OPTIMIZING THE LOCATION OF HARVESTING EQUIPMENT AND ACCESS ROADS

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ABSTRACT – Determining how to harvest and transport timber across a forested area to an outlet or existing road is a difficult problem. This paper considers the situation where an undulating landscape is represented as a series of grid cells, each relatively small with a surface defined by elevation, slope, aspect and timber quantity. Developing a operational harvest management plan involves determining a layout of access roads which connect sited tower (and skidder) units. The objective of the problem is to minimize the costs of unit placement, road building, and timber transport. A mathematical programming formulation for this problem is presented.

INTRODUCTION

The management of lands for timber provision is a difficult and time consuming process. The focus of this paper is on operational planning considerations which must determine tower (and skidder) unit placement and road access to these sites on an undulating landscape. This surface may be represented a series of grid cells at a suitable level of resolution using a raster based geographical information system (GIS). Thus, information on slope, elevation, aspect and timber inventory for a planning area is assumed to be available. The problem is to minimize the costs associated with the placement of units and road building. This ensures that timber transport and provision costs remain as low as possible.

Figure 1 gives a visual representation of this operational forest harvesting problem. Cells 4, 13, 19, and 32 are potential tower unit placement sites. The objective is to determine from this set of cells a specified number of units to site as well as the best road network which links the selected units to the exit site. Figure 1 demonstrates this for the selection of units at cells 4, 13, and 19 which are connected by road linkages to the exit site at cell 40. This basic problem is a critical component of the planning problem faced by the Chilean forest industry (Murray, Church and Weintraub 1997).

RELATED PROBLEMS

The forest management planning process is a complex task and typically involves numerous hierarchy levels of decision making (Church, Murray and Barber 1994). Operational planning is one level in this hierarchy. The operational problem described here differs to the discrete optimization approach presented in Kirby, Hager and Wong (1986) and Murray and Church (1995). Thus, it is a new variety of problem which stems from the data access provided by GIS and a move towards less preprocessing and preparation in the analysis of management planning.

The new operational problem discussed in this paper happens to be related to Steiner minimal tree problem. The Steiner tree problem connects a specified subset of nodes using the arcs in the network (Hakimi 1971) and has proven to be a very difficult combinatorial optimization problem. If we represent the forest planning problem described here in terms of nodes (the grid cells) and arcs (potential road links), then once we have determined which units to site, the problem is in fact a Steiner tree problem in a network. Thus, our problem is an extension of this difficult optimization problem.

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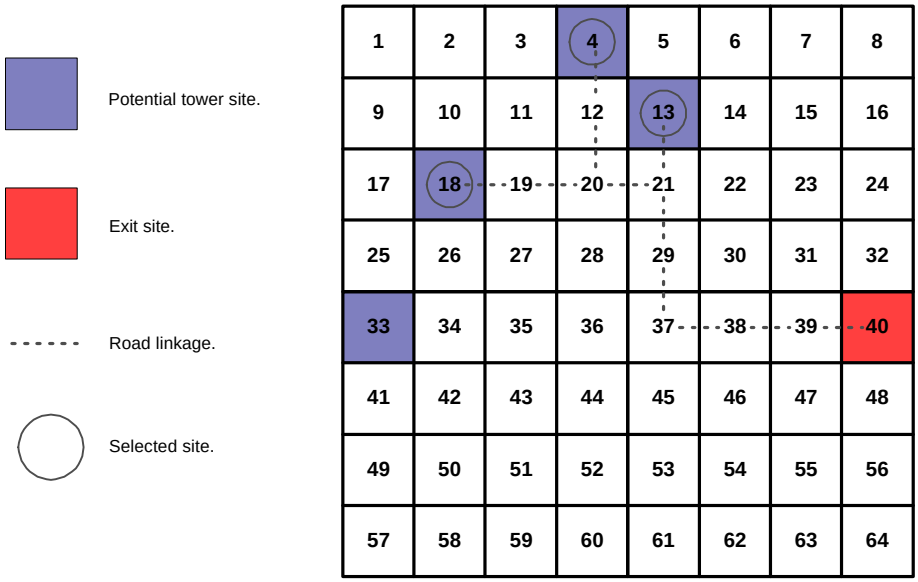

Figure 1.—Operational forest planning problem on a grid**.**

FORMULATION

In formulating the grid based operational forest planning problem it is necessary to provide some information on how this problem is being structured. As done in Murray, Church and Weintraub (1997), the representation of this problem may be structured as a graph with nodes and arcs. The nodes are associated with the grid cells and the arcs are associated with the potential road links. The potential unit sites and exit cell also have arcs associated with them. Finally, the road link arcs are duplicated in order to track the fixed charge costs of establishing a link. We now provide the formulation of this problem.

Consider the following notation:

i, j = index of grid cells;
c_{ij} = cost to construct the road linking cell i to cell j;
t = source node related to flow through the network;
e = sink node related to flow through the network;
T = set of potential tower locations;
E = set of potential exit locations;
p^t = number of tower sites to locate;

Decision variables:

$$f_{tj} = \begin{cases} 1 & \text{if tower location } j \text{ is selected} \\ 0 & \text{otherwise.} \end{cases}$$

$$f_{ij} = \begin{cases} 1 & \text{if a road from cell } i \text{ to cell } j \text{ is built} \\ 0 & \text{otherwise.} \end{cases}$$

$\bar{f}_{ij}$ = additional flow from cell i to cell j.

It is worth pointing out that the use of the additional (or duplicate) link from cell *i* to cell *j* using decision variables $\bar{f}_{ij}$ is above and beyond the use of the actual road link using the decision variable f_{ij}. Thus, f_{ij} is required to equal 1 before $\bar{f}_{ij}$ is allowed to be used.

The problem formulation is as follows:

$$Minimize \quad Z_p = \sum_i \sum_j c_{ij} f_{ij} \tag{1}$$

Subject to

$$\sum_i \left[\left(f_{ij} + \bar{f}_{ij} \right) - \left(f_{ji} + \bar{f}_{ji} \right) \right] = 0 \qquad \left(\forall\, j \neq t \text{ or } e \right) \tag{2}$$

$$\sum_{j \in T} f_{tj} = p^t \tag{3}$$

$$\sum_{j \in E} f_{je} = p^e \tag{4}$$

$$\sum_j f_{ij} \leq 1 \qquad \left(\forall\, i \neq e \right) \tag{5}$$

$$\bar{f}_{ij} \leq \left(p^t - 1 \right) f_{ij} \qquad \left(\forall\, i, j \right) \tag{6}$$

$$f_{ij} = 0,1 \qquad \left(\forall\, i, j \right) \tag{7}$$

$$0 \leq \bar{f}_{ij} \leq p^t - 1 \qquad \left(\forall\, i, j \;\&\; i \neq t \right) \tag{8}$$

The objective (1) is to minimize total costs associated with siting units and building necessary roads. Constraints (2) enforces conservation of flow through the network. Constraints (3) specify the number of tower units to site. Constraints (4) ensure that the road network is connected to the exit site. Constraints (5) require that there be no load splitting. Constraints (6) prevent additional road link capacity unless it has been established. Constraints (7) and (8) impose integer restrictions and bounds on decision variables. Extensions to this basic formulation may be found in Murray, Church and Weintraub (1997).

DISCUSSION

Solving this problem is a difficult task, either heuristically or optimally. Murray, Church and Weintraub (1997) developed a Lagrangian relaxation heuristic approach for solving this problem. Unfortunately, only relatively small problem instances have been approached to date. Thus, solution development for this problem is a much needed area of research.

This paper has demonstrated a new variety of operational forest planning problems. A mathematical programming formulation has been presented. This problem is likely to be an important problem in the coming years as better quality spatial information becomes available through geographical information systems (GIS).

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