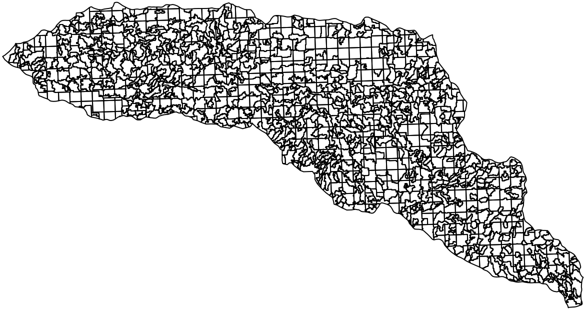
Optimal thinking in forest management with environmental concerns

Isabel Martins

Sinopse

Basic forestry problem

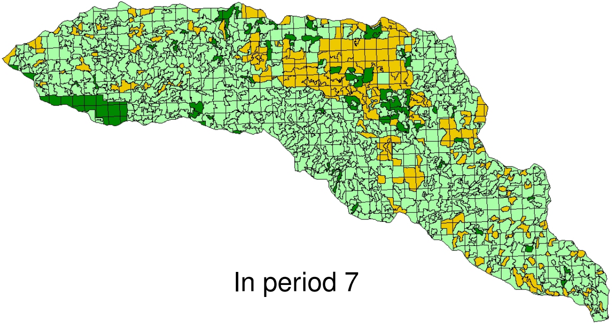
Source: Os Espacialistas



Forest area = 21147.8 ha   # stands = 1363   # periods = 7

Maximize the profit from timber harvested over the planning horizon subject to:

- A regular production of timber in the planning horizon
- A minimum in the average age of the forest at the end of the planning horizon
- ...



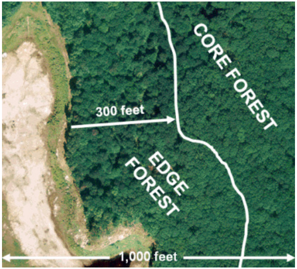
In period 7

Clearcuts

Limiting clearcut size aims at reducing the impact on

- soil
- water quality
- wildlife
- scenic beauty
- ...

Mature patches



Forest patch = Edge + Core area

Core area - interior area of the patch where ecological functioning is not impacted by the effect of immediately surrounding conditions

Edge - buffer area separating core area from outside influences

Edge and core-dependent species

Edge-dependent species

Core-dependent species

Core area

The core area of a forest patch is determined by the **area, shape and immediately surrounding conditions of the patch**

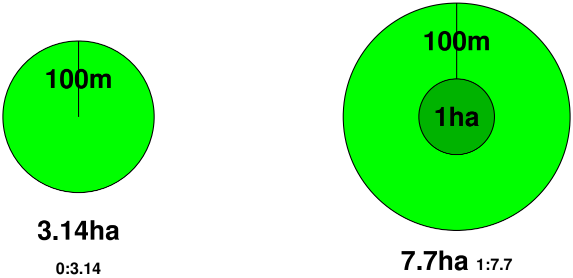
Core area

The core area of a forest patch is determined by the **area, shape and immediately surrounding conditions of the patch**

Area

Similar shapes

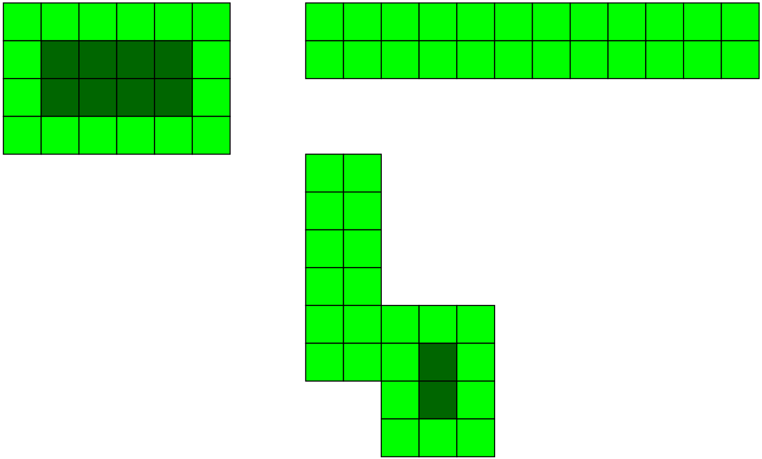
Smaller mature patches ⟷ Less amount of core area



Shape

Similar areas

Elongated or complex shapes $\longleftrightarrow$ Less amount of core area



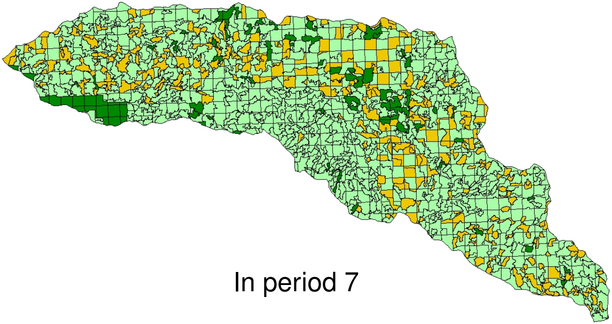
Basic + clearcut constraints

Source: Os Espacialistas

Basic + clearcut constraints

Maximize the profit from timber harvested over the planning horizon subject to:

- A regular production of timber in the planning horizon
- A minimum in the average age of the forest at the end of the planning horizon
- For each period, the area of every clearcut does not exceed the maximum allowed size



In period 7

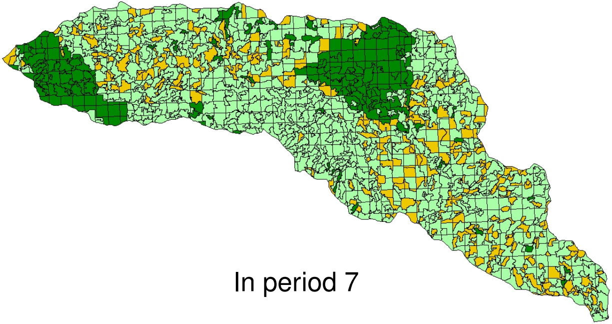
Basic + clearcut + habitat constraints

Source: Os Espacialistas

Basic + clearcut + habitat constraints

Maximize the profit from timber harvested over the planning horizon subject to:

- A regular production of timber in the planning horizon
- A minimum in the average age of the forest at the end of the planning horizon
- For each period, the area of every clearcut does not exceed the maximum allowed size
- Each habitat is a mature patch meeting a minimum core area
- In each period, the total core area inside habitats is greater than or equal to a minimum total core area



In period 7

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Operations Research challenges in forestry: 33 open problems

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Abstract Forestry has contributed many problems to the Operations Research (OR) community. At the same time, OR has developed many models and solution methods for use in forestry. In this article, we describe the current status of research on the application of OR methods to forestry and a number of research challenges or open questions that we believe will be of interest to both researchers and practitioners. The areas covered include strategic, tactical and operational planning, fire management, conservation and the use of OR to address environmental concerns. The paper also considers more general methodological areas that are important to forestry including uncertainty, multiple objectives and hierarchical planning.

Keywords Forestry · OR challenges · Transportation · Harvesting · Environment · Forest management · Fire management · Operations research · Strategic · Tactical · Operational

1 Introduction

The forest industry is very important from both regional and national perspectives in many countries. It constitutes a large proportion of the net exports in, for example, Canada, Chile,

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Open Problem 13 *How can we include complex environmental considerations like fragmentation, corridors, balancing mature patches, etc. into URM and ARM formulations in a computationally feasible way?*

It is well recognized now that adjacency constraints capture only a part of necessary environmental considerations. While maximum opening size limits are important, excessive fragmentation of forests is not particularly satisfactory. In order to allow wildlife to move between habitats, corridors of mature trees need to exist to join them. Similarly, issues of forest edge as well as a balance of mature forest are important for certain species. A few examples exist of attempting to address related issues using heuristic approaches. Thus, exact approaches are needed.

Modelling issues

Modelling issues

- Clearcut $\longleftrightarrow$ **Connected component of the graph** where the nodes are the harvested stands

Modelling issues

- Mature patch $\longleftrightarrow$ **Connected component of the graph** where the nodes are mature stands

Modelling issues

- Core area $\longleftrightarrow$ **Connected component of the graph** where the nodes are mature stands surrounded by a buffer of non-harvested stands

Connectivity

Source: Os Espacialistas

Models in MIP (A)

- $x_i^t = \begin{cases} 1 & \text{if stand } i \text{ is selected to be harvested in period } t \\ 0 & \text{otherwise} \end{cases}$

- $y_i^t = \begin{cases} 1 & \text{if stand } i \text{ is selected to be part of the core area of} \\ & \text{a habitat in period } t \\ 0 & \text{otherwise} \end{cases}$

Models in MIP (A)

- $x_i^t = \begin{cases} 1 & \text{if stand } i \text{ is selected to be harvested in period } t \\ 0 & \text{otherwise} \end{cases}$

- $y_i^t = \begin{cases} 1 & \text{if stand } i \text{ is selected to be part of the core area of a habitat in period } t \\ 0 & \text{otherwise} \end{cases}$

- $\sum_{i \in C} x_i^t \leq |C| - 1; t \in T; C \in \mathcal{C}c^t$

- $\sum_{i \in \Pi^t(M)} y_i^t \geq y_j^t; t \in T; M \in \mathcal{M}h^t; j \in M$

- $\sum_{\substack{t' \leq t: \\ C^{t'} \cap \{i\} \neq \emptyset}} x_i^{t'} \leq 1 - y_j^t; t \in T; j \in M^t; i \in \pi(j) \cup \{j\}$

- $\sum_{i \in M^t} a_i y_i^t \geq COT_{\min}; t \in T$

Clearcuts

$a_i = 1$ ha, $A_{max} = 2$ ha

1	2	3
4	5	6
7	8	9

Mature forest
in period 1

Clearcuts

Connected region, unfeasible as clearcut, minimal

1	2	3
4	5	6
7	8	9

Clearcuts

1	2	3
4	5	6
7	8	9

Clearcuts

1	2	3
4	5	6
7	8	9

Clearcuts

1	2	3
4	5	6
7	8	9

Clearcuts

1	2	3
4	5	6
7	8	9

$$x_1^1 + x_2^1 + x_3^1 \leq 2$$

Clearcuts

1	2	3
4	5	6
7	8	9

$$x_1^1 + x_2^1 + x_3^1 \leq 2$$

$$\sum_{i \in C} x_i^t \leq |C| - 1; \quad t \in T; C \in \mathcal{C}c^t$$

Core area

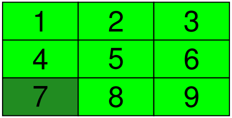
$a_i = 1$ ha, $C_{min} = 3$ ha

1	2	3
4	5	6
7	8	9

Mature forest
in period 1

Core area

Connected region, unfeasible core area



Core area

Connected region, unfeasible core area

1	2	3
4	5	6
7	8	9

Core area

Connected region, unfeasible core area

1	2	3
4	5	6
7	8	9

Core area

Connected region, unfeasible core area

1	2	3
4	5	6
7	8	9

$y_4^1 + y_8^1 \geq y_7^1$

Core area

Connected region, unfeasible core area

1	2	3
4	5	6
7	8	9

Core area

1	2	3
4	5	6
7	8	9

Core area

1	2	3
4	5	6
7	8	9

Core area

1	2	3
4	5	6
7	8	9

Core area

1	2	3
4	5	6
7	8	9

$$y_4^1 + y_5^1 + y_9^1 \geq y_7^1$$
$$y_4^1 + y_5^1 + y_9^1 \geq y_8^1$$

Core area

1	2	3
4	5	6
7	8	9

$$y_4^1 + y_5^1 + y_9^1 \geq y_7^1$$
$$y_4^1 + y_5^1 + y_9^1 \geq y_8^1$$

$$\sum_{i \in \Pi^t(M)} y_i^t \geq y_j^t; t \in T; M \in \mathcal{M}h^t; j \in M$$

Habitat

Habitat

1	2	3
4	5	6
7	8	9

$$\sum_{\substack{t' \leq t: \\ C^{t'} \cap \{i\} \neq \emptyset}} x_i^{t'} \leq 1 - y_j^t; t \in T; j \in M^t; i \in \pi(j) \cup \{j\}$$

- Polynomial number of variables
- Exponential number of constraints

- Polynomial number of variables
- Exponential number of constraints

Branch-and-cut $\longrightarrow$

Solutions within 1% of the optimum in less than three hours

Models in MIP (B)

- $z_c^t = \begin{cases} 1 & \text{if region } c \in \mathcal{C}^t \text{ is harvested in period } t \\ 0 & \text{otherwise} \end{cases}$

- $y_h^t = \begin{cases} 1 & \text{if region } h \in \mathcal{H}^t \text{ is habitat in period } t \\ 0 & \text{otherwise} \end{cases}$

- $w_{ir}^t = \begin{cases} 1 & \text{if subregion } r \in \mathcal{R}_i \text{ is core habitat in period } t \\ 0 & \text{otherwise} \end{cases}$

Clearcuts

Region $c \in \mathcal{C}^1$ that can be a clearcut in period 1 if ...

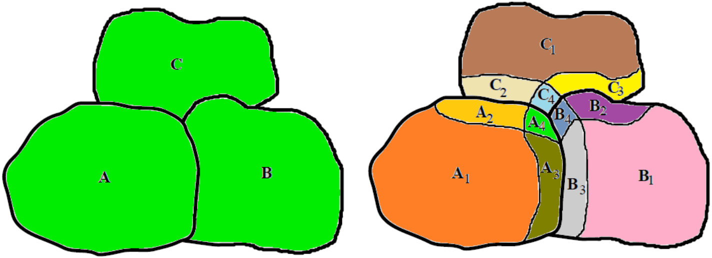
1	2	3
4	5	6
7	8	9

Habitats

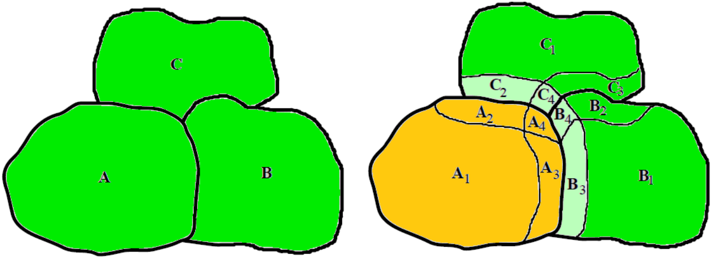
Region $h \in \mathcal{H}^1$ that can be a habitat in period 1 if ...

1	2	3
4	5	6
7	8	9

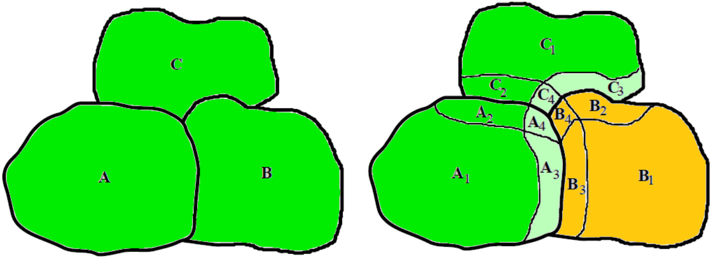
Core area - Subregions



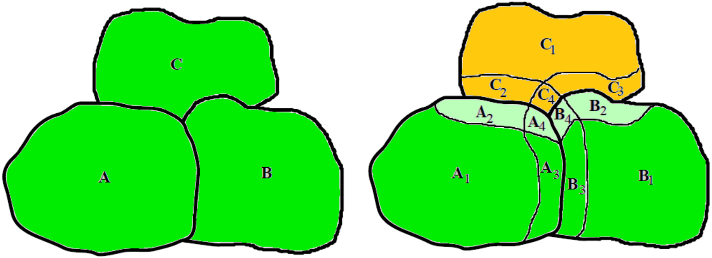
Core area



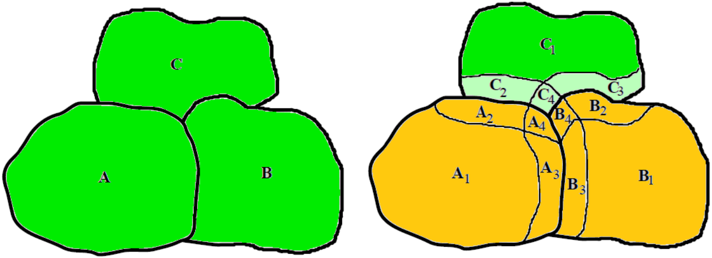
Core area



Core area



Core area



Constraints

- $\sum_{u=1}^{t} \sum_{c \in \mathcal{C}^u:\, i \in c} z_c^u + \sum_{h \in \mathcal{H}^t:\, i \in h} y_h^t \leq 1, \; \forall t \in \mathcal{T}, i \in \mathcal{V}^t$
- $w_{ir}^t + \sum_{\substack{c \in \mathcal{C}^t: \\ j \in c}} z_c^t \leq 1, \; \forall t \in \mathcal{T}, i \in \mathcal{V}^t, r \in \mathcal{R}_i, j \in \mathcal{I}_r \setminus \{i\}$
- $w_{ir}^t \leq \sum_{h \in \mathcal{H}^t:\, i \in h} y_h^t, \; \forall t \in \mathcal{T}, i \in \mathcal{V}^t, r \in \mathcal{R}_i$
- $\sum_{i \in h} \sum_{r \in \mathcal{R}_i} \mathrm{s}_{ir} w_{ir}^t \geq \mathrm{C}^{\mathrm{min}} y_h^t, \; \forall t \in \mathcal{T}, h \in \mathcal{H}^t$
- $\sum_{i \in \mathcal{V}^t} \sum_{r \in \mathcal{R}_i} \mathrm{s}_{ir} w_{ir}^t \geq \mathrm{C}^{\mathrm{mintot}}, \; \forall t \in \mathcal{T}$
- $\sum_{h \in \mathcal{H}^t} \mathrm{s}_h y_h^t \geq \mathrm{H}^{\mathrm{mintot}}, \; \forall t \in \mathcal{T}$

- Polynomial number of constraints 
- Exponential number of variables 

Branch-and-bound $\longrightarrow$

Solutions within 1% of the optimum in less than two hours 

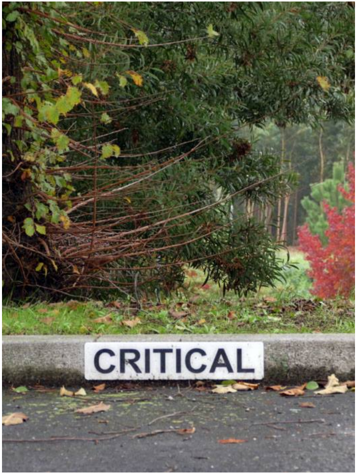
except

for the large instances, with solution gaps slightly above 7% 

Table: Approaches studied.

Exact methods	Heuristics
Solve MILP models	Simulation
Branch-and-cut algorithm	Simulated annealing
Branch-and-bound algorithm	Tabu search
Multi-objective programming	Hybrid heuristics
	Linear programming based heuristics
	Dynamic programming-based heuristics

Obrigada!



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