However, the process of scheduling these activities is inherently complex and involves many decisions given resource constraints (such as demand for production sites and the number of machines available). Optimization methods can successfully solve these decision problems and help make decisions about the location of forestry machinery at different sites. The model developed here can be used to allocate harvesting fronts in such a way as to reduce harvesting and transport costs in different forest conditions. In this way, planners can better schedule forest management and achieve their objectives effectively.

The mathematical programming model developed is capable of representing the established planning problem and can be implemented to provide solutions based on real data. This model can be used as an efficient and practical tool to help develop annual forest harvest scheduling and equipment allocation for contractors, leading to better quality plans and improvement opportunities. Also, it provides a practical way to compute the efficiency gains that can be achieved by cooperation agreements between groups of contractors, which can lead to better overall efficiency and improved profits.

As a future line of research, this work can be integrated with data analysis for projections (*e.g.* demand forecasts), to achieve longer-term planning.

Data availability. We have made available online in a Gitlab repository of Facultad de Ingeniería (Udelar): https://gitlab.fing.edu.uy/victor.viana/fhtp/ [20] the full parameter values for our case study, including the 12 contractors and 75 harvesting sites, in order to allow for reproducibility of our study.

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