

Geographical Considerations in Forest Management Planning

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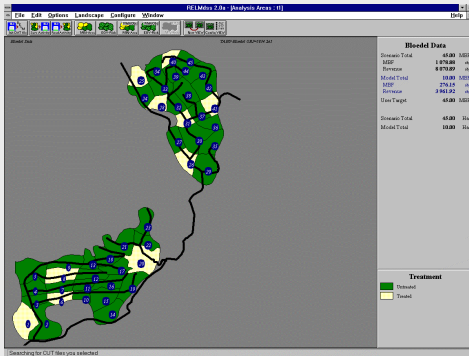
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Harvest Scheduling

- Harvesting is one of the multiple uses of natural resources
- Lowest spatial level of resolution in the forest planning hierarchy
- Typically focused on benefits or returns
- Consistent and stable harvest flows
- Limit environmental impacts and degradation
- Basic problem:
 - maximize realized potential subject to maintaining temporal output commitments and restricting the areal extent of treatment activity

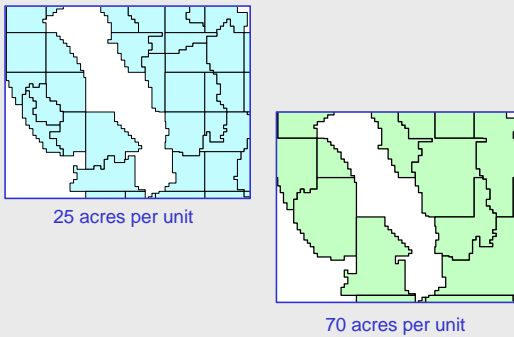
Forest Management



Spatial Restrictions

- Sustainable Forestry Initiative
 - American Forest & Paper Association
 - ⇒ 167 members accounting for 52 million acres of industry forests
- Adjacency constraints
 - Average clearcut areas should not exceed 120 acres
- Inherent ambiguity
 - How to interpret & how to implement
- Two basic approaches

Alternative Representations



Alternatives – Similar Scale

- Both representations average approximately 70 acres per unit
- Which one more appropriate for use?

Notation

i = index of planning units;
 t = index of time periods;
 \mathbf{a}_i = benefit for treating unit i in period t ;
 \mathbf{b}_i = volume of timber in unit i in period t ;
 L_t = lower bound on total timber produced in period t ;
 U_t = upper bound on total timber produced in period t ;
 N_i = set of planning units adjacent to unit i ;
 $x_{it} = \begin{cases} 1 & \text{if unit } i \text{ is treated in period } t \\ 0 & \text{otherwise.} \end{cases}$

Unit Restriction Model (URM)

Maximize $Z = \sum_i \sum_t \mathbf{a}_i x_{it}$ (1)

Subject to $\sum_t x_{it} \leq 1 \quad \forall i$ (2)

$\sum_i \mathbf{b}_i x_{it} \geq L_t \quad \forall t$ (3)

$\sum_i \mathbf{b}_i x_{it} \leq U_t \quad \forall t$ (4)

$x_{it} + x_{jt} \leq 1 \quad \forall i, t, j \in N_i$ (5)

$x_{it} = (0,1) \quad \forall i, t$ (6)

Extensions

- road building
- interval exclusion periods (multiple rotations)
- green up considerations (extended adjacency restrictions to neighbors through time)
- minimum revenue requirements

Additional Notation

Ω_t = set of units violating maximum contiguous area restriction;

v_i = area of unit i ;

A = maximum permissible contiguous area treated;

Area Restriction Model (ARM)

Maximize $Z = \sum_i \sum_t \mathbf{a}_i x_{it}$ (7)

Subject to

(2)-(4), (6)

$\sum_{j \in \Omega_t} x_{jt} \leq |\Omega_t| - 1 \quad \forall t$ (8)

Relating the URM and the ARM

(a) $A \geq \max_i v_i$

(b) $A/2 < \min_i v_i$

Modifiable Areal Unit Problem

- MAUP
 - Scale of analysis variability
 - Unit specification variability
- Significance
 - Researchers have found that common statistical measures and spatial analytic modeling results vary significantly merely by altering geographic representation
- Frame independence
 - Tobler (1989) suggests that if a particular method of analysis is subject to manipulation based upon a change of geographical scale or unit specification, then the method is inappropriate.

What are the implications of MAUP for harvest scheduling?

- Geographical research recognizes that one must explicitly test for MAUP effects in order to understand the behavior of a model (or models) with respect to changes in scale or unit definition
- If sensitivities exist
 - use the most disaggregate information available
 - look for a more appropriate spatial model, if one exists
- No sensitivity
 - approach is frame independent

Solving the URM and ARM

- Challenging and difficult problems
- Exact and heuristic approaches
- Return potential can be substantial in both monetary and sustainability terms
- Reported problem sizes:
 - URM (100-400 units or more)
 - ARM (thousands to nearly 30,000 units)

URM Solution Approaches

- Linear-integer programming problem
- Exact methods
 - adjacency constraint reduction
 - improving adjacency constraint structure
- Heuristic methods
 - interchange
 - simulated annealing
 - Tabu search
- Capabilities are pretty good for the URM

ARM Solution Approaches

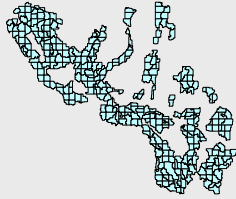
- Capabilities are not so good for the ARM
- Dynamic programming problem (non-linear constraint)
- Exact methods
- Heuristic methods
 - simulated annealing
 - Tabu search
 - Greedy hybrid (Directed search)
 - Indirect

URM and ARM

- With appropriate disaggregate data, could solve a series of URM problems through scale and unit definition variation
 - aggregation
- Thiessen
 1. Randomly select a given number of units
 - ⇒ Seed units
 2. Aggregate remaining units to closest seed unit
- Block building
 1. Consider all units unblocked
 2. Randomly select a unit not yet merged in a block
 3. Aggregate unmerged neighbors (randomly) to form a block until the size limit is reached
 4. If all units are not a member of a block (or merged), return to step (2)

Study Design

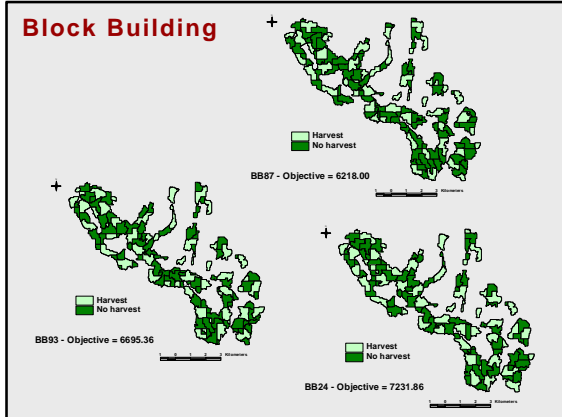
- Butter Creek region
 - 351 units
 - 25 acres per unit
- Restriction goal
 - 120 acre maximum
- Approximate solution to ARM by solving a series of URM
 - Pentium III/600
 - ArcView 3.2
 - Cplex 6.53



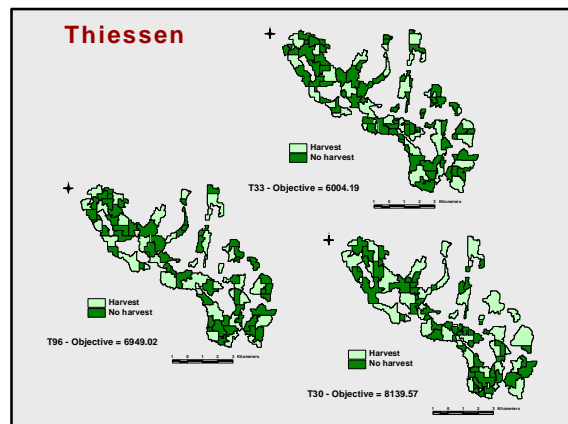
URM Results

- Original data (351 units)
 - Objective value
 - ⇒ 5854.25
- Block building
 - 100 realizations generated (113-127 blocks)
 - Average block size → 69-78 acres
 - Objective value
 - ⇒ Mean = 6700.99
 - ⇒ Minimum = 6218.00
 - ⇒ Maximum = 7231.86
- Thiessen
 - 100 realizations generated (80 blocks)
 - Average block 110 acres
 - Objective value
 - ⇒ Mean = 6935.88
 - ⇒ Minimum = 6004.19
 - ⇒ Maximum = 8139.57

Block Building



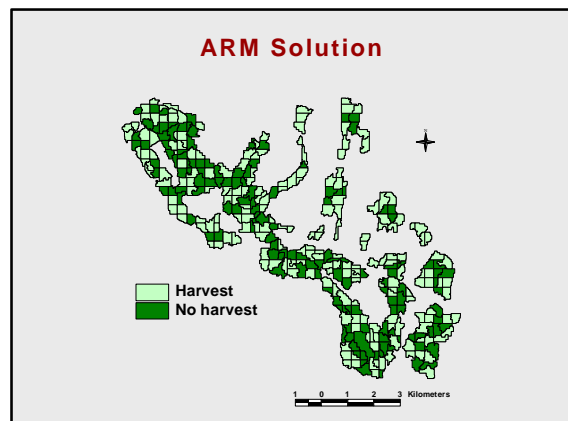
Thiessen



ARM Results

- Fortran program to generate ARM constraints
 - constraints (8) - 64,034
 - 35.76 hours processing time
- 15.22% optimality gap after 19.43 hours
 - 959,793 iterations and 17,208 branches
- Objective value
 - 9482.41

ARM Solution



Interpreting Results

- 201 different spatial representations of forest region analyzed as a URM
 - none are competitive ARM approximations
- Objective value of best ARM solution found was 16.50% higher than the best URM solution
- In terms of economic return
 - significant difference
- Spatial extent of harvest activities is substantially different
- URM is not frame independent
 - variation found in Thiessen and Block Building realizations

What about the ARM?

- Assuming underlying disaggregate data exists, ARM appears to satisfy the spirit of frame independence
- However, one might say that it spatially exploits the nature of the harvest scheduling problem
- Is it appropriate to consider integrating harvest concerns and conservation efforts?

