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LOGISTICS OPTIMIZATION IN FORESTRY VALUE CHAINS: SYNCHRONIZATION OF RESOURCES FOR LOADING AND TRANSPORT OPERATIONS

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The efficient use of available resources is a critical issue in the planning of distribution activities. The utilization of these resources can have a significant impact on the total cost of operations and, therefore, should be considered in the operational planning, making the decision-making process difficult due to the inherent complexity of the problem related to the allocation, sequencing and scheduling of operations at each location of the distribution network.

The present work proposes an optimization methodology that combines exact methods with heuristic algorithms to optimize pickup and delivery activities in the first echelon of the forest industry, taking into account the synchronization of resources allocated to truck loading and unloading operations.

The most outstanding contribution of this work lies in the development of a computational tool that minimizes the total logistic cost while satisfying the requirements defined for each facility over a given planning horizon. The proposed approach's efficiency was verified and analyzed through a variety of practical examples that showcase its potential to aid the decision-making process in the forestry sector.

Keywords: Logistics, Log transportation, Resources synchronization

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1. INTRODUCTION

In today's forest industry, logistics planners are faced with the complex task of combining the knowledge gained over the years with the implementation of innovative technologies that facilitate and support the decision-making process in order to achieve an efficient use of available resources.

In Argentina, the forestry value chain begins with the extraction of logs from forest plantations. This raw material is transported to primary industries that transform it into finished products or intermediate products that are processed by other secondary industries (Broz, Rossit, Rossit, & Cavallin, 2018). The finished products are supplied to the market to meet customer demand. Currently, about 78% of the cultivated forests are concentrated in the Mesopotamian region of our country (Secretary of Agriculture, Livestock and Fisheries, 2023). The mode of transportation generally used to connect the plantation areas with the industries is by road, which has a relatively higher cost per unit shipped compared to other modes, such as train or ships. The Argentine Forest industry is mainly characterized by low competitiveness and high logistics costs due to inadequate infrastructure. Among the critical factors that affect competitiveness are the cost of production and distribution, the quality of the products offered, the supply capability in each link of the value chain, and environmental protection. Therefore, operations planning becomes a key element for the efficient management of wood supply chains, especially for those decisions related to the coordination between harvesting operations and wood industrialization activities, and the sustainable use of by-products derived from these operations.

One of the most well-known planning problems in the forest industry is the optimization of log supply from forest areas to industries. This problem is referred to in the literature as Timber Transport Vehicle Routing Problem (TTVRP) (Karanta, Jokinen, Mikkola, Savola, & Bounsaythip, 2000) or Log-Truck Scheduling Problem (LTSP) (Palmgren, Rönnqvist, & Värbrand, 2004). The main objective of these problems is to define product flows between harvesting areas and industries at minimum cost by considering fleets of trucks geographically distributed in multiple locations (Hirsch & Gronalt, 2008). In this paper, the LTSP definition is used as a reference for the problem at hand.

The LTSP has been widely discussed in the literature without considering the availability of limited resources for loading or unloading activities at each location. However, in the real world, there is a need to synchronize trucks that do not have a crane on board with forest loaders. Soares et. al. (Soares, Marques, Amorim, & Rasinmäki, 2019) state that the synchronization of operations and vehicle routes can play a major role in increasing cost efficiency. In addition, if the vehicle service time is affected by the presence of other vehicles with similar schedules in the same location, delays or unnecessary idle time may occur, affecting the flexibility of the schedule and leading to an increase in transportation costs.

In this way, this work extends the classical LSTP to consider the synchronization of trucks and loaders in a multi-period planning horizon. The objective is to generate an optimal log transportation and storage plan for the different facilities involved in log supply over a given planning horizon. The problem considers decisions related to the routing of vehicles and the inventory levels of each facility, as well as the synchronization of vehicles and loaders available for each day in the predefined horizon.

The proposal is a continuation of a previous work by Vitale et al. (Vitale, Cóccola, & Dondo, 2023), where a column generation (CG) algorithm combined with a Greedy Randomized Adaptive Search Procedure (GRASP) metaheuristic for route generation was developed to solve the Inventory Routing Problem for Log Transportation (IRP-LT). To demonstrate the applicability and usefulness of the proposal, the algorithm is tested on several instances generated using data from forest industries located in the province of Misiones, Argentina.

2. PROBLEM STATEMENT

Let $G\ (H \cup M \cup D;\ A)$ represent a graph consisting of the set of harvest areas (H), the set of mills (M), the set of warehouses (D), and the set of arcs connecting all facilities within the logistics network (A). Each warehouse ($d \in D$) has a fleet of vehicles ($v \in V_d$) based at that location. The set of products being transported from the harvest areas to the mills is denoted by $k \in K$, while the planning horizon is represented by $t \in T$.

To simplify modeling and define constraints, facilities are grouped in the set $F = \{H \cup M\}$. Within a given period $t \in T$, each harvest area $f \in H$ can supply $of_{k,f,t}$ full truckloads of log type $k \in K$, while each mill $f \in M$ demands a quantity of $dem_{k,f,t}$ full truckloads of product $k \in K$. Each facility $f \in F$ has the capability to store various types of products. A minimum storage capacity, $i_{k,f}^{min}$, is set to indicate either the lowest operational capacity or the safety stock for a particular product, while a maximum storage capacity, $i_{k,f}^{max}$, is established. At the start of the planning horizon, all locations maintain an initial inventory level of $i_{k,f}^{0}$ full truckloads. A homogeneous fleet of trucks $V = \{v_1, v_{2,} \dots, v_v\}$, transports logs between facilities. A truck $v \in V_d$ begins its shift from a specific depot, and it must return to the depot by day's end. V_d comprises the trucks belonging to depot d.

As depicted in Figure 1, vehicle routes consist of a series of trips. A trip, denoted as $L = \{l_1, l_{2,} \dots, l_l\}$, refers to any full or empty truckload transportation from one facility to another. Each truck operates at full capacity, and logs are not mixed during the same trip. Legal regulations limit the number of full truckload trips a driver can make. As a result, $|L|$ represents the maximum number of movements a truck can perform along a route. Each route begins with an empty trip from a depot to a harvest site, followed by a full truckload trip to an industry. Once the destination is reached, the empty truck is driven to either the departure depot to end its shift or another pickup location.

In each facility belonging to the set F, there are multiple resources available $Q = \{q_1, q_{2,} \dots, q_q\}$ for loading and unloading operations for trucks. In the case of an empty truck arriving at a harvesting region, it may require idle time before the product load can begin until any loader becomes available for use. Similarly, with a full truckload, unloading can proceed only when a resource is free and ready. A set of tasks defined by $j \in J_v$ specifies loading and unloading operations necessary for a truck v route while set J_q represents the tasks that a resource q can perform.

The solution to the synchronized IRP-LT problem must determine:

- The routes to be taken and the number of trucks traveling on each of them for each period $t \in T$, ensuring satisfaction of all industry demand and preventing logs availability from being exceeded at harvest areas.
- The number of full truckloads required to transport from harvest areas to industries for each period in $t \in T$ and for each product $k \in K$
- The number of trucks operating in each depot $d \in D$, for each period $t \in T$.
- Inventory profiles for harvest areas $h \in H$ and industries $m \in M$ for each product $k \in K$ and for each period $t \in T$
- The arrival and departure sequences of trucks in each facility $f \in F$ for each period $t \in T$.
- The scheduling of loading or unloading operations in each resource $q \in Q$ for each period $t \in T$.

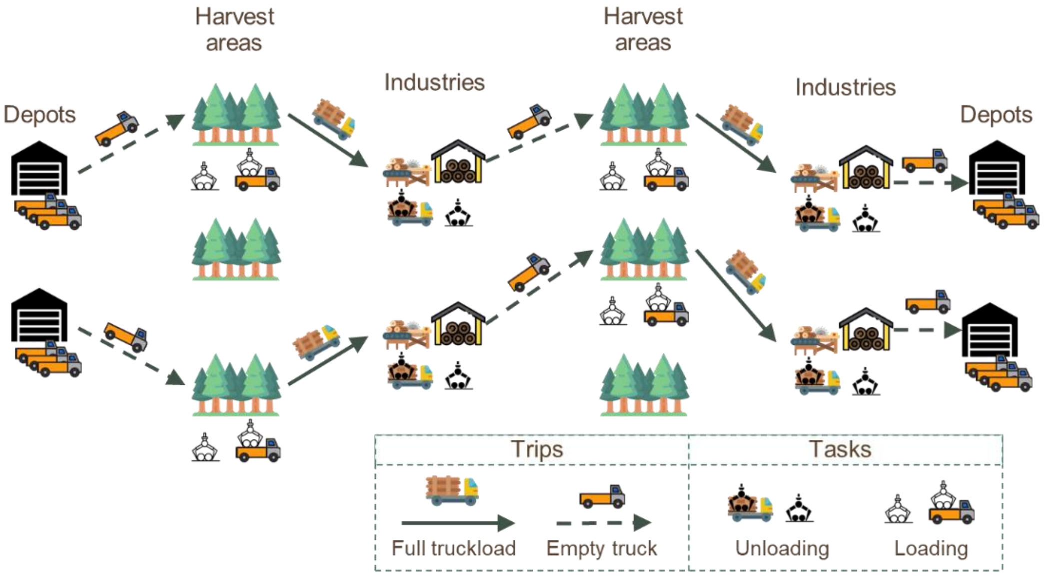

Figure 1 : Route structure for log transportation

Note. Adapted from (Vitale, Cóccola, & Dondo, 2023, p. 8)

3. SOLUTION STRATEGY

A two-step approach has been developed to solve the problem at hand. Figure 2 illustrates the overall process. During the first stage, the IRP-LT is tackled using the mathematical model laid out in Vitale et al. (Vitale, Cóccola, & Dondo, 2023) prior study. Resource restrictions for loading and unloading are not considered; solely the timber movement among facilities is established for each day on the planning horizon through CG and GRASP metaheuristic. Next, the decisions from the previous stage are used as input for a MILP formulation that takes into account synchronization constraints. The objective of this stage is to synchronize operations between loaders/unloaders and trucks. In other words, a schedule that synchronizes the trips with the loading and unloading operations that each truck must follow along a route for each operative day is generated. Each stage of the algorithm is described in detail in the following subsections.

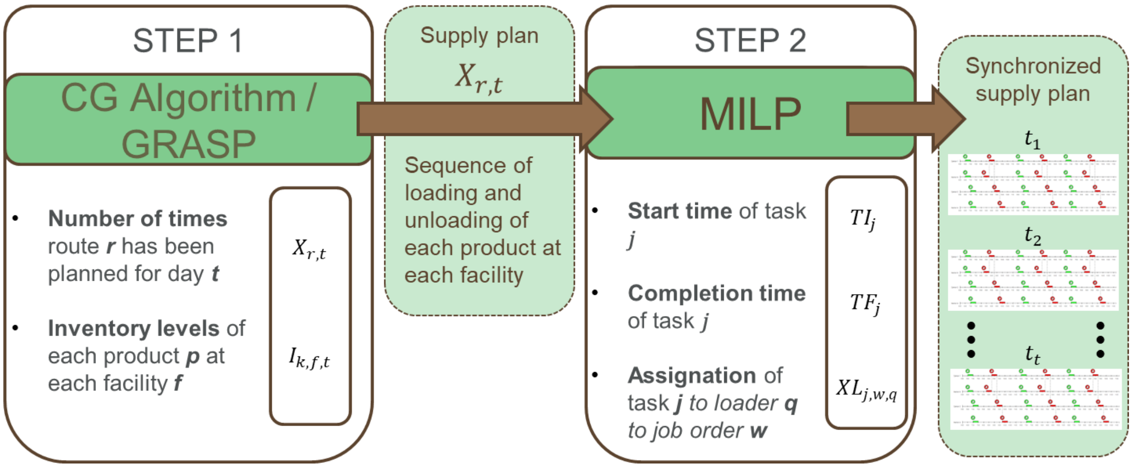

Figure 2 : Overview of the two-stage procedure

3.1 Step 1: Column Generation for Route Assignment

The CG methodology is often used to solve large-scale vehicle routing problems that require significant computational resources to solve using traditional techniques. As illustrated in Figure 3, CG partitions the problem formulation into a master problem and one or more pricing subproblems. From a pool of candidates, the master problem must select the best set of routes with the goal of minimizing (or maximizing) the objective function. The pricing subproblems are used to find attractive vehicle routes according to an objective function called reduced cost, which is computed using the values of dual variables associated with the constraints of the master problem. By continuously updating the route bank (pool of candidates) at each iteration, the pricing problem or subproblem aims to find new, profitable routes with negative reduced cost.

When the master problem is solved by considering only the routes in the candidate pool, it is referred to as the reduced master problem (RMP). During each iteration of the CG algorithm, a linear relaxation of the reduced master problem (LR-RMP) is solved. To provide a feasible initial solution, a heuristic method generates a set of candidate paths at the start of the process. Then, the LR-RMP is solved using the provided initial columns and the dual values of the constraints are passed on to the subproblems for the generation of new paths. If the objective function of the subproblem yields a negative value (when minimizing), it indicates the discovery of a new profitable route, which requires an update in the candidate pool. The procedure persists up to the following iteration, where the LR-RMP is re-solved with the modified column bank. Iterations between the master and subproblems persist until the subproblems do not generate any further negative reduced cost solutions. If the LR-RMP's optimal solution is integer, then the optimal solution to the IRP-LT has been reached.

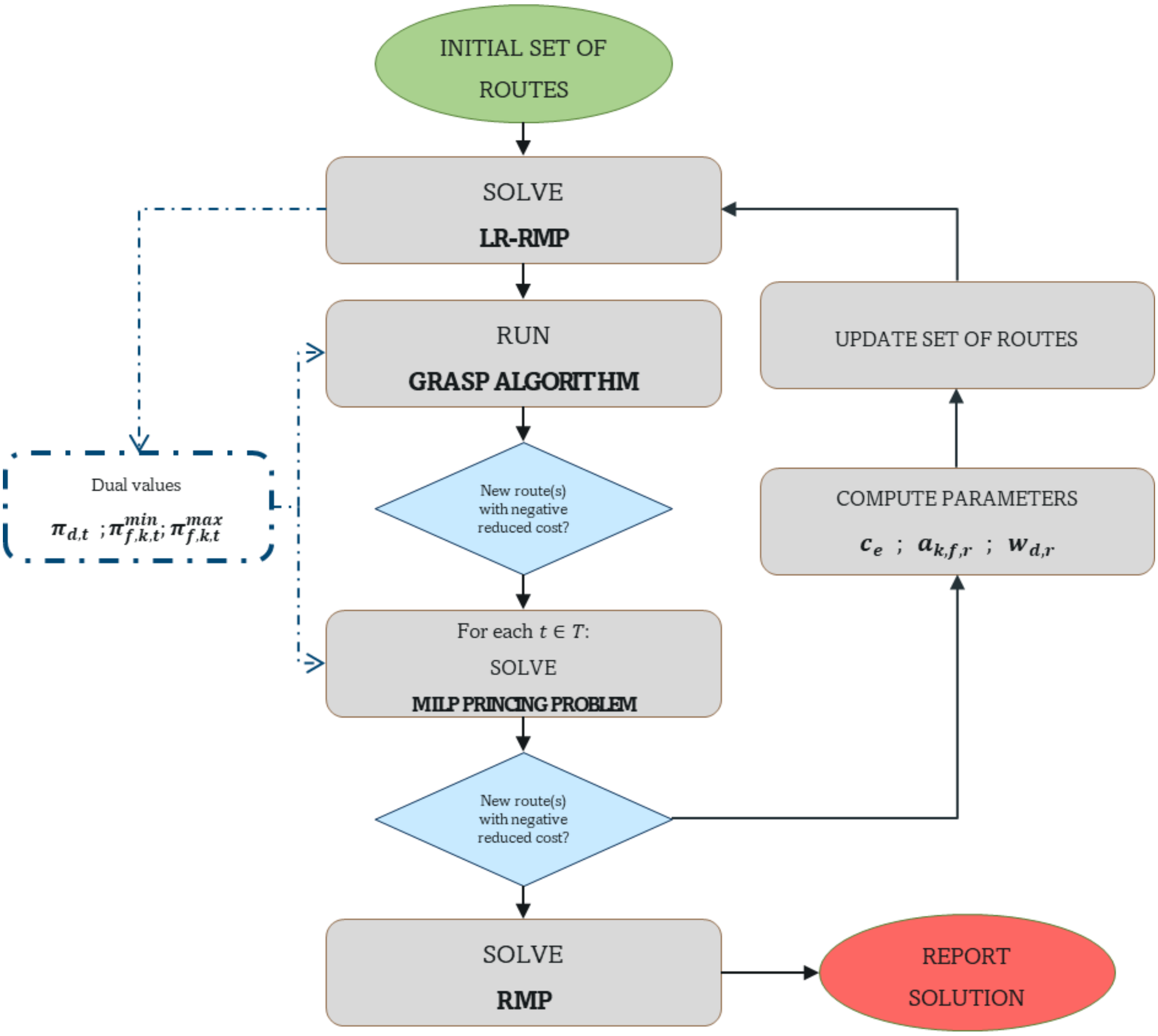

Figure 3. CG algorithm used in the first stage of the procedure.

Note. Adapted from (Vitale, Cóccola, & Dondo, 2023, p. 16)

3.2. Step 2: MILP Approach for Resource Synchronization

A set of operations to be performed by each truck in the supply chain on each planning day is obtained as a result of the previous step. For each period $t \in T$, a fleet of trucks $v \in V$ will be assigned a set of routes $r \in R$ to execute. The assignment of routes to trucks is arbitrary due to homogeneity of the vehicle fleet. Along its route, each vehicle must complete a set of loading and unloading tasks for $j \in J_v$. These tasks directly correspond to the visits planned in the initial algorithmic stage. Using the available data and assessing the availability of loaders and unloaders at each facility, the second step of the procedure focuses on synchronizing the loading and unloading tasks for the set of routes planned to be executed daily throughout the planning horizon. To accomplish this objective, a MILP formulation is employed to mathematically represent the problem, with the inclusion of the following constraints.

- The goal is to minimize the waiting and processing times of the available resources. In this way, the objective function aims at minimizing the makespan for all trucks.

$$Min \sum_{v \in V} MK_v \tag{1}$$

- The subset J_f identifies all tasks *j* performed at each facility *f*. On the other hand, the subset Q_f determines all resources *q* available for loading/unloading at each facility *f*. Moreover, each resource has a limited number of jobs $w \in W$ that can process in every period. In this way, constraint (2) and (3) determine the assignment of task *j* to a single resource *q*.

$$\sum_{q \in Q_f} \sum_{w \in W} XL_{j,w,q} = 1 \qquad \forall f \in F, j \in J_f \qquad (2)$$

$$\sum_{q \in Q_f} \sum_{w \in W} XL_{j,w,q} = 0 \qquad \forall f \in F, j \notin J_f \qquad (3)$$

- Constraint (4) determines that each job *w* in a resource *q* can be assigned to process at most one task *j.* On the other hand, Constraint (5) forces the jobs in each resource to be sequentially assignment.

$$\sum_{j \in J} XL_{j,w,q} \leq 1 \qquad \forall w \in W, q \in Q \qquad (4)$$

$$\sum_{j \in J} XL_{j,w,q} \geq \sum_{j \in J} XL_{j,w',q} \qquad \forall\ (w, w') \in W, q \in Q : w < w' \qquad (5)$$

- For each pair of tasks (j, j') processing on the same resource *q*, the starting time $TI_{j'}$ of task *j'* must be greater than the finishing time TF_j of *j,* whenever *j* is processed before than *j'.*

$$TI_{j'} \geq TF_j - M * (2 - XL_{j,w,q} \text{ - } XL_{j',w',q}) \qquad \forall f \in F, (j, j') \in J_f, q \in Q_f, (w, w') \in W : w < w' \qquad (6)$$

- Completion of the task *j* is determined as the starting time plus its processing time ts_q, which is dependent on the assigned resource *q.*

$$TF_j \geq TI_j + \sum_{q \in Q} \sum_{w \in W} ts_q XL_{j,w,q} \qquad \forall j \in J \qquad (7)$$

- The processing of a task $j \in J_v$ can start after its associated vehicle *v* arrives at the corresponding facility where *j* is performed, as stated Constraint (8). Parameter tv_j determines the travelling time from facility *f* to facility *f'*, where $j \in J_{f'}$, and $(j - 1) \in J_f$.

$$TI_j \geq TF_{j-1} + \ tv_j \qquad \forall v \in V, j \in J_v \, / \, \{\, j > 1 \,\} \qquad (8)$$

- The processing of any task $j \in J_v$ can begin after the start of the work shift of its associated truck determined by parameter st_v. Here, tv_j refers to the travelling time from the truck depot to the facility where task *j* is performed.

$$TI_j \geq st_v + \ tv_j \qquad \forall v \in V, j \in J_v \qquad (9)$$

- The end of the shift for each truck $\boldsymbol{c}$ must not exceed a certain threshold $maxT$.

$$TF_{j'} - TI_j \leq maxT \qquad \forall v \in V, (j, j') \in J_v : j < j' \qquad (10)$$

- The makespan of each truck v is determined by Constraint (11).

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$$MK_v \geq TF_j \qquad \forall v \in V, j \in J_v \qquad (11)$$

4. COMPUTATIONAL RESULTS

To test the performance of the proposed algorithm, three scenarios with differing degree of difficulty were proposed. Table 1 details the number of harvesting areas, industries, products, and trucks considered in each scenario. The experimentation is based on information from a forestry supply chain located in Misiones, Argentina. The company owns multiple harvesting areas widely distributed geographically. In addition, there are several industries demanding different types of logs according to the production process used to add value. All harvesting and transportation operations are outsourced to different logistics operators. In the case of harvesting, machinery and personnel are subcontracted for thinning, cutting, movement of material and loading of logs onto trucks at a stipulated cost based on the harvested area. The loading and unloading tasks take 0.5 h per truck and each facility has available only one resource to carry out these operations. Transportation activities are carried out by multiple fleets of trucks with a capacity of 30 m^3. The trucks start their activities from the depots and can carry out a maximum of three full truckload trips, i.e., $L^{max} = 3$ before returning to the depot. Only one type of log product can be handled per trip. The maximum working time for the trucks is $t^{max} = 10\ h$. With this data, three scenarios were tested.

Table 1 : Testing scenarios

Scenario	***#Harvest areas***	***#Industries***	***#Products***	***#Depots***	***#Trucks per depot***
1	5	1	2	1	10
2	8	2	3	2	15; 10
3	10	4	3	3	12; 10; 14

The scenarios are solved considering a weekly planning horizon (seven days). Travel times and distances between the different facilities in the supply chain were obtained using the Routing API the Here Maps Services (HERE Technologies, 2023) considering the characteristics of the fleets used in the problem.

The two-stage optimization algorithm was coded in Pyomo (Bynum, et al., 2021), a Python-based open-source software package that supports a diverse set of optimization capabilities for formulating, solving, and analyzing optimization models (Hart, Watson, & Woodruff, 2011). All scenarios were solved on an AMD Ryzen 7 Mobile 4800H, a clock speed of 2.9 GHz, and 8 GB of RAM. For the first algorithmic stage, either a maximum of 500 iterations or a threshold of 300 seconds of CPU time were imposed as terminations criterion for the master-pricing cycle. For stage 2, a limit of 150 seconds was imposed as the maximum computational time to find a synchronized schedule between trucks and resources on each planning day.

Table 2 summarizes the computational results obtained for the first algorithmic stage where decisions are taken on a weekly basis.

Table 2 : Computational results for the first algorithmic stage

Scenario	**Cost ($)**			**GAP**	**CPU Time (s)**
	Inventory	**Routing**	**Total**		
1	151.84	5329.41	**5481.25**	0.78%	1.17
2	942.04	10617.22	**11559.26**	3.14%	8.7
3	459.91	13481.08	**13940.99**	3.01%	49.59

The **GAP** column computes the differences between the optimal LR-RMP value and the optimal integer RMP solution. A gap larger than zero indicates that some profitable routes may be missing in the computed pool and hence, the solution reported is not guaranteed to be the optimal one. As shown Table 2, with the addition of new facilities, resources and products, the supply chain configuration becomes increasingly complex and, therefore, more computational resources are needed to compute the solution.

Once computed the routes to be performed by the trucks, the transportation activities must be synchronized with the resources available at each facility to perform the loading/unloading operations. In this way, these routing decisions made in the first stage are transformed as follows:

i. All trucks with no routes assigned, are not considered.
ii. Every visit to a harvest area/industry stands for a loading/unloading operation to be performed by the resources available in this location.

iii. The number of potential jobs $w \in W$ that can be performed by a loader $q \in Q$ is estimated based on its service time ts_q and the total working time $maxT$, as described expression (12).

$$\left\lfloor \frac{maxT}{ts_q} \right\rfloor \tag{12}$$

The synchronization decisions are tackled daily, and the results reported by the second stage of the procedure are summarized in Table 3. The column *Time on Route* show for the total operation times of trucks, the maximum, minimum, and average values.

Table 3 : Computational results for the second algorithmic stage

Scenario	Day	Trucks used	Performance			Time on route (hours)		
			Computational time (s)	**GAP**	**Objetive Function (hours)**	**Max**	**Mean**	**Min**
1	1	6	46.66	0.00%	78.32	9.70	6.47	1.84
	2	5	0.12	0.00%	60.50	7.92	5.80	1.84
	3	6	52.38	0.00%	78.32	9.27	6.80	1.84
	4	5	0.27	0.00%	61.07	7.56	5.81	1.84
	5	6	100.80	0.00%	78.13	9.62	6.69	1.84
	6	5	0.32	0.00%	61.07	7.06	5.91	1.84
	7	5	0.33	0.00%	61.07	6.56	5.61	1.84
2	1	9	58.70	0.00%	145.16	10.00	9.02	6.36
	2	8	2.83	0.00%	117.63	9.45	8.12	6.95
	3	7	2.23	0.00%	107.19	10.00	8.60	6.36
	4	9	150.05	1.82%	142.72	10.00	8.79	7.60
	5	8	4.86	0.00%	130.71	10.00	9.12	6.79
	6	5	0.20	0.00%	75.46	10.00	8.65	7.61
	7	6	0.17	0.00%	91.62	10.00	8.85	7.42
3	1	8	0.26	0.00%	120.28	9.84	8.83	7.60
	2	8	0.34	0.00%	130.74	9.91	9.53	9.24
	3	8	0.31	0.00%	123.40	10.00	9.10	7.33
	4	8	0.58	0.00%	123.66	10.00	8.81	7.60
	5	7	0.22	0.00%	110.01	10.00	9.35	8.94
	6	9	0.69	0.00%	136.31	9.78	8.78	7.28
	7	8	0.14	0.00%	115.84	9.20	8.21	6.70

For Scenario 1, all trucks complete their route in a time shorter than the maximum time allowed of 10 hours. Just days 1, 3, and 5 present vehicles with slack times less than one hour of work. Those days also feature the highest values of the objective function and the highest average value of hours on route.

In scenario 2, most days present routes that are feasible, but some do not have slack time. The objective values evidence that the routes have longer finishing times than the previous scenario and hence, the trucks tend to finish their shifts later. Generally, short-duration routes are not usually used in this case. The number of trucks used between the different planning days denotes that the workload is not balanced compared to the previous scenario. Some resources are used more intensively on some days of the week.

Finally, Scenario 3 features a more efficient workload balance between days with a higher number of trucks used regards previous instances. Like Scenario 2, a growth in the on-road times is observed in this case.

4.1. Resource Synchronization

Day 4 of Scenario 3 is taken as an example to depict how the operations between trucks and loaders are synchronized. In this case, eight trucks were utilized for the loading and unloading operations illustrated in Figure 4. Each truck performs a circuit of six operations, half of which entail loading of logs and the other half unloading. The trucks are authorized to leave after 6:00 a.m. and must return to their depot before 8:00 p.m. each day. Each facility is equipped with a loader that can load or unload a truck in 0.5 hours, allowing each load unit to complete up to twenty jobs throughout 10 hours of work.

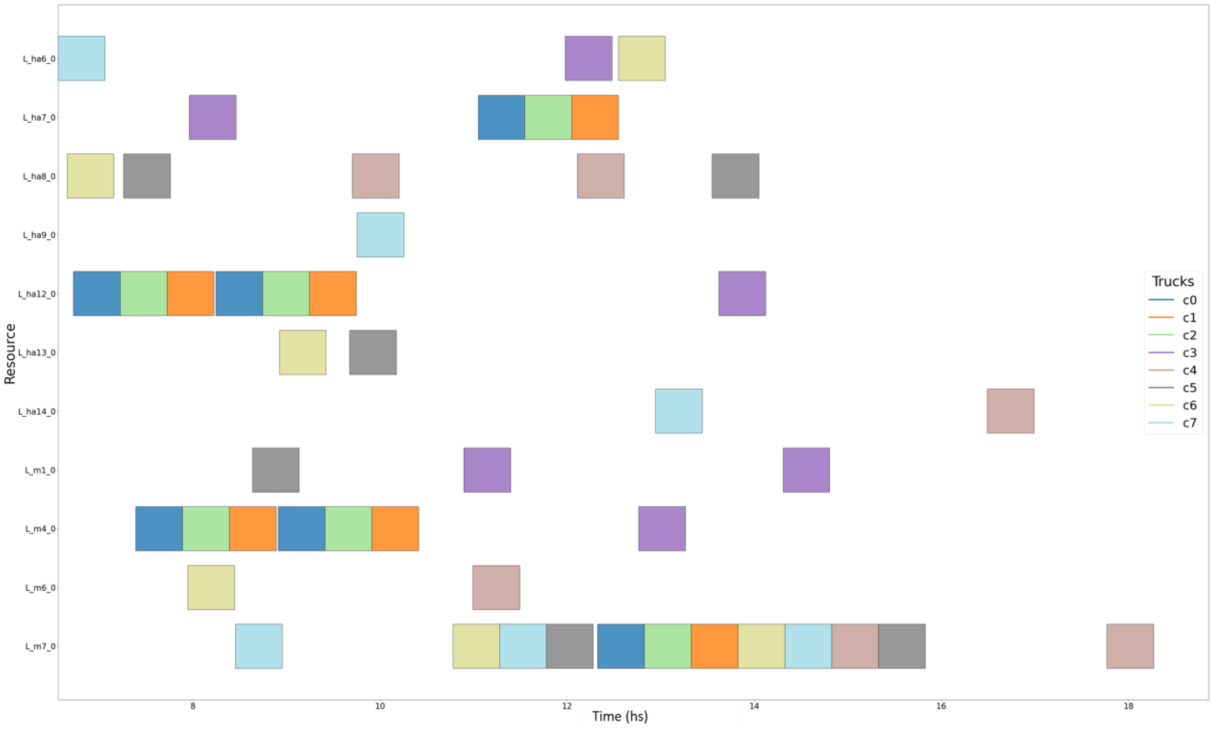

Figure 4: Resource Synchronization for Day 4-Scenario 3

Figure 4 illustrates that several resources utilized for the loading and unloading of logs remain idle for a majority of the time during this stage. This is explained by the synchronization requirements between truck trips upon departure from the depot and the operations conducted at the different locations, which causes a trade-off between a truck's waiting time and its makespan needed to accomplish the tasks.

Table 4 provides data on the work schedule of each truck, including the start and end of their shift, as well as their productive time (either driving or loading), idle time, and waiting time. Idle time is defined as the excess time a truck has before reaching the maximum travel time limit, or t^{max}. Results indicate that a majority of trucks depart the depot early in the day to ensure an early return. Long driving times result in two behaviors: (i) some trucks spend their idle time waiting to carry out tasks (**c4** and **c5**), while others (ii) have high productivity but struggle with meeting time windows due to limited waiting times (**c3**). The proposed objective function aims to reduce wait times, allowing for shifts to be completed earlier and in a more efficient manner.

Table 5 provides comprehensive information on the work shift start and end times for each unit load, the number of assigned tasks, and the duration of idle time. The term **idle time** denotes the duration between shift beginning and end when the machine remains inactive. Table 5 indicates that the idle times of the various loaders are excessively high in comparison to the small number of tasks assigned to each of them. In addition, the number of tasks handled at different sites varies significantly, generating an imbalanced workload, which results in a higher number of tasks being assigned to attractive nodes from an economic perspective. These imbalances are a common occurrence in forestry supply chains due to harvesting operations being conducted over a portion or all of the total area, depending on the current phase of the harvesting front. For these cases, the tool demonstrates that it effectively solves these supply peaks and achieves feasible results with great computational efficiency.

Table 4: Trucks shifts and productivity

Truck	Shift start	Shift end	Truck State (hours)		
			Productive	Idle	Waiting
c0	6.00	13.60	6.83	3.17	0.78
c1	7.00	14.60	6.83	3.17	0.78
c2	6.50	14.10	6.83	3.17	0.78
c3	6.00	14.99	8.81	1.19	0.18
c4	9.05	19.05	8.52	1.48	1.48
c5	6.60	16.60	8.47	1.53	1.53
c6	6.00	15.10	8.23	1.77	0.87
c7	6.00	15.60	8.52	1.48	1.09

Table 5: Loader Shifts and productivity

Loader	Shift start	Shift end	Task procesed	Idle time (hours)
L_ha12_0	6.72	14.12	7	3.90
L_ha13_0	8.92	10.18	2	0.25
L_ha14_0	12.94	16.99	2	3.05
L_ha6_0	6.56	13.05	3	4.99
L_ha7_0	7.96	12.55	4	2.59
L_ha8_0	6.65	14.05	5	4.89
L_ha9_0	9.75	10.25	1	0.00
L_m1_0	8.64	14.81	3	4.67
L_m4_0	7.39	13.26	7	2.38
L_m6_0	7.94	11.49	2	2.55
L_m7_0	8.45	18.27	12	3.82

5. CONCLUSIONS AND FUTURE WORKS

In the forestry supply chain, a significant portion of costs results from inadequate planning of day-to-day operational activities. Thus, proper planning and synchronization of felling, thinning, and log transportation operations in response to market demand can yield substantial savings.

At the operational level, it is often impractical to solve MILP models for managing product flows in multi-period planning horizons due to their complex nature in realistic instances. Therefore, this paper presents a two-stage algorithm that connects inter-facility product flow planning with truck loading and unloading operations synchronization. In the first stage, the CG-based paradigm is used alongside a GRASP metaheuristic to optimize inventory profiles and transportation decisions based on cost. In the second stage, the available resources for loading or unloading at each facility are synchronized with these transportation decisions as input. The objective is to improve vehicle schedules by synchronizing resources over time for each day of the planning period.

By solving different examples, the proposal has shown significant computational efficiency and could function as a valuable support tool for inventory and transportation planning in multi-period scenarios.

For future analysis, it would be interesting to propose and study different objective functions to assess the impact of decisions on the productivity of loading and unloading units. This is a crucial matter as the outsourcing of these tasks is allocated to third parties who work on a productivity-based model. Additionally, these activities will be assessed in dynamic contexts where resource availability is prone to be affected by disruptive events. In such instances, the computational tool should respond efficiently to handle planning in a real-time context. The primary objective is to revise the harvesting and transportation procedures to minimize their impact on operations in terms of time and operating expense.

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