SPATIAL ANALYSIS IN TIMBER MANAGEMENT PLANNING

by

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ABSTRACT

The objective of this thesis was to develop a spatially sound timber management strategy design tool. Long-range timber management modelling systems were identified as being limited by the inability to perform large-scale spatial analysis. Large-scale spatial analysis capabilities, realized with the introduction of Geographic Information Systems (GIS), allow resource managers to consider the spatial distribution of treatments, haul costs and timing of access (termed the spatial problem). Three candidate modelling systems were evaluated for integration with large-scale spatial analysis. Timber RAM was chosen because of the transferability, ease of modification and sufficient constraint capabilities. The mathematical structure of a modified Timber RAM system was described.

A management planning algorithm was proposed as a means of developing spatially sound treatment schedules. The heart of the management planning algorithm was the HAULCOST.CPL routine which attached haul cost and timing of access attributes to individual stands in a forest property. These attributes were used in stand class aggregations in performing the modified Timber RAM analysis.

The management planning algorithm was implemented for a case study forest. Results of the case study were evaluated with respect to the ability of the management planning algorithm to address the spatial problem and the feasibility of implementation in an actual planning situation. The management planning algorithm was able to produce spatially sound harvest schedules, and thus achieved the stated objective. Practical implementation was considered to be feasible for those organizations maintaining an ARC/INFO GIS and database.

Key Words: long-range timber management planning, Geographic Information System, spatial analysis, management planning algorithm

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CHAPTER 1

INTRODUCTION

Timber management planning is the design of strategies which control the scheduling and distribution of the harvest as well as the renewal and protection of the resource (Baskerville, 1982). Implicit to strategy design is the requirement for resource managers to control both the location and timing of management activities to provide the greatest net return to the organization. Because woodlands operations are generally considered to be cost centres, the objective becomes to obtain the desired volume, at minimum cost.

A recent approach to strategy design has been long-range planning models based on Linear Programming (LP) optimization techniques. The Timber Resource Allocation Method (Timber RAM) modelling system (Navon, 1971) was one of the first large-scale attempts at capturing the essence of the timber harvest scheduling problem. An identified shortcoming of Timber RAM was the inability to incorporate spatial considerations (Chappelle et al., 1976: 291). In reducing the problem size to manageable complexity (computational feasibility), significant abstraction of spatial detail was required. Spatial analysis was limited to an increasing percentage of accessible stand class area, mimicking road construction projects. This was considered to be a shortcoming of Timber RAM, but was more likely the result of a lack of ability to perform large-scale spatial analysis. Efficient methods of spatially analyzing alternative road network designs with respect to haul cost and timing of access (hereafter termed the spatial problem) were required to: 1) determine the spatial distribution of activities during a particular period of time; and 2) consider the effect of haul costs and timing of access constraints on both sustainable harvest levels and strategy design. Given the requirements of resource managers, the spatial problem was of considerable concern in planning situations. The end result of the expensive and time-consuming analysis using Timber RAM was a biologically sound strategy, but one which was potentially infeasible to implement because of practical economic and/or physical restrictions imposed on the spatial requirements of the management schedule.

The objective of this thesis is to address the spatial problem by developing a procedure which incorporates timing of access and haul costs with the design of timber management strategies. The approach centres around the recent advances in spatial analysis capabilities realized with the use of Geographic Information Systems (GIS) such as the Environmental Systems Research Institute (ESRI) ARC/INFO system (ESRI, 1987). A GIS allows one to maintain a relational database; linking the geographic location of features (e.g. forest stands) with the desired physical attributes. Because of the relational database structure, spatial analysis may be undertaken which would otherwise be manually impractical to perform. For a more detailed description of GIS, Jordan (1986) describes GIS technology and applications in forest management.

To address the spatial problem, generic and custom software were used to attach haul cost attributes to individual stands for future time periods, to account for road construction. Timing of access was assumed to be in the period which first had the minimum haul cost. Based on the relationship of stand distance from the mill and from roads, "haul zones" could be generated. Aggregation for each time period, based on both traditional inventory criteria and the generated criteria of access timing and haul cost, permitted determining forest age structures, by haul zone, for each future time period. The capability of GIS to perform spatial analysis is thus used to capture spatial detail at the time of structuring the problem to be analyzed with the long-range planning system.

An assumption of such an aggregation was that the spatial distribution of activities within each haul zone would be both acceptable and feasible to implement. Such an aggregation removed the element of choice of location (within each haul zone) from the manager, but replaced this with economic optimization of location-based haul costs.

This chapter provides background information on management planning systems in general, and details the spatial capabilities of three optimization systems. The systems are then evaluated using the criteria of Rose (1984) to assess the appropriateness of the three modelling systems for integration with a GIS to address the spatial problem. The chapter concludes with a discussion of the rationale for selecting Timber RAM as the modelling system to be linked with ARC/INFO.

Chapter 2 presents the mathematical structure of the linked GIS/Timber RAM procedure and the haul cost algorithm. Chapter 3 presents a case study using both the integrated GIS/Timber RAM procedure (stand classes based on traditional inventory criteria and spatial attributes), and the standard Timber RAM form (stand class aggregations based solely on traditional inventory criteria). Chapter 4 is the discussion and conclusions regarding the value of the integrated management planning algorithm as a practical planning tool.

Lougheed and Walker (1988) is a guide to the installation of the haul cost programs and implementation of the management planning algorithm.

DESCRIPTION OF MODELLING SYSTEMS

Hann and Brodie (1980) identified two levels of models which were used to assist in the decision-making process. First, stand-level growth and yield models were designed to forecast the future development of individual stands. The models were used to generate a series of possible stand development alternatives (crop plans) given application of different types, intensities and sequences of silvicultural treatment. The knowledge gained from this type of model was of value to the forest-level modelling systems. Forest-level modelling systems were designed to forecast the future development of multi-stand forests. Generally, these systems were designed to assess or optimize the application of stand-level silvicultural treatments (including harvesting) in achieving a desired forest-level outcome (costs, net revenue, volume, etc.). Here the concern was in the choice of which silvicultural strategies to implement given forest-level objectives for output and constraints on treatment levels.

Two types of forest-level modelling systems, simulation-based and optimization-based, have undergone steady development in attempts to capture the complex relationships found in assessing forest dynamics. Simulation systems sequentially project timber inventories based on specified activities per period. Hall (1978:iii) described the purpose of the Wood Supply and Forest Planning system (WOSFOP) to be "to systematically test and explore management options, and to develop and evaluate management strategies." Criticism of simulation systems centres about the potential for suboptimization since the treatments are applied based on an assessment of the forest condition in individual periods.

The key difference between simulation systems and optimization (usually LP-based) systems was that in addition to the design of stand-level management alternatives, optimization systems select the particular combination of alternatives which best contribute to the forest-level objective function.

The process of directly integrating spatial and temporal analysis into the LP formulation has been gradual, beginning with Timber RAM, expanding somewhat in Multiple-Use Sustained Yield Calculation (MUSYC) (Johnson and Jones, 1980) and continuing with FORPLAN (Johnson _et al_., 1986).

The following description and critique of the three modelling systems will centre on the capability of the systems to incorporate spatial considerations. Discussion of the capabilities of the systems will be in chronological order of development, since this provides an indication of the criticisms raised and the response taken.

Timber RAM

Navon (1971) described Timber RAM as a method for developing long-range forest management plans for lands under multiple-use management. Spatial analysis capabilities included constraining the stand class areas to the cumulative proportion accessible in five successive decades. The stand classes were defined as "all timber stands with similar silvicultural and economic characteristics" (Navon, 1971: 2).

The stand classes are therefore aggregations of homogeneous, but non-contiguous stands.

Chappelle et al. (1976) criticized the lack of spatial resolution in the analysis as well as in the reporting of the results. They claimed that the aggregation prevents direct linkage of the optimal plans to implementation attempts. Iverson and Alston (1986) also criticized the aggregation on the basis of lack of control of the spatial distribution of clearcut areas (both from an operational and a multiple-use point of view).

MUSYC

The Multiple-Use Sustained Yield Calculation (MUSYC) system (Johnson and Jones, 1980) represented significant improvements over Timber RAM constraint capabilities. Three independent identifiers were attached to each timber class, with the MUSYC formulation allowing "constraints with regard to acres or volume treated forest-wide by treatment type per period, and by groups of inventory categories formed by some combination of the identifiers" (Iverson and Alston, 1986: 13). Essentially, greater control was given to the user in specifying constraints on area aggregates composed of entire or partial stand classes. The result of the additional constraints was more realistic harvest schedules.

Iverson and Alston (1986: 13) stated that MUSYC still failed to "give explicit recognition to the geographic areas important to specialists from wildlife, recreation, watershed and so forth." This indicated a requirement to enhance the ability of models to recognize non-timber values. They further indicated that for economic analysis, geographically defined zones were required for estimating timber costs wherever road costs were important. Transportation analysis required location-specific data, which were not included in the MUSYC formulation.

Multiple-use planning requirements of the U.S. National Forests exceeded the capabilities of MUSYC in both spatial resolution of the analysis, and specification of non-timber use in the objective function.

FORPLAN

Forest Planning (FORPLAN) Version 2 (Johnson *et al.*, 1986) was developed in an effort to address the concerns voiced by managers over the lack of spatial resolution (ability to determine alternatives for specific geographic areas) and limited objective function capability in existing models.

Johnson *et al.* (1986) indicated that in choosing the basic unit of area for analysis, one was in essence choosing the decision variables. Two basic types of decision variables were identified. First, the traditional strata-based approach resulted in decision variables defined on a yield per unit area basis. Second, the proposed area-based approach had decision variables defined on a yield per geographic zone basis.

Strata-based Approach

The strata-based approach defined decision variable as "acres assigned to a timing choice k of prescription i of stratum s," with each stratum defined to be an "analysis area" (Johnson et al., 1986: 4-2). With strata-based analysis, it was possible to aggregate the analysis areas according to specified geographic zones (e.g. watersheds or ranger districts). One problem identified by Johnson et al. (1986) was the difficulty in assessing the spatial feasibility of the management regimes chosen in the LP solution. This occurred when allocating a stratum within an area to a particular management regime, as there was an attendant loss of ability to determine specific geographic locations of activities within the area. Partitioning or splitting of the stratum by the LP procedure allowed more flexibility in implementation, but was reported to "reduce the ability to portray in the model those implications of the schedule which have important spatial dimensions" (Johnson et al., 1986: 4-18). The immediately obvious answer was to define smaller areas (more stand classes), but this had the result of increasing the number of area accounting constraints required. This, in turn, resulted in an increase in solution time required (LP is sensitive to the number of rows), and had computational feasibility limits. As well, the spatial distribution of activities was not addressed, resulting in the chance of allocating incompatible activities adjacently, or similar activities too dispersed to be feasible.

Area-based Approach

The area-based approach, unique to FORPLAN Version 2, defined decision variable yields on a per area (geographic zone) basis. Alternative packages of predetermined management schedules, termed Coordinated Allocation Choices (CAC), for all analysis areas within the

Allocation Scheduling (ALSC) zone were developed, each directed toward management of a particular resource (wildlife, recreation, timber production, wilderness), and each constituting an allocation scheduling (ALSC) choice. In effect, one was allowed to specify a "choice within a choice" (Iverson and Alston, 1986: 14).

Johnson et al. (1986) identified several advantages and disadvantages of the approach. Two advantages were: i) the ability to locate specific geographic areas for treatment because of the predetermined management schedules (CAC) and ii) the ability to constrain the assignment of ALSC zones to meet a particular objective (wilderness, timber, etc.). However, two problems were generated by this approach. First, there was a requirement for Integer Programming (IP) techniques to be employed whenever an ALSC zone was partitioned, since allocation of part of a geographic zone to wilderness and the remainder to timber production was not feasible. The IP requirement severely limits the problem size, since solution techniques capable of handling the problem sizes commonly encountered have yet to be developed. Second, in developing the management schedule (CAC) alternatives for each ALSC zone, there was difficulty in representing sufficient choices to meet the objectives and constraints of the problem.

EVALUATION OF MODELLING SYSTEMS

Rose (1984) reported 12 criteria for evaluating planning models. The criteria were used to evaluate the relative strengths and weaknesses of the three modelling systems in attaining the stated objective of incorporating timing of access, haul costs and spatial distribution of activities into the planning process. Each of the criteria can not be given the same weight in evaluation or choice of the best model for the requirements at hand; failure to meet a critical planning or operational requirement may result in a decision against use of that system. The following evaluation is based on the criteria of Rose (1984).

1. "Does the model generate solutions which are at least theoretically sound (valid)?"

Each of the three systems is designed to produce theoretically sound solutions.

2. "Does the model develop an implementable plan or can results be used to develop an implementable plan?"

Timber RAM and MUSYC, because of the limitations of the strata-based approach, contain more assumptions regarding spatial distribution of activities. This may result in biologically sound solutions being impractical to implement. FORPLAN, with the area-based approach, addresses the spatial distribution concern with the ability to design CAC for ALSC zones, and to constrain and link the choices among adjacent ALSC zones.

3. "How can the model fit into the general planning process?"

Each of the three systems was developed for use by the United States Forest Service. To this end, the design was intended to mesh with the planning procedures then in place. Timber RAM and MUSYC were less readily integrated because of their inabilities to account for multiple-use aspects of the Forest Service mandate. FORPLAN utilized the 1974 Forest and Rangeland Renewable Resources Planning Act (RPA) criteria in specifying activities and yields, as well as permitting multiple-use objectives and constraints in the analysis (Iverson and Alston, 1986: 7). These improvements increased the acceptance of FORPLAN by Forest Service planners. Timber RAM and MUSYC, because of their smaller size, would be easier to modify for other users. FORPLAN, however, because of the large program size and high degree of Forest Service orientation, would require a significant effort to integrate with other organizations.

4. "Will the planning process be cost-effective with this model?"

This refers to the improvement in net return to the organization. There may be both tangible and intangible returns, but from an industrial perspective, the tangible returns should be expected to justify implementation. Timber RAM and MUSYC have the advantage of relatively small size in comparison to FORPLAN. This would be expected to result in savings in costs of both maintaining and using the code. FORPLAN, especially in the area-based approach, is labour-intensive in the typing of the ALSC zones, resulting in a cost not incurred by the other models. The advantages of the area-based approach would then have to be judged against the strata-based approaches of Timber RAM and especially MUSYC.

5. "Would different planners reach different results?"

The results of optimization in choosing strategies are responsive to the specified yield functions. Different planners would affect the solutions given their preference for optimistic or pessimistic outlooks on expected yields. Timber RAM, MUSYC, and the strata-based approach of FORPLAN are subject to such effects. FORPLAN is subject to the additional effect, in using the area-based approach, for differing specification of the ALSC zones, resulting from the individual planner's biases.

6. "Can the plan be made flexible and responsive to questionable model assumptions about the future?"

When faced with a range of possible future development, the accepted approach has been to perform a sensitivity analysis. Because of the differences in system size and execution requirements, Timber RAM and MUSYC would allow sensitivity analysis in certain situations where such an exercise with FORPLAN would be prohibitively expensive. Apple (1982), in a survey of FORPLAN users, found that 79 percent reported sensitivity analysis to be important, but only 33 percent reported using the technique, primarily because of time and budget constraints.

7. "Is the model large enough to recognize most of the pertinent data?"

The system with the simplest data structure, Timber RAM, with some extension to array sizes, is capable of performing the analysis required to meet the haul cost/spatial distribution objective. MUSYC and FORPLAN have additional constraint and analytical capabilities, which are not required to develop a planning tool to meet the stated objective. The effect of using the more complex structures would be to incorporate additional computational requirements, increasing the computational cost and possibly exceeding the capacity of the LP code to determine a solution.

8. "Is the planning model understandable or viewed as a black box?"

Timber RAM model structure, because of the fewer constraint capabilities, is simpler than MUSYC. MUSYC is less complex than FORPLAN because of the additional area-based approach constraints. Of the three systems, Timber RAM requires the least adaptation by new users to their concept of forest dynamics and management planning procedures.

9. "Does the model deal effectively with uncertainty aspects?"

The effect of uncertainty is generally addressed with sensitivity analysis, as previously discussed. Timber RAM would be the least costly to use in testing factors by sensitivity analysis.

10. "Is the model transferable to other users?"

Transferability to other users implies the capability to make model runs, as well as the ability to generate on-site understanding of the model. As discussed, the simpler structure of Timber RAM and MUSYC represents a more transportable code, with smaller computational requirements than FORPLAN. As well, documentation of Timber RAM and MUSYC is more complete. FORPLAN, because of model complexity, has required a large time and economic committment, as well as off-site user support to undertake model runs.

11. "Does the model allow for adjustments to specific situations?"

Each of the three models can readily reflect different locations. It would likely be desirable to customize or localize the reporting of the results to reflect the individual management concerns. The complexity of such modifications would again increase from Timber RAM to MUSYC to FORPLAN.

12. "Can model results help evaluate specific alternatives not recognized in the model?"

Modifications to the systems to reflect specific user requirements or planning situations vary in difficulty. This again refers back to system size. Timber RAM and MUSYC, being considerably smaller than FORPLAN, would be less demanding to customize. FORPLAN size and complexity would not favour modifications by users.

SYSTEM CHOICE

The decision to use Timber RAM for the spatial problem resulted from the desire to use the simplest model structure which was able to adequately represent the desired spatial resolution. The evaluation showed Timber RAM to have advantages over MUSYC and FORPLAN with respect to feasibility (problem size), transferability (program size and complexity) and the ability to consider questionable assumptions regarding the future (sensitivity analysis).

MUSYC and the strata-based approach of FORPLAN, in defining sub-forest constraints, were identified to impose further computational burdens. The sub-forest constraints, not being specifically required in the spatial problem, were considered an unnecessary increase in both problem and program complexity. Whether the increase in problem size can remain computationally feasible while specifying both access timing and sub-forest constraints will remain for further study.

FORPLAN used with the area-based and mixed area- and strata-based approaches was initially considered the ideal choice. However, two problems were identified with the area-based approaches, and resulted in the decision against using FORPLAN. First, defining CAC for each ALSC zone (area-based approach) constituted the original problem, that of determining the optimal management schedule. Second, specifying allocation choices for strata within each zone (mixed area- and strata-based approach) resulted in decision variables and land accounting for each ALSC zone, a greater problem size than only land accounting as would be required with Timber RAM. Thus, the area-based or mixed area- and strata-based approaches of FORPLAN would not be appropriate.

CHAPTER 2

METHODS

This chapter describes the approach designed to address the spatial problem in timber management planning. First, a mathematical model of the spatial problem is presented. This is followed by a description of the "management planning algorithm", which provides a framework for integrating spatial analysis with the mathematical model.

MATHEMATICAL STRUCTURE

The following mathematical structure reflects the addition of timing of access variables and constraints, and periodic minimum harvest levels by species, to the structure and notation of Walker and Lougheed (1985).

Variables and Data

Several possible treatment regimes are defined for each stand class. A stand class is a collection of individual stands considered to have similar biological and economic attributes, while a treatment regime is a sequence of silvicultural treatments applied to a stand class from clearcut to final harvest. Each alternative assignment of a treatment regime to a stand class defines a decision variable. The level of a decision variable is the area, in hectares, of a particular stand class assigned to that treatment regime.

Composite variables are used to reflect harvest volume flow constraints and accessibility restrictions. The objective and constraint functions use the data element notation shown in Table 1, and the decision and composite variable notation shown in Table 2.

Objective Functions

Optimization of the harvest volumes and management costs requires that equations representing these values over the length of the critical period be defined.

Table 1. Data elements.

Name	Notation	Function
Stand class area	a_i	Initial area of stand class i (ha)
Area accessibility	ac_{ik}	Percentage of stand class i accessible in period k, where k=1, 2, ... tr_i
Timing of access for treatment	b_{ijk}	1.0 if stand class i assigned to regime j produces volume in period k; 0.0 otherwise
Treatment cost	c_{ijk}	Cost ($) incurred in period k from each hectare of stand class i assigned to regime j
Current harvest level	hc	Current harvest level from forest area (m^3/5 years)
Current-initial lower flow tolerance	hcl	Maximum percentage decrease in harvest level from present level to first planning period
Current-initial upper flow tolerance	hcu	Maximum percentage increase in harvest level from present level to first planning period
Periodic lower flow tolerance	hpl_k	Maximum percentage decrease in harvest level from period k-1 to period k, where k = 2, 3, ... tp
Periodic upper flow tolerance	hpu_k	Maximum percentage increase in harvest level from period k-1 to period k, where k = 2, 3, ... tp
Number of stand classes	m	Initial number of stand classes
Number of regimes	n	Initial number of silvicultural regimes
Periodic harvest levels	ph_{kl}	Minimum harvest volume of species l in period k, where l = 1, 2, 3
Discount rates	rc	Real (deflated) discount rate for costs
Critical period length	tz	Number of planning periods for which objective functions are in effect

Table 1. (Continued).

Name	Notation	Function
Planning horizon	tp	Number of planning periods in problem
Last period of restricted access	tr_i	Last period in which only a percentage of stand class i may be assigned to a management regime
Last period of constrained species harvest volume	ts_l	Last period in which minimum harvest levels for species l are in effect, where l = 1, 2, 3
Species harvest volume	s_{ijkl}	Volume (m^3) of species l harvested in period k from each hectare of stand class i assigned to regime j, where l = 1, 2, 3
Total volume	v_{ijk}	Total volume (m^3) harvested in period k from each hectare of stand class i assigned to regime j
Minimum volume	z	Minimum total volume (m^3) obtained from all periods of the critical period

Table 2. Decision and composite variables.

Name	Notation	Definition
Management variables	X_{ij}	Area (hectares) of stand class i assigned to regime j
Accessibility variables	AC_{ik}	Area of stand class i accessed in period k, where k=1, 2, ... tr_i, and tr_i is the last period in which only a percentage of stand class i may be assigned to a management regime
Periodic harvest level variables	HP_k	Total harvest level (m^3) from all stand classes in period k, where k=1, 2, ... tp, and tp is the number of planning periods in the problem

Maximize Volume

Maximization of the volumes harvested (from clearcut harvests and commercial thinnings) from all stand classes during the critical period has the form

$$\text{Maximize} \quad \text{VOLUME } (m^3/tz \text{ periods}) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tz} v_{ijk} * X_{ij} \ . \qquad [1]$$

Minimize Cost

Minimization of the discounted treatment costs incurred in all stand classes during the critical period has the form

Minimize

$$\text{COST } (\$/tz \text{ periods}) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tz} c_{ijk} * X_{ij} / (1+rc)^{5k-2.5} \ . \qquad [2]$$

The exponent used for discounting reflects the assumption that all treatment costs are incurred at the midpoint of each planning period.

Constraint Functions

Constraint functions are abstractions of biological, physical and economic limitations.

Composite Variable Definitions

The composite variables AC_{ik} and HP_k are defined as

$$AC_{ik} = \sum_{j=1}^{n} b_{ijk} * X_{ij} \ , \text{ for } i=1, 2, \ldots m \text{ and } k=1, 2, \ldots tr_i \ , \qquad [4]$$

and

$$HP_k = \sum_{i=1}^{m} \sum_{j=1}^{n} v_{ijk} * X_{ij} \ , \text{ for } k=1, 2, \ldots tp \ . \qquad [5]$$

Physical Constraint Functions

Physical constraint functions reflect limits on the available area of each stand class, and on the minimum total harvest volume to be produced during the critical period.

Area Availabilities. These constraint functions (one for each initial stand class) ensure that the total area of each initial stand class assigned to the various regimes does not exceed the total available area of that stand class. These have the form

$$\sum_{j=1}^{n} X_{ij} \leq a_i \text{ , for } i=1, 2, \ldots m \text{ .} \qquad [6]$$

Area Accessibilities. These constraint functions (up to five for each stand class) restrict, by period, the area accessible for management activities. This permits increasing the area available for management activities as road networks reach previously inaccessible locations. These have the form

$$AC_{ik} \leq ac_{ik} \cdot a_i \text{ , for } i=1, 2, \ldots m \text{ ; } k=1, 2, \ldots tr_i \text{ .} \qquad [7]$$

Minimum Volume Level. This constraint function ensures that the total volume level produced from harvests occurring during the critical period are at least equal to a specified minimum volume level. This constraint function links the two objective functions by specifying the volume level for which the cost objective is optimized. It has the form

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tz} v_{ijk} \cdot X_{ij} \geq z \text{ .} \qquad [8]$$

Flow Constraint Functions

Flow constraint functions restrict fluctuations in harvest levels among planning periods. Two series of these are defined.

Current-Initial Harvest Levels. These constraint functions restrict harvest levels in the first planning period to a percentage range above and below the current, or present, harvest level. Increases from the current harvest level are restricted by

$$HP_1 \leq (1+hcu) \cdot hc \ . \qquad [9]$$

Decreases from the current harvest level are restricted by

$$HP_1 \geq (1-hcl) \cdot hc \ . \qquad [10]$$

Sequential Harvest Levels. Moderation of harvest level fluctuations during the planning horizon is achieved by restricting harvest levels in each period to a percentage range above and below the harvest level in the preceding period. Increases to harvest levels are restricted by

$$HP_k \leq (1+hpu_k) \cdot HP_{k-1} \ , \text{ for } k=2, 3, \ldots tp \ . \qquad [11]$$

Decreases to harvest levels are restricted by

$$HP_k \geq (1-hpl_k) \cdot HP_{k-1} \ , \text{ for } k=2, 3, \ldots tp \ . \qquad [12]$$

Periodic Harvest Levels. Minimum species volume requirements for specified periods are restricted by

$$\sum_{i=1}^{m} \sum_{j=1}^{n} s_{ijkl} \cdot X_{ij} \geq p_{kl} \ , \text{ for } k=1, 2 \ldots ts_l, \text{ and } l = 1, 2, 3 \ . \qquad [13]$$

Linear Programming Structure

Two LP formulations, volume maximization and cost minimization with constrained volume production, are used.

Volume Maximization

The volume maximization formulation is used to identify the capacity of the forest, under each of the alternative roading options, to produce total harvest volume during the critical period. No constraint functions are placed on the cost of attaining this volume, so that a measure of the effectiveness of the set of management regimes for producing volume is obtained.

The volume maximization formulation is

Maximize

$$\text{VOLUME } (m^3/tz \text{ periods}) = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tz} v_{ijk} * X_{ij} \text{ ,} \qquad [1]$$

subject to

$$\sum_{j=1}^{n} (b_{ijk} * X_{ij}) - AC_{ik} = 0.0 \text{ , for } i=1, 2, \ldots m \text{ and } k=1, 2, \ldots tr_i \qquad [4]$$

$$HP_k - \sum_{i=1}^{m} \sum_{j=1}^{n} v_{ijk} * X_{ij} = 0.0, \text{ for } k=1, 2, \ldots tp \text{ ,} \qquad [5]$$

$$\sum_{j=1}^{n} X_{ij} \leq a_i \text{ , for } i=1, 2, \ldots m \text{ ,} \qquad [6]$$

$$ACi_k \leq ac_{ik} * a_i \text{ , for } i=1, 2, \ldots m \text{ ; } k=1, 2, \ldots tr_i \text{ ,} \qquad [7]$$

$$HP_1 \leq (1+hcu) * hc \text{ ,} \qquad [9]$$

$$HP_1 \geq (1-hcl) * hc \text{ ,} \qquad [10]$$

$$HP_k - (1+hpu_k) * HP_{k-1} \leq 0.0, \text{ for } k=2, 3, \ldots tp \text{ ,} \qquad [11]$$

$$HP_k - (1-hpl_k) * HP_{k-1} \geq 0.0, \text{ for } k=2, 3, \ldots tp \text{ ,} \qquad [12]$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} s_{ijkl} * X_{ij} \geq ph_{kl} \text{ , for } k=1, 2 \ldots ts_l, \text{ and } l = 1, 2, 3 \text{ ,} \qquad [13]$$

$$X_{ij} \geq 0.0, \text{ for } i=1, 2, \ldots m; j=1, 2, \ldots n \text{ .} \qquad [14]$$

Equation [14] describes a set of non-negativity constraint functions, which ensure that all decision variables are assigned non-negative values.

Cost Minimization

The cost minimization formulation is used to identify the lowest-cost strategy for achieving a particular total harvest volume during the critical period. The cost minimization formulation is employed, under each of the alternative access options, after the volume maximization formulation. The maximum volume level from the first formulation is established as the required volume level, and the minimum-cost strategy for attaining this level is determined. A measure of the efficiency of the set of management regimes for producing volume may be obtained by successive LP runs constrained to progressively lower volume levels. The result of this series of LP runs is a set of independent volume-cost tradeoff points and associated timber management strategies.

The formulation is

Minimize

$$\text{COST (\$/tz periods)} = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tz} c_{ijk} \cdot X_{ij} / (1+rc)^{5k-2.5} \ , \qquad [2]$$

subject to

$$\sum_{j=1}^{n} (b_{ijk} \cdot X_{ij}) - AC_{ik} = 0.0 \ , \text{ for } i=1,\ 2,\ \ldots\ m \text{ and } k=1,\ 2,\ \ldots\ tr_i , \qquad [4]$$

$$HP_k - \sum_{i=1}^{m} \sum_{j=1}^{n} v_{ijk} \cdot X_{ij} = 0.0, \text{ for } k=1,\ 2,\ \ldots\ tp\ , \qquad [5]$$

$$\sum_{j=1}^{n} X_{ij} \le a_i \ , \text{ for } i=1,\ 2,\ \ldots\ m\ , \qquad [6]$$

$$AC_{ik} \le ac_{ik} \cdot a_i, \text{ for } i=1,\ 2,\ \ldots\ m\ ;\ k=1,\ 2,\ \ldots\ tr_i\ , \qquad [7]$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{tc} v_{ijk} \cdot X_{ij} \geq z \ , \qquad [8]$$

$$HP_1 \leq (1+hcu) \cdot hc \ , \qquad [9]$$

$$HP_1 \geq (1-hcl) \cdot hc \ , \qquad [10]$$

$$HP_k - (1+hpu_k) \cdot HP_{k-1} \leq 0.0, \text{ for } k=2, 3, \ldots tp \ , \qquad [11]$$

$$HP_k - (1-hpl_k) \cdot HP_{k-1} \geq 0.0, \text{ for } k=2, 3, \ldots tp \ , \qquad [12]$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} s_{ijkl} \cdot X_{ij} \geq ph_{kl} \ , \text{ for } k=1, 2 \ldots ts_l, \text{ and } l = 1, 2, 3 \ , \qquad [13]$$

$$X_{ij} \geq 0.0, \text{ for } i=1, 2, \ldots m; \ j=1, 2, \ldots n \ . \qquad [14]$$

MANAGEMENT PLANNING ALGORITHM

Because of the scale and complexity of the spatial problem, implementing the mathematical structure requires use of a management planning algorithm (Figure 1).

The algorithm consists of two primary activities, data acquisition and simulation. The following sections describe the routines to implement the data acquisition and simulation components of the management planning procedure.

Data Acquisition

Two levels of data are required by the planning algorithm. Strata data are required for each of the recognized stand classes. Forest data are required from the forest as a whole. Both strata and forest data are comprised of temporal and spatial components. The spatial data components, of primary interest in this study, are derived using a haul cost algorithm developed by the author. Data acquisition culminates with stratification of the forest area into stand classes, based upon temporal and spatial data components.

Forest Data

Forest-level objectives and constraints are derived from the physical and economic requirements of the organization managing the forest property. Temporal data required are the total volume and cost objectives and constraints on total volume harvest flows. The specific temporal data elements are: current harvest level; minimum volume by species; current-initial and periodic total harvest flow tolerances; critical period length; and planning horizon length.

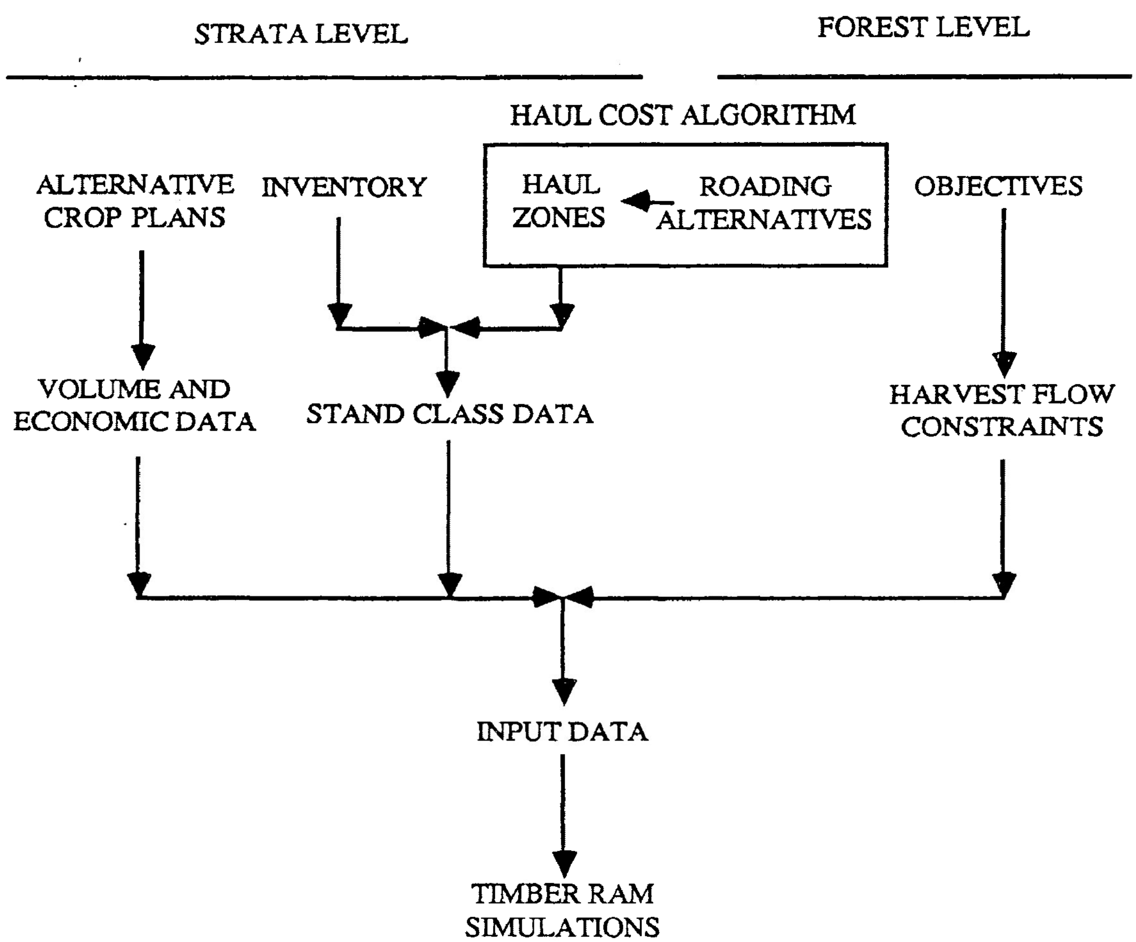


Figure 1. Management planning algorithm.

Spatial data are digital maps containing roading alternatives for five periods into the future. Procedures suggested for designing roading alternatives vary from subjective placement to optimal road location (Weintraub and Navon, 1976; Jones *et al*., 1986; Kirby *et al*., 1986). The procedure chosen should reflect the objectives of the specific planning situation. Roading alternatives, designed in a forest-level context, are the basis for determining transportation costs.

Strata Data

Strata data include: inventory data from aggregates of individual stands; alternative crop plans; and volume and economic data.

Temporal Data Elements. The temporal data elements are the age-dependent harvest costs and harvest volumes.

A fundamental task in performing a wood availability analysis is to forecast present and future stand class development. Normally, several alternative futures exist for each present stand class, with each requiring different types, timing or intensities of silvicultural treatments.

Volume development curves reflect the growth and yield of a stand class over time in response to a silvicultural regime. Development curves for different stand classes are derived using different calculation procedures (or estimation procedures in the case of expected yield from future stand classes), according to the requirements of the organization performing the analysis.

Roadside harvest cost curves (transforming standing timber to piles at roadside) are calculated for each stand class according to the requirements of the organization.

Spatial Data Elements. The spatial data elements of the mathematical structure associated with stand class data are: area; area accessibility; timing of access for management activity; and the last period of restricted access. These are derived using the haul cost algorithm described below.

The haul cost algorithm bridges the gap between strata and forest level data, as shown by the boxed area in Figure 1. The means of representing the spatial dimension in the planning process is to use zones of equivalent haul cost (haul zones) as one of the attributes for stratifying the forest into stand classes. Forest level roading alternatives in the location and timing of future road construction impact on the amount of area in each stand class.

The haul cost algorithm, Figure 2, is implemented using two CPL (Command Processing Language) routines (Landy, 1986). The first routine, DEFBAT.CPL, creates a CONTROL file. The second routine, HAULCOST.CPL, performs the haul cost analysis according to the specifications in the CONTROL file. The coding for both routines is provided in Appendix I.

Executed as an interactive program, DEFBAT.CPL prompts the user for the data listed in Table 3. A detailed description of the map coverages (digital maps and associated attribute files) is given in Table 4. The routine verifies existence of the required coverage files. If an error is found, a message is given indicating the error. Non-fatal errors return to the original prompt, while fatal errors exit from the routine. Once verified, the data are written to the CONTROL file.

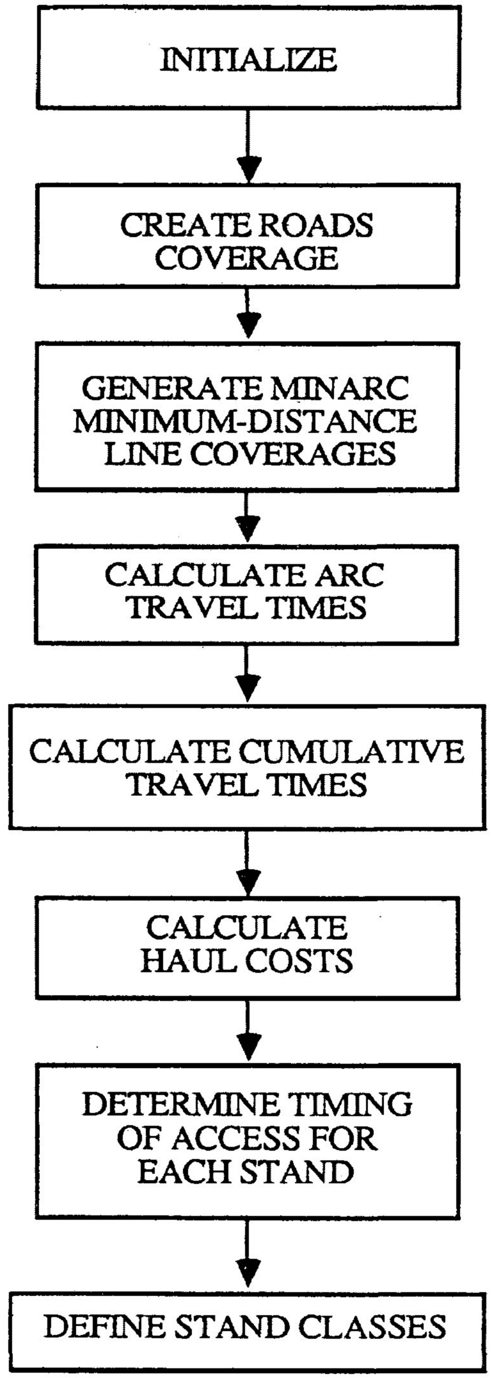


Figure 2. Haul cost algorithm.

Table 3. Data requirements.

Data	Format	Comments
ROAD	map coverage	One map of all roads for 5 five-year planning periods
STAND	map coverage	Up to 20 forest stand maps
INVENTORY FILE	attribute file	Name of up to 20 files containing STAND attributes
RELATE ITEM	name	One item name common for each STAND and INVENTORY file
BARRIER	map coverage	Up to 20 polygon coverages of physical barriers to access
SEARCH TOLERANCE	number	The maximum distance from a stand to the nearest road for access to be achieved
HAUL SPEED	number	Up to five classes of road assigned a haul speed (km/h)
ACCESS POINTS	number	Two-way travel time between up to five access points and haul destination(s)

Table 4. Map coverage descriptions.

Coverage	Description
ROADS	Line coverage. Two-digit code to indicate the period first available and road class. For example, "25" identifies a class 5 road available in period 2.
STAND	Polygon coverages. An INVENTORY file must contain the stand attribute data, linked by the RELATE ITEM.
BARRIER	Polygon coverages. Normally a subset of STAND coverages, i.e. lakes and two-line (major) rivers. Two-line rivers must break at a bridge or a planned bridge. Islands, or "donuts" within barrier polygons result in errors, and must be removed from the barrier coverages.

HAULCOST.CPL performs the data manipulations required to attach the haul cost and time of access attributes, for each stand in the forest, to an INVENTORY file. The procedure used to implement the algorithm outlined in Figure 2 is as below.

1. Initialize. Read coverage and numeric data from the CONTROL file.

2. Create road coverages. Create coverages representing the road networks as they would exist during five periods in the future (ROAD1 through ROAD5). The ROAD coverage is coded to enable extracting of the roads existing during each period. Extraction is made using the ARC ARCEDIT utility (ESRI, 1987).

3. Generate minimum-distance line coverages. Line coverages MINARC1 through MINARC5 are created containing: all ROAD arcs existing in that period; the associated MINDST arcs; all intersected BARRIER polygons. This step is completed using the Fortran-77 standard program MINARC.F77 (Appendix I). The program reads the required coordinates from the input coverages, calculates the minimum distance arcs, removes barriers, and prints all MINDST arc endpoint coordinates to scratch files (MINDST1 for ROAD1, MINDST2 for ROAD2 etc.). The scratch files are input to the ARC GENERATE utility which creates the ARC/INFO coverages MINARC1 through MINARC5.

If the distance between a stand and the nearest road is greater than the search tolerance, the stand is considered inaccessible at that time. With a fine road network, a small search tolerance is applicable, whereas roading corridors require a large search tolerance to approximate construction of access roads. Sections of the MINDST arcs which intersect BARRIER polygons are deleted, with hauling assumed to be along the perimeter of the BARRIER polygon. To link the MINARC and STAND coverages, each of the minimum distance arcs in the MINARC coverages is assigned the same id as the associated stand polygon.

4. Calculate arc travel times. Arc travel times are assigned to each arc in the five MINARC line coverages. The travel times are dependent on the arc length and the haul speed, with the haul speed determined by the road class. INFO (Henco Software, 1985) processing is used for calculating arc travel times and assigning these times as the impedance or "cost" of travelling the arc.

5. Calculate cumulative travel times. Calculate the minimum cumulative time required to travel from a forest access point to each arc in the network. The ARC ALLOCATE utility (ESRI, 1987) is used to perform this procedure. ALLOCATE determines the minimum-impedance path from the access points to each arc in the network, storing the cumulative impedance (time) as an attribute of each arc. INFO processing is used to add the two-way travel time between the mill and the forest access point for each stand.

6. Calculate haul costs. Calculate the haul cost ($\$/m^3$) from the cumulative haul time of each arc in the five MINARC coverages. This procedure is performed only for those MINDST arcs associated with a stand in one of the STAND coverages. Haul cost is a function of the time required for a round-trip haul and the hourly labour (regular time, overtime) and machine rates (tractor and trailer). The INFO program COST (Appendix I) accesses the cumulative impedance attributes in the MINARC coverage, calculates the haul costs, and writes the stand identifier and

haul cost to a temporary file. Five temporary files are created, MINARC1.TAB through MINARC5.TAB.

7. Determine timing of access for each stand. Determine the period at which the haul cost first reaches a minimum. This period is considered as the time of first access. The period and the associated haul cost are written as attributes to the appropriate INVENTORY file. This procedure is implemented in INFO, using both interactive and program formats. The interactive sections relate the MINARCx.TAB files with the STAND coverage, which, in turn, is related to the INVENTORY file. The INFO program TRANSFER (Appendix I) calculates, from the MINARCx.TAB files, the period of first access, and the associated haul cost for each stand in the STAND coverages. The resulting minimum cost period (MCP) and minimum cost (MC) for each arc are written as attributes to the INVENTORY file.

8. Determine stand class areas. Stand class areas are calculated using the inventory map coverages maintained on the GIS. INFO reports are used to perform the stratification based on haul zone, stratum, and age class. The stratified areas are subsequently used in simulation.

Simulation

Simulation consists of implementing the mathematical structure within the modified Timber RAM framework to determine alternative solutions to the spatial problem. The flowchart of Timber RAM activities, Figure 3, depicts the three "steps" of a simulation run. First, the matrix generator accepts the input data and generated the LP input matrix. Second, the LP package "XMP" (Marsten, 1986) accepts the

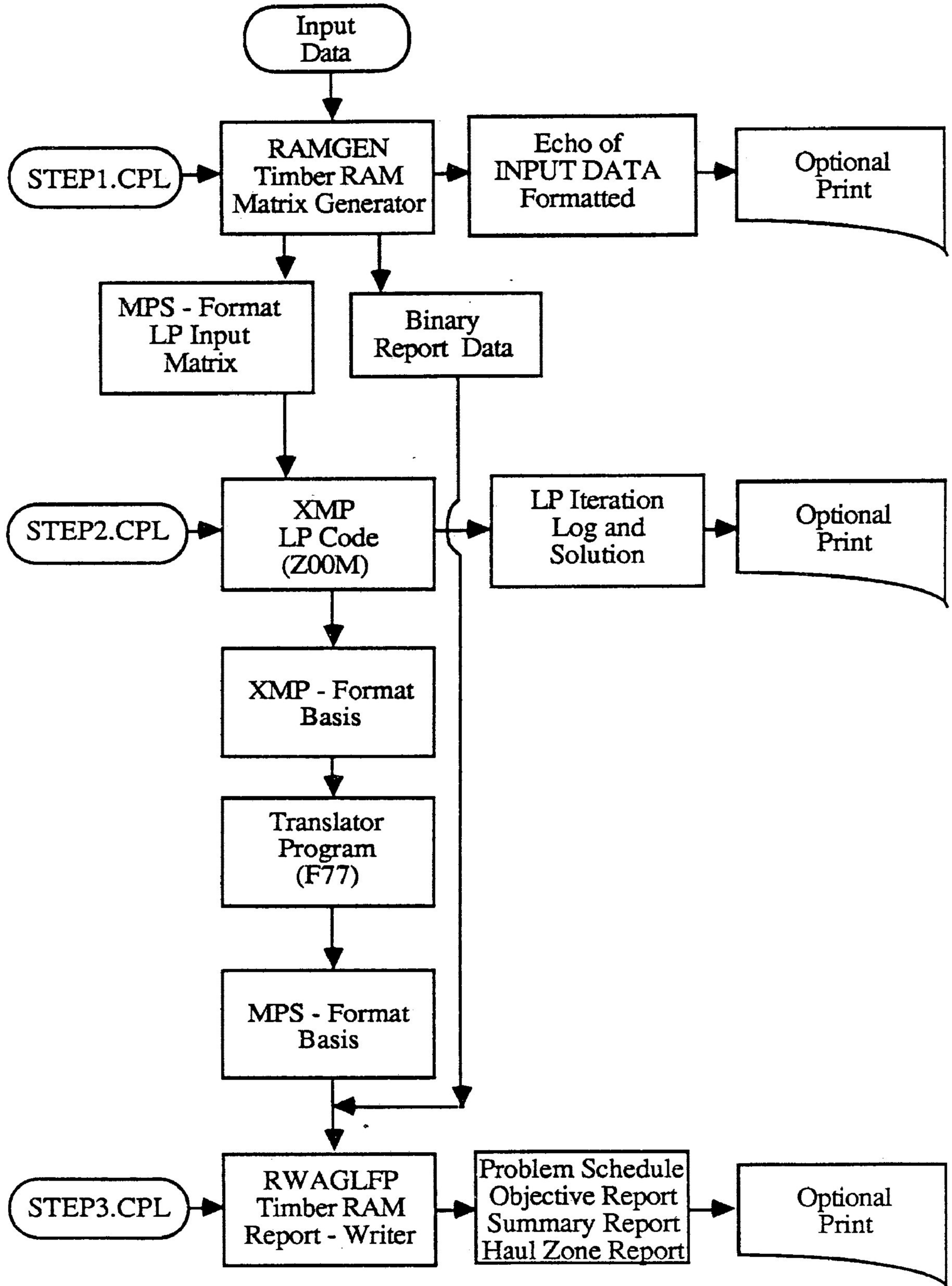


Figure 3. Timber RAM simulation steps (after Navon, 1971).

input matrix and uses the Simplex Method to calculate an optimal solution (basis). The report-writer translates the basis (and binary datafiles created by the matrix generator) into a more readable solution, and generated reports on volume and economic development.

Changes to the original Timber RAM program structure were required to permit three volume development curves for each stand class. By including species composition in the analysis, species-specific volume constraints are available, in addition to flow constraint of total volume. The species volume constraints are used to ensure minimum volume requirements by species, by period. The report-writer was modified to provide reports of harvest volume by species, and harvest area totals by haul zone. The modifications are specific to the requirements of the Case Study, but indicate the type of analysis possible with program modifications.

CPL programs are used to control program execution and file management. The CPL programs used for making the simulation runs are provided in Appendix II.

CHAPTER 3

CASE STUDY

The case study provided an opportunity to implement the management planning algorithm to assess the potential of the linked GIS/Timber RAM approach in addressing the spatial problem.

A 980 km^2 project area (14 km by 70 km) was located approximately 73 km from Thunder Bay, Ontario. The area consisted of approximately 66 500 ha of productive forest land (potentially harvestable). Working Groups (Ontario Ministry of Natural Resources (OMNR), 1986) represented were: spruce (*Picea glauca* (Moench) Voss and *Picea mariana* (Mill.) B.S.P.) and balsam (*Abies balsamea* (L.) Mill.) (60 percent); jack pine (*Pinus banksiana* Ait.) (20 percent); aspen (*Populus tremuloides* Mitchx.) and birch (*Betula papyrifera* Marsh.) (20 percent). A small stand (16 ha) of red pine (*Pinus resinosa* Ait.) was not used in the analysis. The project area was a portion of the Dog River - Mattawin Forest, a 6 773 km^2 area of Crown Land managed by Great Lakes Forest Products Ltd. (GLFP) under a Forest Management Agreement (OMNR, 1985).

This chapter first describes the procedures for acquiring and/or deriving the data required to perform the analysis described for the management planning algorithm. The simulations performed are then described, followed by a summary of the simulation results. The case study thus illustrates one type of analysis possible using the management planning algorithm.

DATA ACQUISITION AND DERIVATION

The primary source of data was GLFP. GLFP staff provided data either from direct measurement or, when not readily available, from subjective estimates. The following sections describe the data acquisition and derivation procedures used for strata and forest data, as described in the management planning algorithm.

Roading Alternatives

As defined in the mathematical structure, restricted access was permitted for five 5-year periods. The 25-year time period corresponded to the reasonable length of time for which roading forecasts could be made in management planning.

Roading consisted of alternatives in the location and/or timing of road construction. Two roading alternatives were defined for the project area. Network 1 (258 km of roads) was acquired from GLFP records (GLFP, n.d.), along with estimates of the proposed areas to be harvested, with no road construction planned for Period 5. Network 2 (238 km of roads) was contrived, save for the two Class 2 roads in existence in Period 1. The objective of defining this alternative was to assess the effects of an alternative access option on sustainable harvest levels, costs and treatment schedules.

Search Tolerance

Observations from GLFP records indicated that access roads were rarely built more than 1600 metres from the secondary gravel roads (defined later as Class 4 roads). The search tolerance was therefore 1600 metres.

Haul Speeds and Access Points

Road class haul speeds were obtained from GLFP for each road class. The haul speeds are provided in Table 5. The haul speeds were used for calculating haul times between forest access points and stand label points.

Forest access points were identified on the forest stand maps. The distance from the mill to the access point was measured from 1:250000 topographic maps, and the total time required for two-way travel between the mill and the access point was calculated. The total time included all fixed time requirements (fueling, loading, unloading, weigh scales and check points) and variable travel time (function of distance and rate of travel). The forest access point data is given in Table 6.

Preliminary Area Stratification

A preliminary stratification was used to assess requirements for age-dependent volume and economic data. The strata chosen in consultation with GLFP staff were Site Class (Plonski, 1981) by Working Group (OMNR, 1986). Ten strata were recognized, and are defined in Table 7.

An INFO report was used to determine the amount of area by age class in each stratum. If, in consultation with GLFP staff, the area in any particular stratum would have been too large, or the volume and

Table 5. Haul speeds by road class.

Road Class	Haul Speed (km/h)	Description
1	80	Paved highway
2	80	Paved primary
3	65	Gravel primary
4	50	Gravel secondary
5	20	Gravel tertiary
Access	10	Temporary access

Table 6. Forest access point data.

Access Point	One-way Distance (km) Class 1	Class 3	Two-way Time (min)	Fixed Time (min)	Total Time (min)
1	73.0	0.0	110	108	218
2	111.3	0.0	167	108	275
3	60.6	37.8	161	108	269
4	131.3	9.6	215	108	323

Table 7. Stratum definitions.

Stratum Name	Description	
S1a	spruce and balsam	Site Class 1a
S1	Working Groups	1
S2		2
S3		3
P1	jack pine	Site Class 1
P2	Working Group	2
P3		3
A1	aspen and birch	Site Class 1
A2	Working Groups	2
A3		3

economic yield for the area within the stratum too variable, further stratification would have been required. The ten strata above were considered appropriate.

Alternative Treatment Regimes

Alternative treatment regimes for each stratum were developed by GLFP staff (Tables 8 to 10). The regimes described a range of possible management action for each stratum, from minimum (no post-cut intervention) to maximum (scarify, plant, herbicide treatments, and commercial thinning).

Volume Development Data

For each stratum, volume development curves were required. Pure species development curves for fully stocked pure species stands, Tables 11 to 13, were obtained from GLFP staff, and were based on Plonski (1981). The development curves acquired from GLFP had maximum ages of 150 for spruce and 100 for pine and aspen. Stand decline for spruce was assumed to be linear from the volume at age 150 to 0 m^3/ha at age 200. The linear rate of decline was also assumed for pine and aspen, from the volume at age 100 to 0 m^3/ha at age 150.

Table 8. Treatment regimes for the spruce strata (S1a, S1, S2, S3).

Present						Future	
Site Class	First/Last Harvest (years)	Treatments (years)[1] 1-5	6-10	26-30	31-35	Yield Curve[2]	Harvest Age (years)
1a	55 / 150	P,He	He		T	sP1	40,50
		Pg,He	He	T		sP1+	35,50
1	75 / 150					A2	75,95
		P				s1	55,75
		P,He				s1a	50,65
		P,He	He		T	sP1	45,55
		Pg,He	He	T		sP1+	35,50
2	90 / 150					S3	90,110
		P				s1	60,80
		P,He				s1a	55,75
		Pg,He	He		T	sP1	50,60
3	90 / 150					S3	100,120
		P				s2	80,100

[1] - P - scarify and plant
Pg - scarify and plant genetically improved stock
He - herbicide treatment
T - commercial thin

[2] - s1a - spruce Site Class 1a
s1 - spruce Site Class 1
s2 - spruce Site Class 2
s3 - spruce Site Class 3
A2 - aspen Site Class 2
sP1 - Type 1 spruce plantation
sP1+ - Type 1+ spruce plantation
S3 - spruce stratum, Site Class 3

Table 9. Treatment regimes for the pine strata (P1, P2, P3).

Present						Future	
Site Class	First/Last Harvest (years)	Treatments (years) 1-5	6-10	11-15	31-35	Yield Curve[2]	Harvest Age (years)
1	55 / 100					P2	65,85
		Sa				p1	55,65
		Sa		Sp		pP1	50,65
		Sc	He			pP1	45,60
		P	He		(T 26-30)	pP1	40,55
		Pr	He		T	prP	45,55
		Pg,He	He		T	pP1+	40,60
2	65 / 90					P3	75,95
		Sa				p2	65,75
		Sa		Sp		p1	55,65
		Sc	He			p1	50,60
		P				p1	45,55
		Pr	He		T	prP	40,55
		Pg,He	He		T	pP1+	40,60
3	75 / 90	Sa				p3	75,85
		Sc				p2	65,75
		P				p1	55,65

[1] - P - scarify and plant jack pine
Pr - scarify and plant red pine
Pg - scarify and plant genetically improved stock
Sa - aerial seed jack pine
Sc - spacing-controlled seed jack pine
He - herbicide treatment
Sp - spacing
T - commercial thin
T(26-30) - commercial thin at age 26-30

[2] - p1 - jack pine Site Class 1
p2 - jack pine Site Class 2
p3 - jack pine Site Class 3
pP1 - Type 1 jack pine plantation
pP1+ - Type 1+ jack pine plantation
prP - red pine plantation
P3 - pine stratum, Site Class 3

Table 10. Treatment regimes for the aspen strata (A1, A2, A3).

Present						Future	
Site Class	First/Last Harvest (years)	Treatments (years) 1-5	6-10	11-15	31-35	Yield Curve[2]	Harvest Age (years)
1	35 / 100					a1	100
			Sp			a1+	80
2	40 / 90					A2	65,85
		P,He	He			s1a	50,65
		Pg,He	He		T	sP1	40,50
		P,He	He			p1	55,65
		Pg,He	He		T	pP1	40,55
3	55 / 80					A3	75,95
		P,He				s1a	45,55
		P,He			T	pP1	40,55
		Pg,He			T	pP1+	40,60
		Pr,He				prP	40,55

[1] - P - scarify and plant jack pine
Pr - scarify and plant red pine
Pg - scarify and plant genetically improved stock
He - herbicide treatment
Sp - spacing
T - commercial thin

[2] - p1 - jack pine Site Class 1
a1 - aspen Site Class 1
a2 - aspen Site Class 2
a3 - aspen Site Class 3
s1a - spruce Site Class 1a
pP1 - Type 1 jack pine plantation
pP1+ - Type 1+ jack pine plantation
prP - red pine plantation
A2 - aspen Site Class 2 stratum
A3 - aspen Site Class 3 stratum

Table 11. Spruce normal stand merchantable volumes (m^3/ha).

Age Class	Site Class s1a	s1	s2	s3	Plantation sP1	sP+1
20	0	0	0	0	34	37
25	11	0	0	0	95	105
30	34	0	0	0	148	163
35	69	23	0	0	200	220
35	69	23	0	0	140	150
40	110	40	0	0	200	220
45	148	58	0	0	260	286
50	182	75	0	0	313	344
55	214	93	0	0	340	374
60	242	111	21	0	366	403
65	268	128	36	0	384	422
70	292	146	53	0	405	446
75	313	163	71	0	418	460
80	333	179	88	25	442	486
85	351	195	104	38	454	499
90	366	210	119	50	464	510
95	380	225	134	62	473	520
100	392	238	146	74	481	529
105	402	250	158	84	488	537
110	411	261	169	94	494	543
115	418	271	179	103	499	549
120	424	279	187	111	503	553
125	429	285	195	118	506	557
130	434	289	201	124	508	559
135	438	292	206	129	505	556
140	441	294	211	133	502	552
145	444	295	214	137	498	548
150	446	296	217	140	492	541
155	401	266	195	126	443	487
160	357	237	174	112	394	433
165	312	207	152	98	344	379
170	268	178	130	84	295	325
175	223	148	109	70	246	270
180	178	118	87	56	197	216
185	134	89	65	42	148	162
190	89	59	43	28	98	108
195	45	30	22	14	49	54
200	0	0	0	0	0	0

Table 12. Pine normal stand merchantable volumes (m^3/ha).

Age Class	Site Class p1	p2	p3	Plantation pP	pP+1	prP
20	19	2	0	58	64	84
25	53	25	0	99	109	155
30	98	50	13	145	160	217
35	138	75	29	192	211	271
35	138	75	29	135	149	190
40	171	99	46	190	209	262
45	196	121	65	245	270	328
50	216	143	83	291	320	382
55	232	162	99	314	345	406
60	245	178	114	333	366	426
65	255	191	128	350	385	444
70	262	201	140	365	402	460
75	267	209	149	377	415	474
80	271	216	155	387	426	486
85	273	219	160	397	437	496
90	275	221	163	406	447	504
95	276	223	165	413	454	510
100	276	224	166	420	462	514
105	248	202	149	378	416	463
110	221	179	133	336	370	411
115	193	157	116	294	323	360
120	166	134	100	252	277	308
125	138	112	83	210	231	257
130	110	90	66	168	185	206
135	83	67	50	126	139	154
140	55	45	33	84	92	103
145	28	22	17	42	46	51
150	0	0	0	0	0	0

Table 13. Aspen normal stand merchantable volumes (m^3/ha).

Age Class	Site Class a1	a2	a3
20	29	11	0
25	68	33	3
30	112	66	16
35	160	107	34
35	160	107	34
40	203	150	58
45	241	190	87
50	275	224	118
55	304	253	154
60	328	277	183
65	349	297	203
70	365	312	218
75	377	324	227
80	386	333	234
85	393	339	238
90	398	344	239
95	401	344	239
100	403	344	236
105	363	310	212
110	322	275	189
115	282	241	165
120	242	206	142
125	201	172	118
130	161	138	94
135	121	103	71
140	81	69	47
145	40	34	24
150	0	0	0

From the preliminary stratification, volume development curves were required for ten strata. A stratum development curve was calculated using the stratum species composition (weighted average, by area) and the stratum density (weighted average, by area), Table 14, applied to the pure species curves. The procedure for calculating total volume was

$$V_{ij} = v_{ij} \cdot p_i \cdot s_j \qquad \text{for all ages } j,$$

where:

Vi_j = volume (m^3/ha) of species i in stratum at age j
v_{ij} = normal stand volume (m^3/ha) of species i at age j
s_j = decimal percent stand density of stratum at age j
p_i = proportion (decimal percent of total) of species i present in stratum over all ages.

Appendix III contains the stratum development curves used in the simulations. The component species volumes, also in Appendix III, were calculated for use in the modified Timber RAM framework, which allowed optimising, constraining and reporting on the harvest volume of each species.

Table 14. Weighted average species composition and stand density by stratum.

Stratum	Species Composition (percent)			Stand Density (percent)
	spruce	pine	aspen	
S1a	0.71	0.02	0.10	0.58
S1	0.76	0.07	0.07	0.59
S2	0.86	0.04	0.02	0.52
S3	0.85	0.01	0.00	0.50
P1	0.13	0.78	0.07	0.91
P2	0.19	0.63	0.14	0.85
P3	0.23	0.57	0.16	0.89
A1	0.22	0.00	0.04	0.40
A2	0.26	0.04	0.47	0.62
A3	0.26	0.12	0.44	0.74

Area-based Costs

The area-based costs ($/ha) were provided as estimates of costs by GLFP staff. These costs included $418/ha for scarification and planting, \$86/ha for herbicide treatments. Seeding costs were estimated by the author at \$200/ha for aerial and \$350/ha for controlled-spacing.

Volume-based Costs

Volume-based costs were comprised of harvest costs and haul costs. Age-dependent harvest costs for natural stands and plantations were calculated using the procedures described below which were developed by the author. Haul costs were calculated using the previously described haul cost algorithm (HAULCOST.CPL), also developed by the author.

Harvest costs. A mill gate sample of tree diameters and volumes (GLFP, 1987), Plonski's Normal Yield Tables (Plonski, 1981), and the GLFP Piecework Rate Schedule (GLFP, 1985) were available for determining harvest cost estimates. It was assumed that applying Plonski's number of trees per hectare at each age, to the GLFP rate schedule, at the average stand diameter, would provide reasonable estimates of the basic labour rate. The estimates developed by this method were found to exhibit anomalies which were attributed to the class interval of the average stand diameter. Because of these anomalies, and knowing that the rate schedule was a function of tree diameter, it was decided that the rate schedule should be applied to a diameter distribution at each age (essentially a stand table). The normal distribution was chosen for this purpose. Because the cost estimates were intended only to be reasonable, pursuing more precise alternative distribution types was not considered worthwhile.

The general form of the normal distribution, from Mendenhall (1979:190), is:

$$Z = (y - \mu) / \sigma$$

where:

Z = standardized normal distribution in standard deviations
y = value
μ = population mean
= population standard deviation.

The population mean and standard deviation were assumed to be approximated by the mill gate sample. The Coefficient of Variability (V) was calculated from the mill gate samples, and was used to estimate the standard deviation for the average stand diameters at each age. The calculated values of V were 0.3227 for black spruce, 0.2672 for jack pine and 0.262 for aspen.

The data elements used in describing the harvest cost calculation procedure are shown in Table 15.

Table 15. Data element definition for the harvest cost model.

d_i = stand average diameter at breast height at age i
N_i = number of trees per hectare at age i
v_i = gross merchantable volume (m^3/ha) at age i
k_i = number of diameter classes at age i
V = Coefficient of Variability

C_j = piece rate per tree ($) in diameter class j

l_j = lower bound of diameter class j
u_j = upper bound of diameter class j

n_{ij} = number of trees per hectare in diameter class j at age i
Z_{ij} = calculated Z value for diameter class j at age i
a_{ij} = area under normal curve between d_i and l_j or u_j of diameter class j at age i (from Table of Normal Curve Areas, Mendenhall, 1979:534)
p_{ij} = proportion of N_i in diameter class j at age i

Calculation of the proportion of N_i in each of the diameter classes at a particular age was done in one of three ways, depending on whether the diameter class was less then, equal to or greater than the average stand diameter. The calculations were:

$$\text{when } j < d_i : \quad Z_{ij} = \frac{\| l_j - d_i \|}{V * d_i}$$

$$a_{ij} = \text{tabular} \; (\; Z_{ij} \;)$$

$$p_{ij} = a_{ij} - a_{ij-1}$$

$$\text{when } j > d_i : \quad Z_{ij} = \frac{\| u_j - d_i \|}{V * d_i}$$

$$a_{ij} = \text{tabular} \; (\; Z_{ij} \;)$$

$$p_{ij} = a_{ij} - a_{ij+1} \qquad ; \text{ and}$$

$$\text{when } j = d_i : \quad Z_{ij1} = \frac{\| l_j - d_i \|}{V * d_i}$$

$$a_{ij1} = \text{tabular} \; (\; Z_{ij1} \;)$$

$$Z_{ij2} = \frac{\| u_j - d_i \|}{V * d_i}$$

$$a_{ij2} = \text{tabular} \; (\; Z_{ij2} \;)$$

$$p_{ij} = a_{ij1} + a_{ij2}$$

The formula for calculating the Basic Labour Rate ($\$/m^3$) was

$$BLR_i = \frac{\sum_{j=1}^{k} (\; C_j * N_i * p_{ij} \;)}{v_i} \qquad [15]$$

The Basic Labour Rate (BLR) was the labour cost of cutting the trees. Roadside harvest costs required addition of all charges from stumpside to the road. Table 16 lists the components of stump to roadside charges and the procedure used to calculate the age-dependent values. Four procedures were used: constant; interpolation; BLR curve; and regression. The constant procedure added to the BLR values at each age a constant cost per m^3. The remaining procedures added a calculated

Table 16. Stump to roadside harvest cost components for normal spruce, pine and aspen stands.

Component	Type[1]	Site Class	Spruce-fir ($\$/m^3$)	Pine and Aspen ($\$/m^3$)
Fringe benefits and sorting	C	1,2,3	0.347	0.347
Skidway and rigging	C	1,2,3	0.76	0.76
Cost of Living	I	1	0.30-0.18	0.30-0.18
		2	0.35-0.25	0.35-0.25
		3	0.45-0.32	0.45-0.32
Skidding	B	1	2.90-1.70	2.10-1.50
		2	3.60-2.40	2.25-1.95
		3	4.30-2.90	2.40-2.10
Slashing labour	I	1	1.20-1.00	1.20-1.00
		2	1.25-1.12	1.25-1.12
		3	1.30-1.20	1.30-1.20
Slashing equipment	I	1	1.25-1.00	1.25-1.00
		2	1.35-1.20	1.35-1.20
		3	1.50-1.35	1.50-1.35
Loading	R	1,2,3	-0.0204(age) + 1.814 $r^2 = 0.931$	

[1] - (I) Linear interpolation; (B) BLR curve rate; (R) Regression; (C) Constant

variable cost per m^3 to the BLR values at each age. The interpolation procedure assumed the first and second values (Table 16) corresponded to the youngest and oldest harvest ages respectively. The BLR curve procedure assumed the shape of the curve between the first and last values (Table 16) to be the same as the BLR curve. The regression procedure used the average stand diameter at each age and a regression of loading cost on diameter.

Natural stand harvest costs were calculated by the following procedure

$$HC_i = BLR_i + F + S + CL_i + SK_i + SL_i + SE_i + L_i \qquad [16]$$

where:

HC_i = roadside harvest cost ($\$/m^3$) at age i
BLR_i = basic labour rate ($\$/m^3$) at age i
F = fringe benefits ($\$/m^3$)
S = skidway construction and rigging costs ($\$/m^3$)
CL_i = cost of living allowance ($\$/m^3$) at age i
S_i = skidding costs ($\$/m^3$) at age i
SL_i = slashing labour costs ($\$/m^3$) at age i
SE_i = slashing equipment costs ($\$/m^3$) at age i
L_i = loading costs ($\$/m^3$) at age i.

Stratum harvest costs (Appendix III) were calculated as the weighted average harvest cost ($\$/m^3$) of the three component species at each age. The calculation procedure was

$$C_j = \left(\sum_{i=1}^{n} (v_{ij} * HC_{ij}) \right) / \sum_{i=1}^{n} v_{ij} \qquad \text{for all ages } j, \qquad [17]$$

where:

C_j = harvest cost ($\$/m^3$) of stratum at age j
HC_{ij} = harvest cost ($\$/m^3$) of species i at age j
v_{ij} = volume (m^3/ha) of species i at age j
n = number of species in stratum.

Plantation harvest costs were not readily available, nor was the natural stand procedure applicable to plantations because of the lack of average diameter data for the plantation development curves provided by GLFP staff. Plantation harvest costs were estimated as a proportion (based on volume) of the Site Class 1 harvest costs, which assumed the higher plantation yields resulted in lower harvest costs. The calculation for plantation harvest costs was

$$HCP_i = (HC1_i * v1_i) / vP_i \qquad [18]$$

where: HCP_i = plantation harvest cost at age i
$HC1_i$ = Site Class 1 harvest cost at age i
$v1_i$ = normal stand Site Class 1 merchantable volume at age i
vP_i = plantation merchantable volume at age i.

Tables 17 to 19 show the calculated harvest costs for normal stands of black spruce, jack pine and aspen, respectively. Adjusting equation [15] for non-normal stocking (i.e. decreasing N_i and v_i) would not result in a change to the harvest costs per cubic metre (the coefficients would cancel). The apparent anomaly was the result of having only variable costs included in the piecework rate schedule.

Haul Costs. Haul costs were calculated for each stand in the project area using the HAULCOST.CPL routine. The data required to perform the analysis has been described in previous sections. The coverages used to perform the HAULCOST analysis are summarized in Table 20.

The BARRIER coverages were subsets of the STAND coverages, and consisted of all lakes and 2-line rivers with an area greater than 10 ha. All islands were removed from the BARRIER coverages prior to processing with HAULCOST.CPL.

Table 17. Spruce normal stand roadside harvest costs ($\$/m^3$).

Age Class	Site Class s1a	s1	s2	s3	sP1	sP+1
20						
25						
30						
35	37.68	37.68				
40	34.64	34.64				
45	32.06	32.06				
50	29.20	29.20			16.98	15.45
55	27.37	27.37			17.23	15.66
60	25.38	25.38	73.93		16.78	15.24
65	23.69	23.69	50.50		16.53	15.04
70	22.30	22.30	39.66		16.08	14.60
75	21.18	21.18	33.82		15.86	14.41
80	20.42	20.42	29.70	63.72	15.38	13.99
85	19.53	19.53	27.15	48.04	15.10	13.74
90	18.86	18.86	25.60	40.68	14.88	13.53
95	18.26	18.26	23.93	36.38	14.67	13.34
100	17.87	17.87	23.42	32.96	14.56	13.24
105	17.38	17.38	22.40	31.03	14.32	13.01
110	16.99	16.99	21.57	28.84	14.14	12.86
115	16.69	16.69	21.18	27.69	13.98	12.71
120	16.47	16.47	20.73	26.86	13.88	12.63
125	16.23	16.23	20.11	26.14	13.76	12.50
130	16.26	16.26	19.87	25.45	13.89	12.62
135	16.05	16.05	19.58	25.14	13.92	12.64
140	15.95	15.95	19.32	24.80	14.01	12.74
145	15.95	15.95	19.20	24.22	14.22	12.92
150	15.95	15.95	19.16	24.16	14.46	13.15
155	15.95	15.95	19.16	24.16	14.46	13.15
160	15.95	15.95	19.16	24.16	14.46	13.15
165	15.95	15.95	19.16	24.16	14.46	13.15
170	15.95	15.95	19.16	24.16	14.46	13.15
175	15.95	15.95	19.16	24.16	14.46	13.15
180	15.95	15.95	19.16	24.16	14.46	13.15
185	15.95	15.95	19.16	24.16	14.46	13.15
190	15.95	15.95	19.16	24.16	14.46	13.15
195	15.95	15.95	19.16	24.16	14.46	13.15
200	15.95	15.95	19.16	24.16	14.46	13.15

Table 18. Pine normal stand roadside harvest costs ($\$/m^3$).

Age Class	Site Class p1	p2	p3	pP	pP+1	prP
20						
25						
30	20.38			13.77	12.48	9.20
35	17.98	21.81		12.92	11.76	9.16
40	16.53	20.62		16.90	15.31	12.01
45	15.70	19.23	22.86	14.13	12.85	10.25
50	15.15	18.04	21.23	12.12	10.99	9.05
55	14.61	17.22	20.25	10.84	9.86	8.26
60	14.24	16.59	19.22	10.52	9.58	8.14
65	13.89	16.12	18.42	10.22	9.30	7.99
70	13.66	15.88	17.90	9.95	9.05	7.85
75	13.49	15.62	17.46	9.69	8.79	7.69
80	13.31	15.40	17.21	9.43	8.56	7.50
85	13.19	15.29	17.06	9.23	8.39	7.35
90	13.08	15.20	16.95	8.99	8.17	7.20
95	12.95	15.16	16.95	8.77	7.97	7.07
100	12.90	15.07	16.91	8.62	7.84	6.98
105	12.90	15.07	16.91	8.48	7.71	6.93
110	12.90	15.07	16.91	8.48	7.71	6.93
115	12.90	15.07	16.91	8.48	7.71	6.93
120	12.90	15.07	16.91	8.48	7.71	6.93
125	12.90	15.07	16.91	8.48	7.71	6.93
130	12.90	15.07	16.91	8.48	7.71	6.93
135	12.90	15.07	16.91	8.48	7.71	6.93
140	12.90	15.07	16.91	8.48	7.71	6.93
145	12.90	15.07	16.91	8.48	7.71	6.93
150	12.90	15.07	16.91	8.48	7.71	6.93

Table 19. Aspen normal stand roadside harvest costs ($\$/m^3$).

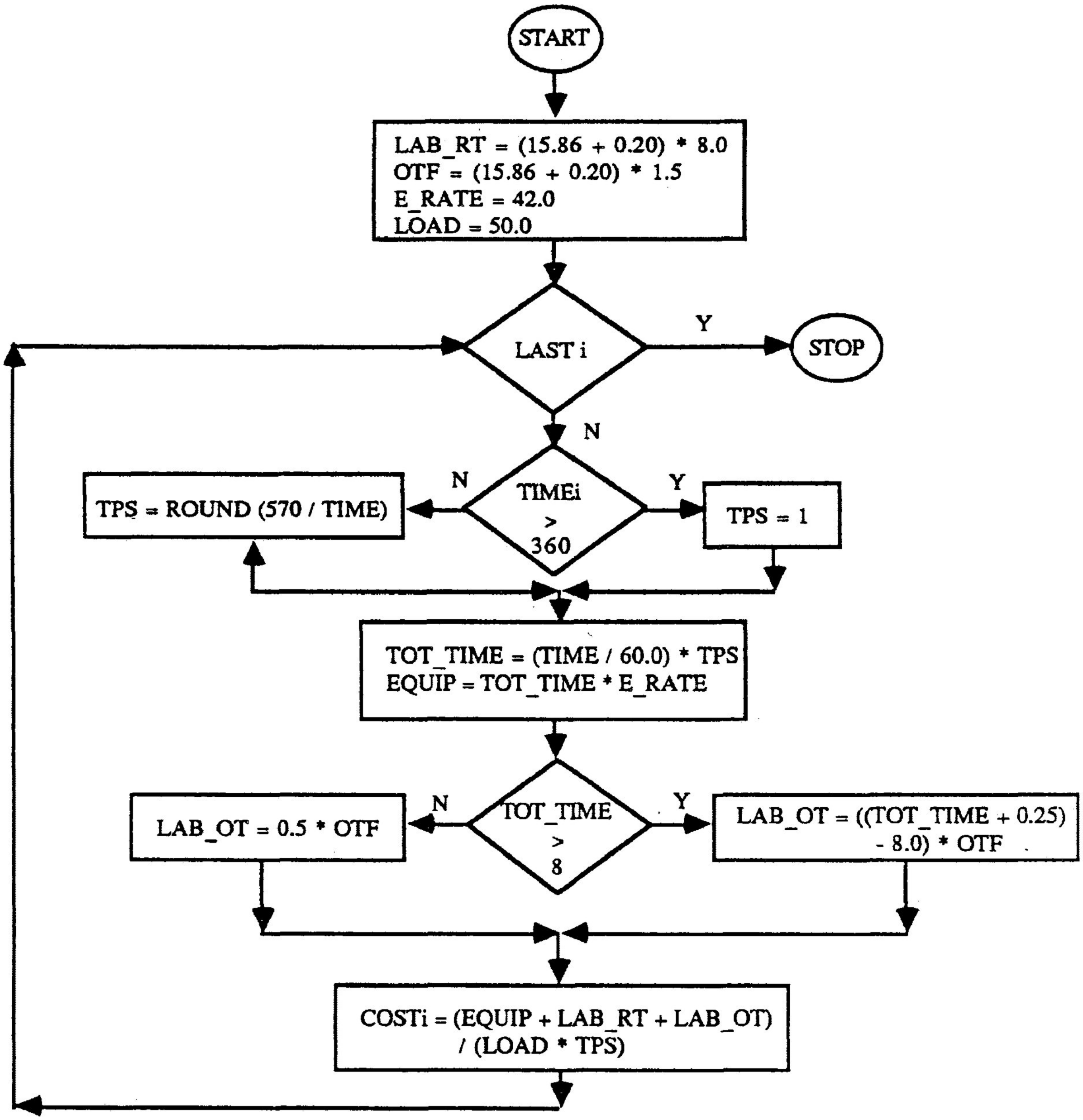
Age Class	Site Class a1	a2	a3
20			
25	19.89		
30	16.15	22.07	
35	14.01	17.16	
40	13.16	14.82	24.46
45	12.55	13.60	19.35
50	12.14	12.82	16.69
55	11.78	12.42	14.69
60	11.55	12.11	13.79
65	11.31	11.83	13.24
70	11.09	11.65	13.03
75	10.92	11.49	12.85
80	10.75	11.34	12.69
85	10.63	11.22	12.55
90	10.51	11.08	12.53
95	10.42	11.02	12.48
100	10.32	10.99	12.45
105	10.32	10.99	12.45
110	10.32	10.99	12.45
115	10.32	10.99	12.45
120	10.32	10.99	12.45
125	10.32	10.99	12.45
130	10.32	10.99	12.45
135	10.32	10.99	12.45
140	10.32	10.99	12.45
145	10.32	10.99	12.45
150	10.32	10.99	12.45

Internal calculation of haul costs by the INFO program COST (Appendix I) was based on the flowchart shown in Figure 4. The result of the HAULCOST analysis was calculation of the minimum cost period (MCP) (period of first access) and minimum cost (MC) as attributes of the forest polygons in each of the STAND coverages.

Figure 5 shows, for BM485903, the MINARC4 line coverage resulting from Network 1. The shaded areas correspond to the area available for harvest by period, as determined by the MCP attribute. Figure 6 shows, for BM485903, the MINARC5 line coverage resulting from Network 2. The shaded areas correspond to the haul zones.

Table 20. Coverages used in HAULCOST.CPL for road Networks 1 and 2.

Data	Name	Source
ROAD coverage	ALT1 (ALT3)	created by author
STAND coverages	FORT76 in BM485901 through BM485904	GLFP
INVENTORY file	ALT1.FRI (ALT3.FRI)	GLFP
RELATE item	POLY	
BARRIER coverages	BAR901 through BAR904 in BM485901 through BM485904, respectively	ARC RESELECTS from STAND coverages



where:

LAB_RT = regular time pay ($/hr)
OTF = overtime factor
E_RATE = equipment rate ($/hr)
LOAD = load size (m3/load)
TPS = trips per shift
TIMEi = round-trip haul time for stand i (minutes)
TOT_TIME = shift time (hrs)
EQUIP = equipment cost ($/hr)
LAB_OT = overtime pay
COSTi = haul cost for stand i ($/m3)

Figure 4. Flowchart of calculation procedure used by INFO program COST.PG.

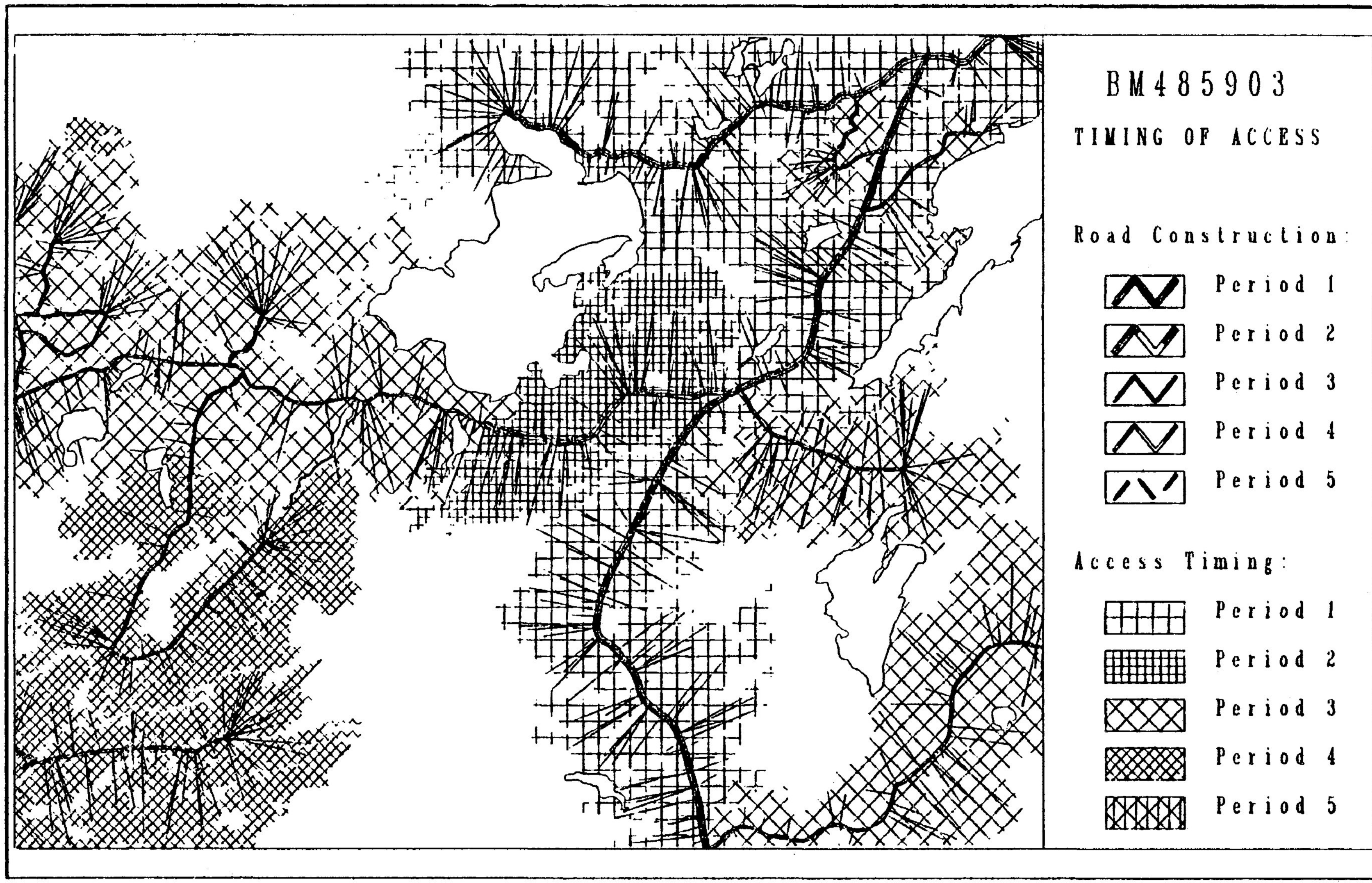


Figure 5. Network 1 MINARC4 coverage showing available harvest area by period for BM485903.

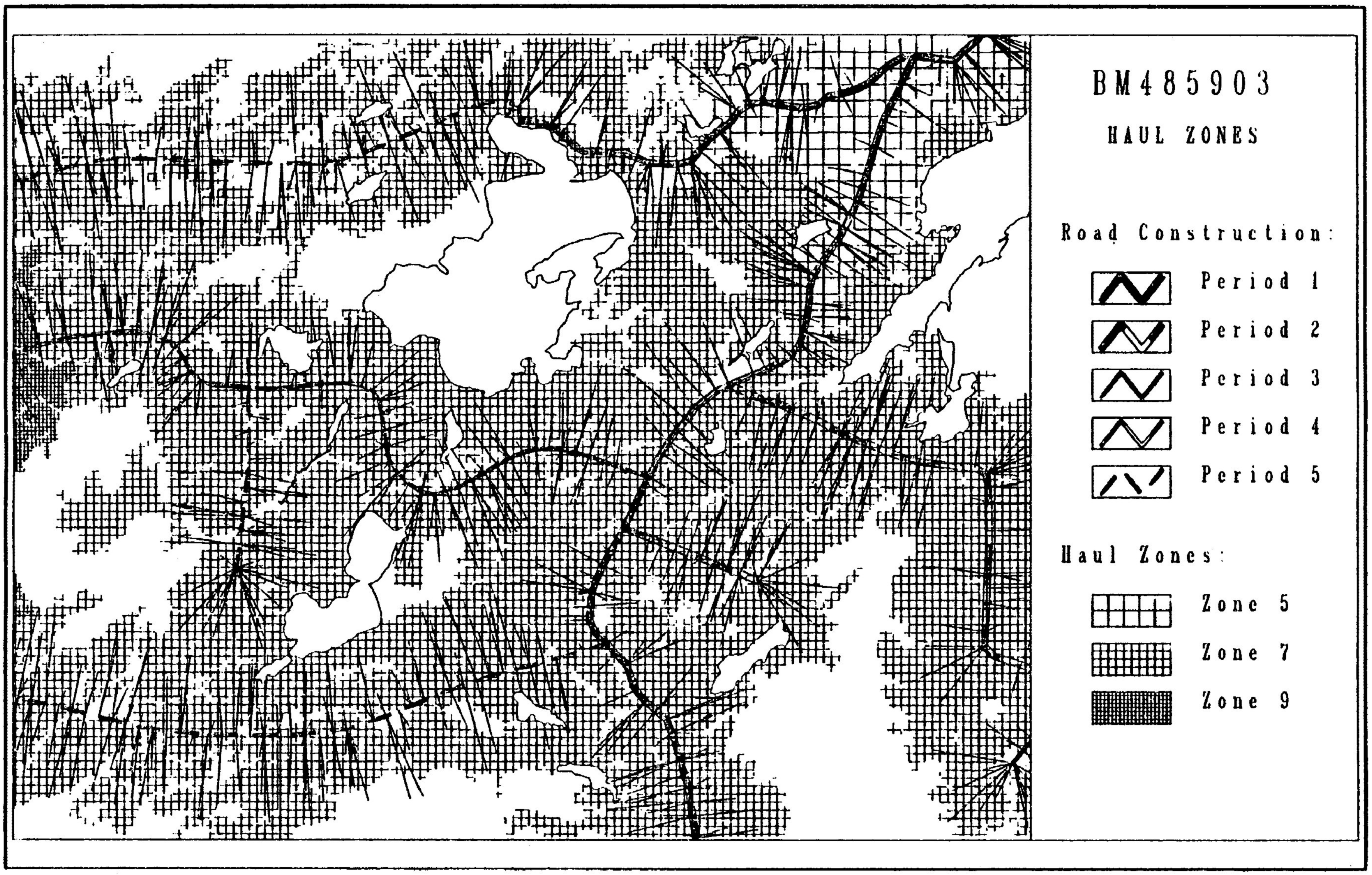


Figure 6. Network 2 MINARC5 coverage showing haul zones for BM485903.

TIMBER RAM SIMULATIONS

To assess the effects of roading, haul costs and timing of access on sustainable harvest levels, mill gate costs and harvest schedules, several alternative problem configurations were analyzed using the modified Timber RAM framework. Table 21 is a list of the parameters used in each alternative formulation.

Area Stratification

Each alternative required the accessed area to be stratified into stand classes. Stand classes for the different alternatives carried

Table 21. Alternatives analyzed with Timber RAM.

Alternative	Forest Base (road Network)	Access Constraints[1]	Haul Costs[2]	Flow Constraints (percent)
CTRL	Full	No	Constant ($\$7/m^3$)	+/- 5
ALT1	Network 1	Yes	Zone	+/- 5
ALT3	Network 2	Yes	Zone	+/- 5
ALT4	Network 1	No	Zone	+/- 5
ALT5	Network 1	No	Constant ($\$7/m^3$)	+/- 5

[1] - Yes - Timing of access constraints included
No - Timing of access constraints excluded

[2] - Constant - All areas assumed in Zone 7
Zone - Areas stratified into Zones 5, 7, and 9

differing levels of spatial resolution, as indicated by the parameters in Table 21.

The simplest area stratifications were for the CTRL and ALT5 alternatives. Both assumed a constant haul cost, resulting in stratification of the respective forest bases by age classes within strata. Figure 7 shows the area by stratum for the CTRL alternative. Age classes were omitted for clarity, and comparison with other forest bases.

Area stratification for alternatives ALT1 and ALT3 was more complex because of the addition of haul zones and timing of access constraints. Three haul zones were defined at intervals of $2/m^3. The zones were termed zone 5, 7 and 9, corresponding to the cost per cubic metre of transportation to the mill. Each stand in the forest base was assigned to a haul zone, determined by the value of the MC attribute. Timing of access constraints required five area stratifications to be performed, one for each of the first five periods. The forest base in period 1 consisted of all those stands which had the MCP attribute equal to 1. The period 1 forest base was stratified by age class within strata within haul zone. The stratification was repeated for the accumulated forest bases in each period (Figures 8 and 9). The period 5 forest base then consisted of all stands with an MCP between 1 and 5 (0 indicated no access, beyond search tolerance). Figures 10 and 11 depict the distribution of area among haul zones during the last period of road

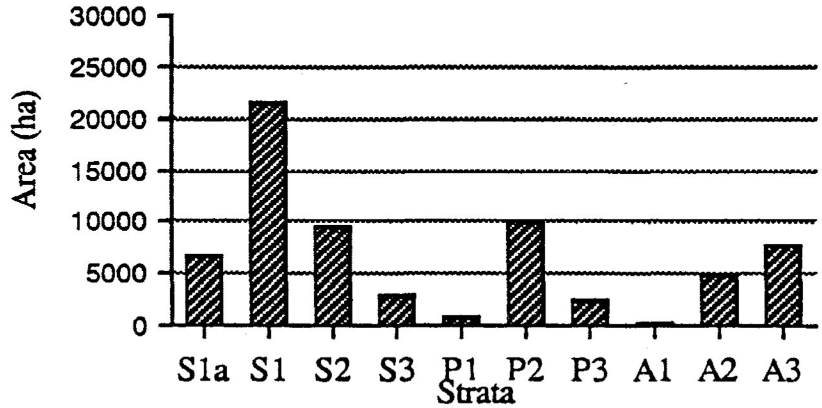


Figure 7. Forest structure of CTRL alternative in Period 5.

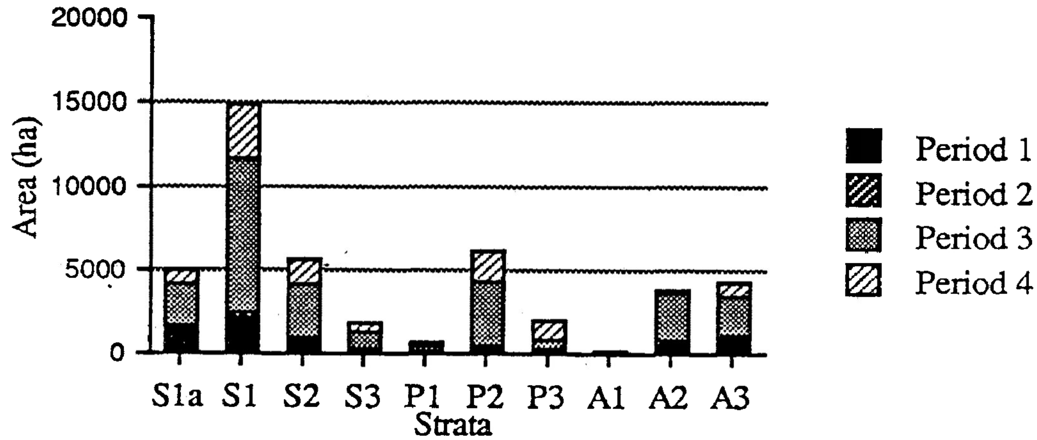


Figure 8. Forest structure of ALT1 alternative by period.

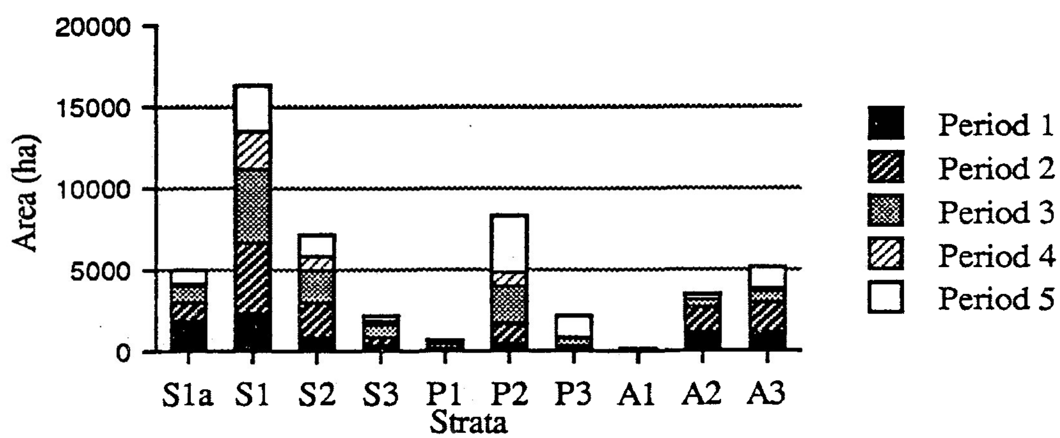


Figure 9. Forest structure of ALT3 alternative by period.

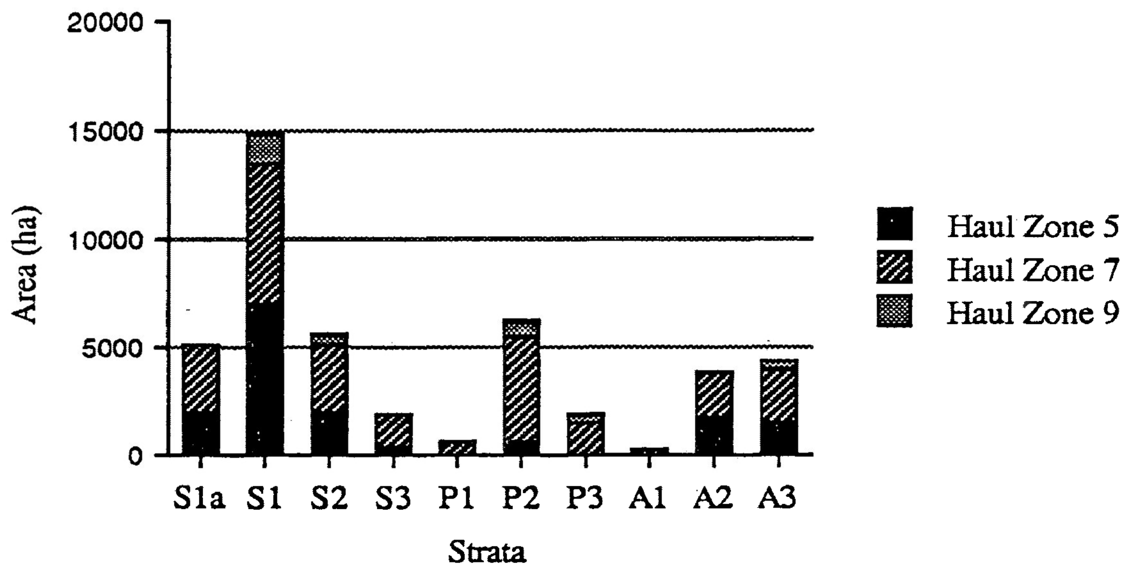


Figure 10. Forest structure of ALT1 alternative in period 4 showing haul zones.

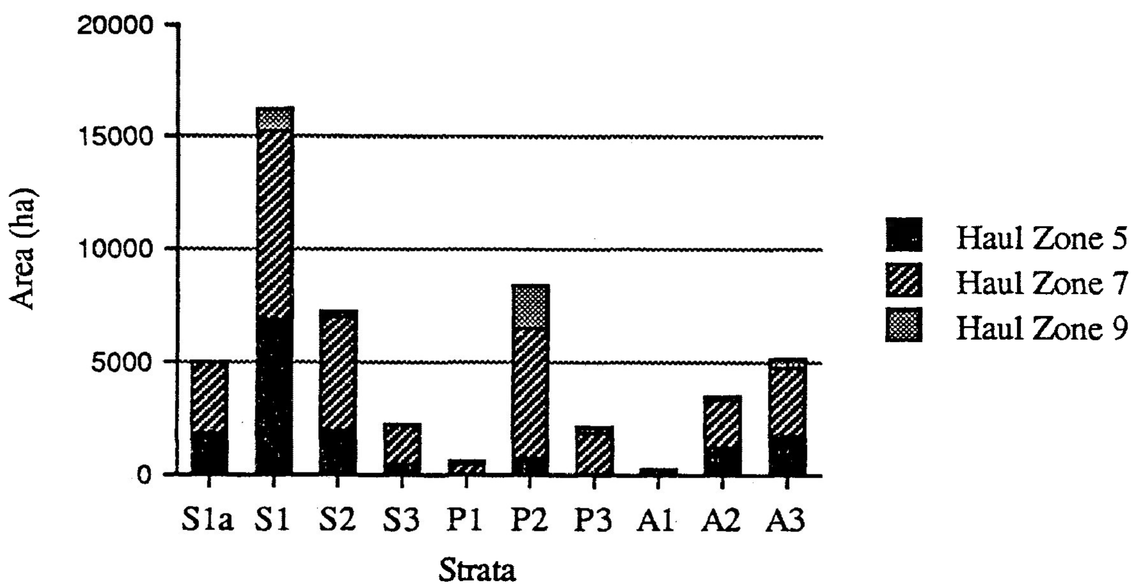


Figure 11. Forest structure of ALT3 alternative in Period 5 showing haul zones.

construction activity (final forest base) for alternatives ALT1 and ALT3, respectively.

Stratification of both ALT4 and ALT5 were modifications of ALT1 in that haul zones were omitted.

Data

A Timber RAM datafile was created for each of the alternatives. Because the primary interest was to demonstrate the algorithm, rather than to assess the relative merits of alternative treatment regimes, only the first two regimes and associated regenerated timber harvest ages (Tables 8 to 10) were used in simulation, resulting in four alternative futures for each stand class. In choosing the treatment regimes, the first defined a non-intensive management option (no treatment, except for S1a), and the second defined an intensive management option.

Basic volume and economic data were the same for each of the seven alternatives. Differences among alternatives resulted from the amount and timing of areas accessed, and transportation costs.

Results

Figure 12 summarizes the results of a series of simulations made with Timber RAM for the CTRL, ALT1 and ALT3 alternatives. Each point represents a cost minimization objective, with a constrained harvest level over 25 years. The right-most point on each curve was determined by first maximizing harvest volume, followed by minimizing costs while obtaining the maximum harvest volume.

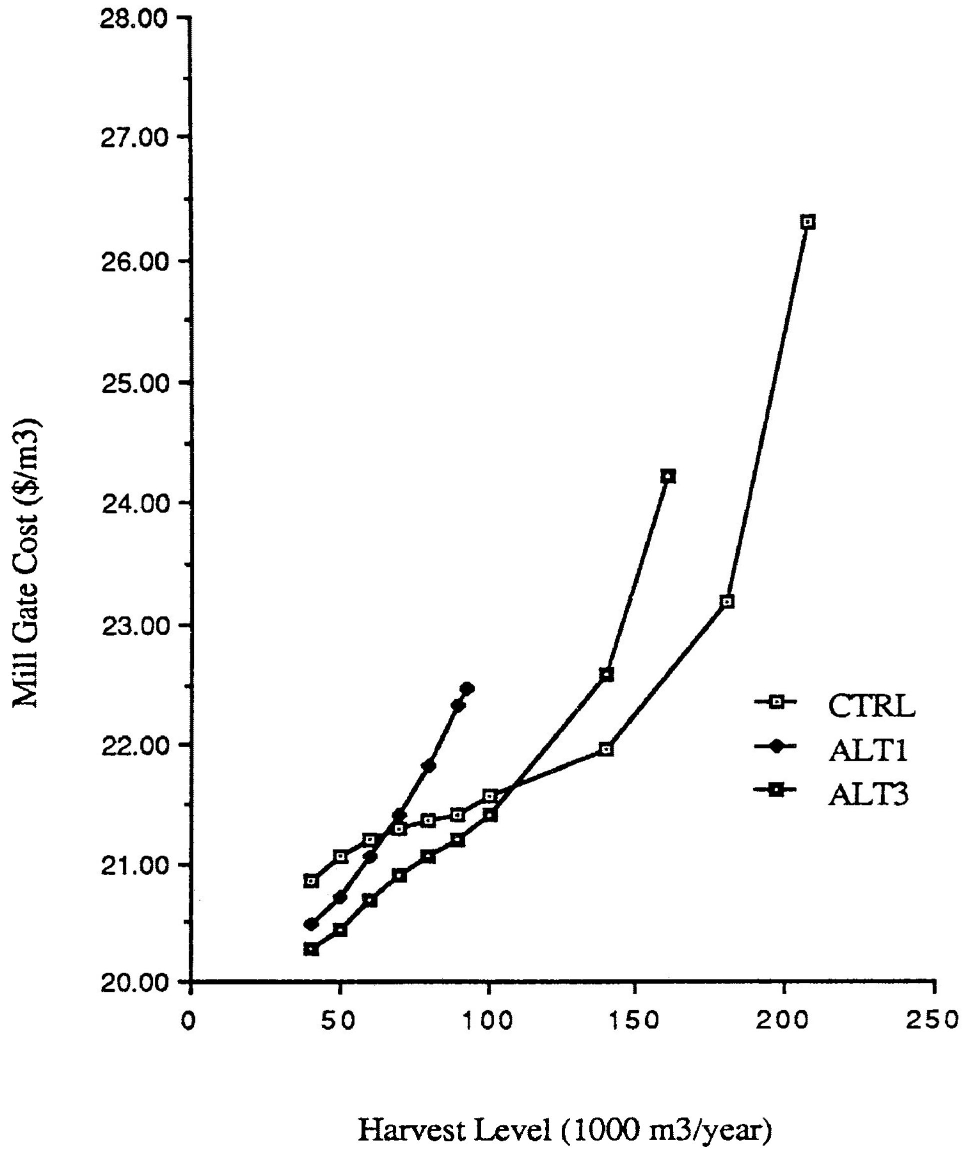


Figure 12. Production possibility curves for CTRL, ALT1 and ALT2 alternatives.

The CTRL mill gate costs assumed an average haul cost of $\$7/m^3$. Changes to the average haul cost estimate would raise or lower the production possibility curve by the same amount. The curve reflected the harvest area assigned to intensively managed treatment regimes at each harvest level (Table 22). Harvest levels greater than 100 000 m^3/year required that increasing amounts of harvest area be intensively treated to achieve the minimum volume constraint. Below 100 000 m^3/year, non-intensive treatment regimes were chosen, because the harvest level constraint was easily satisfied with natural regeneration. Increasing savings would be made as volume requirements decreased. Intensively treated areas accounted for 72.5 percent of the harvested area to produce 208 000 m^3/year. Beyond this level of intensive treatment, no improvement to the harvest level could be made without providing additional treatment alternatives.

Table 22. Intensively treated harvest areas during Period 1 through Period 5.

Harvest Level ($1000\ m^3$)	Harvest area intensively treated (percent)				
	CTRL	ALT1	ALT3	ALT4	ALT5
60		1.2			
70		2.8			
80		5.0			2.1
90		8.2		1.1	1.9
92.8		9.0	-	-	-
100			1.7	1.3	0.0
140	1.4		8.9	52.5	52.7
160	-		32.1		
180	21.8				
208	72.5				

The results of ALT1 and ALT3 indicate the effects of the partial forest base lowering the maximum sustainable harvest level. The total area accessed by ALT3 was 50 649 ha by period 5, while ALT1 accessed only 44 641 ha by period 5. Roading in ALT3 was more intensive than ALT1, resulting in more area accessed at an earlier time. The effect on sustainable harvest is observed in Figure 12 in two ways. First, ALT3 has a lower mill gate cost than ALT1 throughout, caused by the larger forest base allowing more periodic harvest to be from cheaper stand classes. Second, the slower rise in the slope of ALT3 was the result of the larger forest base satisfying the harvest level constraint requiring less harvest area be treated intensively than ALT1 (at the same harvest level, Table 22).

To explore the reasons for the shape of the ALT1 production possibility curve, two additional series of Timber RAM simulation runs were made. Both ALT4 and ALT5 omitted timing of access constraints, while only ALT4 included haul costs. ALT5 then was different from CTRL only in the partial forest base. Figure 13 shows the results of these simulation runs. Removal of the timing of access constraints has the dual effect of increasing the maximum sustainable harvest level, and decreasing the amount of intensively treated area required to achieve a given harvest level, which in turn reduces the mill gate cost. ALT1 required intensive treatment to attain the specified minimum harvest level, from 1.2 percent at 60 000 m^3/year to 9.0 percent at 92 800 m^3/year. ALT4 and ALT5 both attained the required harvest levels with less than 3 percent intensive treatment until a jump to approximately 52 percent at 140 000 m^3/year.

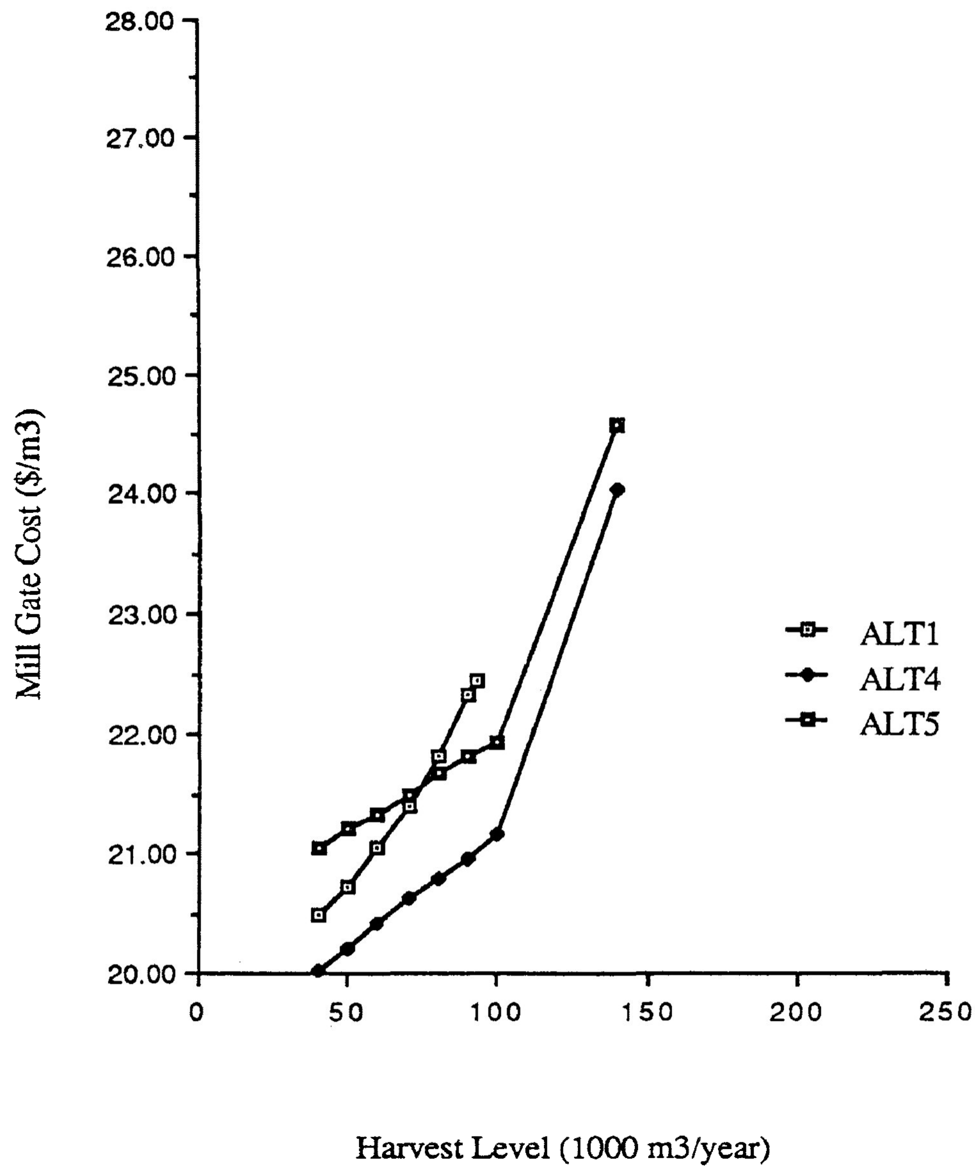


Figure 13. Production possibility curves for ALT1, ALT4 and ALT5 alternatives.

In comparing the harvest schedules of the CTRL, ALT1 and ALT3 alternatives, Tables 23 to 25, respectively, the difference in complexity is apparent. The CTRL alternative had a very simple harvest schedule, with few stand classes chosen for harvest in each period.

Haul cost effects may be seen in comparing ALT4 and ALT5 (Figure 13). At lower harvest levels, ALT4 maintained significant harvest from Zone 5, while ALT5 assumed harvest only from Zone 7 (Tables 26 and 27). The difference in mill gate cost decreases as harvest level increases, since an increasing proportion of ALT4 harvest was coming from Zone 7 (76 percent at 60 000 m^3/year to 36 percent at 140 000 m^3/year). This was the result of assuming perfect access during all periods. ALT1, with severely restricted access had a more complex schedule than ALT3, which had less restricted access.

Table 23. CTRL timber harvest schedule for Periods 1 and 2 at 80 000 m^3/year (ha).

Stratum	Site Class	Age Class	CC[1] Zone 5	CC[1] Zone 7	P,He[2] Zone 5	P,He[2] Zone 7
Period 1						
A	3	81-100		2202		
		101-120		861		
Period 2						
P	1	41- 60		28		
		81-100		129		
		100-120		51		
	2	61- 80		510		
A	2	41- 60		575		
	3	41- 60		2476		

[1] - Clearcut
[2] - Scarify, plant, herbicide treatment

Table 24. ALT1 timber harvest schedule for Periods 1 and 2 at 80 000 m^3/year (ha).

Stratum	Site Class	Age Class	CC Zone 5	CC Zone 7	P,He Zone 5	P,He Zone 7
Period 1						
S	1	81-100	218	149		
		101-120	226	277		
		121-140		98		
	2	121-140		55		
	X	101-120	23	91	23	91
P	1	41- 60	28			
		61- 80		88		
		81-100		17		
P	2	61- 80		79		
		81-100		93		
		101-120		8		
A	2	61- 80	49	27		
		81-100	479	67		
		101-120		24		
A	3	61- 80	122	223		
		81-100	145	194		
Period 2						
S	1	61- 80	197	316		
		81-100		13		
		101-120		29		
		121-140		13		
	2	81-100	121	209		
		101-120	110	134		
		121-140		36		
	3	101-120	50	147		
		121-140		8		
	X	41- 60	121		121	
		61- 80	286	259	286	259
		81-100		11		11
		101-120			23	91
P	1	61- 80		42		
		81-100		14		
	2	41- 60	12	23		
		61- 80		252		
	3	61- 80		221		
A	1	61- 80	23			
	2	21- 40		16		
		41- 60		75		
		81-100		72		
	3	41- 60	26	21		
		61- 80		43		
		81-100		146		146

Table 25. ALT3 timber harvest schedule for Periods 1 and 2 at 80 000 m^3/year (ha).

Stratum	Site Class	Age Class	CC Zone 5	CC Zone 7	P,He Zone 5	P,He Zone 7
Period 1						
S	1	81-100	180			
		101-120	188	41		
		121-140	16	71		
P	1	41- 60	28			
		61- 80		88		
		81-100		3		
P	2	61- 80	87			
		81-100	7	86		
A	2	41- 60		98		
		61- 80	128	22		
		81-100	662	125		
		101-120		79		
A	3	41- 60	88	218		
		61- 80	144	67		
		81-100	292			
Period 2						
S	1	101-120	33	4		
		121-140	109			
P	1	81-100		33		
	2	41- 60	131			
		61- 80		36		
		81-100	452			
A	2	41- 60		134		
		81-100	290	244		
	3	41- 60	153	560		
		61- 80	205			
		81-100	411			

ALT4 and ALT5 harvest schedules (Tables 26 and 27) indicated an effect resulting from including Haul Zones. In period 2, the ALT4 harvest schedule indicated 1 082 ha of S1 and 590 ha of A3 age 81-100 to be cut in Zone 5. In ALT5 (constant haul cost), the harvest schedule showed the S1 and A3 harvests to be replaced by increases in harvest of P2 age 81-100 and A3 age 41-60. The changes were assumed to be the result of changes to the mill gate costs between ALT4 and ALT5. For example, stand class "x" with a mill gate cost of $20.00 in Zone 5 of ALT4 would have a mill gate cost of $22.00 in ALT5, whereas stand class "y" in Zone 7 of ALT4 with a mill gate cost of $21.00 would have the same cost in ALT5. Thus, by including Haul Zones, the cost relationship of stand classes "x" and "y" is reversed between ALT4 and ALT5.

Table 26. ALT4 timber harvest schedule for Periods 1 and 2 at 80 000 m^3/year (ha).

Stratum	Site Class	Age Class	CC		P,He	
			Zone 5	Zone 7	Zone 5	Zone 7
Period 1						
P	1	81-100		49		
		101-120		51		
A	2	81-100	1383	594		
		101-120		945		
Period 2						
S	1	101-120	1082			
		121-140	256			
P	1	41- 60	28			
		81-100		80		
	2	81-100	526			
A	3	41- 60	410			
		81-100	590			

Table 27. ALT5 timber harvest schedule for Periods 1 and 2 at 80 000 m^3/year (ha).

Stratum	Site Class	Age Class	CC		P,He	
			Zone 5	Zone 7	Zone 5	Zone 7
Period 1						
P	1	81-100		49		
		101-120		51		
A	2	81-100		1977		
		101-120		945		
Period 2						
P	1	41- 60		28		
		81-100		80		
	2	81-100		1508		
A	2	41- 60		166		
	3	41- 60		1091		

CHAPTER 4

DISCUSSION AND CONCLUSIONS

The case study of Chapter 3 showed that the management planning algorithm was capable of addressing the spatial problem (distribution of treatments, haul costs and timing of access). This chapter begins with an evaluation of the management planning algorithm as a feasible and implementable management strategy design tool. The chapter ends with conclusions based upon the evaluation.

EVALUATION OF THE MANAGEMENT PLANNING ALGORITHM

In Chapter 1, the criteria of Rose (1984) were used to evaluate the relative suitability of three long-range timber or resource management modelling systems for incorporation with large-scale spatial analysis as an integrated management planning tool. The same criteria are used here to evaluate the management planning algorithm. The evaluation considers strengths, limitations, and potential uses of the planning algorithm.

1. "Does the model (system) generate solutions which are at least theoretically sound (valid)?"

The treatment schedules produced using the management planning algorithm would have comparable theoretical validity to treatment schedules produced using non-spatially characterized stand class data.

2. "Does the model (system) develop an implementable plan or can results be used to develop an implementable plan?"

The management planning algorithm provided a means of determining, by period, the area available for harvest within each stand class. Using the timing of access constraints in simulation limited the area harvested from a stand class to the area accessible in each period. The treatment schedules are therefore more implementable than where timing of access is ignored because of the improved spatial resolution.

One area of concern remains in the implementation of the timber harvest schedules. When entire stand classes are scheduled for harvest during a five-year period, the spatial distribution of yearly activities remains undetermined. The manager must allocate the specified harvests within a stand class (e.g. S1a, age 81-100, in haul zone 5) among the constituent stands. This provides an opportunity for operational planning best suited to the individual or organization. A planning aid of potential value in the choice of operational locations would be a Decision Support System (DSS) such as that reported by Robak (1984).

3. "How can the model (system) fit into the general planning process?"

Numerous organizations are presently using long-range planning models for timber supply analysis, as well as maintaining a GIS and database. The integrated management planning algorithm was considered a means of augmenting the capabilities of the economic timber supply analysis for those organizations.

4. "Will the planning process be cost-effective with this model (system)?"

Net tangible return to the organization directly resulting from using the integrated management planning algorithm would be as difficult to determine as the net tangible returns of using Timber RAM without spatially characterized data. The practical benefits of implementable harvest schedules and the ability to forecast mill gate costs are obvious, but the economic value is not readily quantifiable. The ability to assess potential savings from design of more efficient road networks is also a benefit, but would be specific to individual planning situations.

Cost-effectiveness is, therefore, specific to the requirements of the organization with respect to accuracy of forecasts, and detail of planning required by either institutional or legislative policies. Conclusions regarding cost-effectiveness cannot be made from the present study.

5. "Would different planners reach different results?"

Different planners would reach different results because of the subjective nature of determining alternative road networks. Although not consistent among planners, subjective road network design permits planners to use individual knowledge of the area, and consider innumerable tangible and intangible factors in the choice of road location.

6. "Can the plan be made flexible and responsive to questionable model (system) assumptions about the future?"

Extensive sensitivity analysis can be performed to determine which activities are particularly sensitive to changes in assumptions. The most robust harvest schedule (that which exhibits the least fluctuation given changes to input data), would be preferable. This was one of the primary reasons for choosing Timber RAM, since sensitivity analysis was much more likely to be undertaken with the smaller planning system.

In addition to the traditional LP sensitivity analysis, consequences of changes to road network design or timing may be determined. This type of analysis was performed in the Case Study, where treatment schedules were determined for Network 1 and Network 2. In addition, the effects on the treatment schedule of changes to road construction timing can be assessed, and plans made for that eventuality. The management planning algorithm is, therefore, responsive to questionable assumptions about the future.

7. "Is the model (system) large enough to recognize most of the pertinent data?"

Timber RAM, in the modified form, was sufficient to adequately perform the analysis in that the factors desired to be considered were included in the analysis. The LP code required a tolerance adjustment because of the objective function scaling in the cost minimization runs. The problem size, approximately 600 rows (constraints) and 6000 columns (variables) did not appear to approach the ability of the LP code to solve. The criticism of Chappelle et. al. (1976), that problem size restrictions would not allow meaningful spatial analysis does not hold in this case. Meaningful spatial analysis was possible, with the ability to consider much larger problems.

The management planning algorithm was sufficiently large to recognize the data pertinent to the case study. Both the haul cost algorithm and the LP code were capable of handling larger problems.

8. "Is the planning model (system) understandable or viewed as a black box?"

The HAULCOST program would be considered a black box to non-programmers. The haul cost algorithm, however, would be more easily understood through iterative use in planning situations. The modified Timber RAM analysis should not be considered a black box since a great deal of understanding of the problem structure is required to create the datafiles and interpret the solutions.

9. "Does the model (system) deal effectively with uncertainty aspects?"

As stated previously, the effects of uncertainty are generally addressed with sensitivity analysis.

10. "Is the model (system) transferable to other users?"

Transferability is more restricted with the integrated management planning algorithm than with a traditional analysis with the Timber RAM system because of the required access to a GIS and a maintained database. The HAULCOST program was written to access the ARC/INFO database structure. Use of the HAULCOST program thus requires purchase of the ARC/INFO system.

Significant effort was made to develop the interactive DEFBAT.CPL program to shield the user (manager) from the programming requirements of the HAULCOST.CPL program, yet provide an opportunity to understand the dynamic elements of road construction, timing of access and haul costs.

11. "Does the model (system) allow for adjustments to specific situations?"

Modifications of either the HAULCOST algorithm or the Timber RAM system are possible. Changes to the HAULCOST algorithm would require knowledge of Fortran programming, ARC/INFO commands and CPL programming. Modifications to the HAULCOST algorithm may require changes to only the ARC/INFO or CPL routines, a relatively simple task. Changes to the MINARC.F77 program would require knowledge of the internal ARC/INFO data structures, and would be a relatively major undertaking. Changes to Timber RAM, such as those made for the Case Study, would require knowledge of Fortran programming.

The management planning algorithm, therefore, does permit adjustments for specific planning situations.

12. "Can model (system) results help evaluate specific alternatives not recognized in the model (system)?"

HAULCOST.CPL can be modified to perform the analysis based on any parameter. COST.PG calculated haul costs based on travel time, but any descriptor of the arc may be used with any function to calculate impedance values to be used in the ALLOCATE procedure. Users familiar with the tool may adapt it to their particular situation.

The results from HAULCOST.CPL analysis are not necessarily tied to performing long-range timber management planning, as with the modified Timber RAM. The value of the haul cost and timing of access stand attributes go beyond the use made for the Timber RAM runs. For example, the calculated haul costs could be used on a smaller time scale for operational planning. The additional attributes could also be used for producing maps of accessible areas by time period, and haul cost zones.

Components of the management planning algorithm may therefore be used to address alternative management questions.

CONCLUSIONS

Chapter 1 identified the objective of developing a spatially sound management strategy design tool by integrating large-scale spatial analysis and long-range timber management planning. Evaluation of candidate modelling systems resulted in the choice of Timber RAM. Chapter 2 presented a mathematical structure and an algorithm for addressing the spatial problem (spatial distribution of treatments, haul costs and timing of access). In the case study of Chapter 3, the management planning algorithm was found to be capable of addressing the spatial problem.

Evaluation based on the criteria of Rose (1984) showed the management planning algorithm to be a feasible and implementable management strategy design tool. The algorithm was found to adequately integrate large-scale spatial analysis (timing of access and haul costs) with long-range timber management planning. Two limitations of the algorithm are the costly proprietary software requirement (ARC/INFO) and the time and financial committment required by the organization to maintain the database. For those organizations already supporting ARC/INFO and a database, the algorithm presents an additional analytical opportunity. Both the haul cost algorithm and the modified Timber RAM system were determined to be adaptable to other planning situations.

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APPENDICES

APPENDIX I

HAULCOST PROGRAMS

```
/* *****************************************************************
/*
/* Program:         DEFBAT.CPL
/* Written by:      W.H. Lougheed
/* Computer:        PR1ME 550-II
/* Date:            27 January 1988
/* Status:          Operational
/*
/* *****************************************************************
/*
TYPE
TYPE *************
TYPE ROAD COVERAGE
TYPE *************
&LABEL IN.ROADALL
TYPE
&S NAME := [TRIM [RESPONSE 'Enter name of ROAD coverage']]
&CALL NAMGEN
&IF %IERR% = 1 &THEN &GOTO IN.ROADALL
&S W_UNIT := [OPEN_FILE DAT_%NAME% -MODE W OK]
&IF %OK% = 1 &THEN &DO
  TYPE
  TYPE Error: Could not open file for writing
  TYPE
  &RETURN
&END
&S IER := [WRITE_FILE %W_UNIT% %PATH%]
&S IER := [WRITE_FILE %W_UNIT% %NAME%]
TYPE
TYPE ***********
TYPE HAUL SPEEDS
TYPE ***********
&LABEL IN.HAULSPEED
&DO I := 1 &TO 5
  &S V%I% := 0
&END
TYPE
&S N := [TRIM [RESPONSE 'Enter number of road classes']]
&IF %N% > 5 &THEN &DO
  TYPE
  TYPE Warning : Maximum number of road classes is 5
  &GOTO IN.HAULSPEED
&END
&S V1 := [TRIM [RESPONSE 'Enter Road Class 1 haul speed (km/h)']]
&IF %N% = 1 &THEN &GOTO PASS1
&S V2 := [TRIM [RESPONSE 'Enter Road Class 2 haul speed (km/h)']]
&IF %N% = 2 &THEN &GOTO PASS1
&S V3 := [TRIM [RESPONSE 'Enter Road Class 3 haul speed (km/h)']]
&IF %N% = 3 &THEN &GOTO PASS1
&S V4 := [TRIM [RESPONSE 'Enter Road Class 4 haul speed (km/h)']]
&IF %N% = 4 &THEN &GOTO PASS1
&S V5 := [TRIM [RESPONSE 'Enter Road Class 5 haul speed (km/h)']]
```

```
&LABEL PASS1
&S VO := [TRIM [RESPONSE 'Enter Access Road haul speed (km/h)']]
TYPE
TYPE          Haul Speed
TYPE   =========================
TYPE   Road Class 1 :  %V1% km/h
&IF %N% = 1 &THEN &GOTO PASS2
TYPE   Road Class 2 :  %V2% km/h
&IF %N% = 2 &THEN &GOTO PASS2
TYPE   Road Class 3 :  %V3% km/h
&IF %N% = 3 &THEN &GOTO PASS2
TYPE   Road Class 4 :  %V4% km/h
&IF %N% = 4 &THEN &GOTO PASS2
TYPE   Road Class 5 :  %V5% km/h
&LABEL PASS2
TYPE   Access Roads :  %V0% km/h
TYPE
&S ANS := [QUERY 'Do you wish to make a change']
&IF %ANS% = TRUE &THEN &GOTO IN.HAULSPEED
&S IER := [WRITE_FILE %W_UNIT% %V1%]
&S IER := [WRITE_FILE %W_UNIT% %V2%]
&S IER := [WRITE_FILE %W_UNIT% %V3%]
&S IER := [WRITE_FILE %W_UNIT% %V4%]
&S IER := [WRITE_FILE %W_UNIT% %V5%]
&S IER := [WRITE_FILE %W_UNIT% %V0%]
/*
TYPE
TYPE *********************************
TYPE FOREST ACCESS POINTS TRAVEL TIMES
TYPE *********************************
&LABEL IN.CENTIME
&DO I := 1 &TO 5
  &S T%I% := 0
&END
TYPE
&S N := [TRIM [RESPONSE 'Enter number of forest access points']]
&IF %N% > 5 &THEN &DO
  TYPE
  TYPE Warning : Maximum number of access points is 5
  &GOTO IN.CENTIME
&END
&S T1 := [TRIM [RESPONSE 'Enter haul time to ACCESS POINT 1 (min)']]
&IF %N% = 1 &THEN &GOTO PASS3
&S T2 := [TRIM [RESPONSE 'Enter haul time to ACCESS POINT 2 (min)']]
&IF %N% = 2 &THEN &GOTO PASS3
&S T3 := [TRIM [RESPONSE 'Enter haul time to ACCESS POINT 3 (min)']]
&IF %N% = 3 &THEN &GOTO PASS3
&S T4 := [TRIM [RESPONSE 'Enter haul time to ACCESS POINT 4 (min)']]
&IF %N% = 4 &THEN &GOTO PASS3
&S T5 := [TRIM [RESPONSE 'Enter haul time to ACCESS POINT 5 (min)']]
&LABEL PASS3
TYPE
```

```
TYPE Access Point : Haul Time
TYPE ========================
TYPE      1       :   %T1% min
&IF %N% = 1 &THEN &GOTO PASS4
TYPE      2       :   %T2% min
&IF %N% = 2 &THEN &GOTO PASS4
TYPE      3       :   %T3% min
&IF %N% = 3 &THEN &GOTO PASS4
TYPE      4       :   %T4% min
&IF %N% = 4 &THEN &GOTO PASS4
TYPE      5       :   %T5% min
&LABEL PASS4
TYPE
&S ANS := [QUERY 'Do you wish to make a change']
&IF %ANS% = TRUE &THEN &GOTO IN.CENTIME
&S IER := [WRITE_FILE %W_UNIT% %N%]
&S IER := [WRITE_FILE %W_UNIT% %T1%]
&IF %N% = 1 &THEN &GOTO PASS5
&S IER := [WRITE_FILE %W_UNIT% %T2%]
&IF %N% = 2 &THEN &GOTO PASS5
&S IER := [WRITE_FILE %W_UNIT% %T3%]
&IF %N% = 3 &THEN &GOTO PASS5
&S IER := [WRITE_FILE %W_UNIT% %T4%]
&IF %N% = 4 &THEN &GOTO PASS5
&S IER := [WRITE_FILE %W_UNIT% %T5%]
&LABEL PASS5
/*
TYPE
TYPE ****************
TYPE SEARCH TOLERANCE
TYPE ****************
TYPE
&S SRCHTOL := [TRIM [RESPONSE 'Enter search tolerance in map units']]
&S IER := [WRITE_FILE %W_UNIT% %SRCHTOL%]
TYPE
TYPE *********************
TYPE STAND MAP INFORMATION
TYPE *********************
&LABEL IN.STAND
TYPE
&S BM_NUM := [TRIM [RESPONSE 'Enter number of base maps']]
&IF %BM_NUM% > 20 &THEN &DO
  TYPE
  TYPE Warning : Maximum number of base maps is 20
  &GOTO IN.STAND
&END
&S IER := [WRITE_FILE %W_UNIT% %BM_NUM%]
&DO I := 1 &TO %BM_NUM%
  &LABEL IN.BASE
  TYPE
  TYPE ----------------
  TYPE Base map %I% of %BM_NUM%
```

```
  TYPE ----------------
  TYPE
  &S NAME := [TRIM [RESPONSE 'Enter base map name']]
  &CALL NAMGEN
  &IF %IERR% = 1 &THEN &GOTO IN.BASE
  &CALL PATCHK
  &IF %IERR% = 1 &THEN &GOTO IN.BASE
  &CALL LABCHK
  &IF %IERR% = 1 &THEN &GOTO IN.BASE
  &S MPATH := %PATH%
  &S MNAME := %NAME%
  &S INV := [TRANSLATE [TRIM [RESPONSE 'Enter name of inventory file']]]
  &S REL := [TRANSLATE [TRIM [RESPONSE 'Enter name of relate item']]]
  &LABEL IN.BAR
  &S NAME := [TRIM [RESPONSE 'Enter name of barrier coverage']]
  &CALL NAMGEN
  &IF %IERR% = 1 &THEN &DO
    TYPE
    &GOTO IN.BAR
  &END
  TYPE
  TYPE Error Check:
  TYPE ============================================
  TYPE Base map name:      %MPATH%>%MNAME%
  TYPE Inventory file:     %INV%
  TYPE Relate item:        %REL%
  TYPE Barrier coverage:   %PATH%>%NAME%
  TYPE
  &S ANS := [QUERY 'Do you wish to make a change']
  &IF %ANS% = TRUE &THEN &GOTO IN.BASE
  &S IER := [WRITE_FILE %W_UNIT% %MPATH%]
  &S IER := [WRITE_FILE %W_UNIT% %MNAME%]
  &S IER := [WRITE_FILE %W_UNIT% %INV%]
  &S IER := [WRITE_FILE %W_UNIT% %REL%]
  &S IER := [WRITE_FILE %W_UNIT% %PATH%]
  &S IER := [WRITE_FILE %W_UNIT% %NAME%]
&END
/*
CLOSE -UNIT %W_UNIT%
TYPE
TYPE
**********************************************************************
TYPE
&S N := [QUERY 'Do you want to submit the batch job']
&IF %N% = TRUE &THEN &DO
  &S HOME := [DIR [PATHNAME *]]
  &S QUEUE := [TRIM [RESPONSE 'Enter batch queue name: ']]
  JOB PRJ016>MINARC>HAULCOST.CPL -QUEUE %QUEUE% -ARGS %HOME%>DAT_%NAME%
&END
&RETURN
/*
/*
```

```
&ROUTINE NAMGEN
&S IERR := 0
&S PATH := [DIR %NAME% -BRIEF]
&S PATH := [SUBST %PATH% * [DIR [PATHNAME *]]]
&S NAME := [ENTRYNAME %NAME%]
&IF ^ [EXISTS %PATH%>%NAME%] &THEN &DO
  TYPE
  TYPE Warning : %PATH%>%NAME% does not exist
  &S IERR := 1
&END
&RETURN
/*
&ROUTINE LABCHK
&S IERR := 0
&IF ^ [EXISTS %PATH%>%NAME%>LAB] &THEN &DO
  TYPE
  TYPE Error : %PATH%>%NAME% does not have a LAB file
  &S IERR := 1
&END
&RETURN
/*
&ROUTINE PATCHK
&S IERR := 0
&IF ^ [EXISTS %PATH%>%NAME%>PAT] &THEN &DO
  TYPE
  TYPE Error : %PATH%>%NAME% does not have a PAT file
  &S IERR := 1
&END
&RETURN
/*
```

```
/* ********************************************************************
/*
/* Program:          HAULCOST.CPL
/* Written by:       W.H. Lougheed
/* Computer:         PR1ME 550-II
/* Date:             27 January 1988
/* Status:           Operational
/*
/* ********************************************************************
/*
/* Input name of control file created by DEFBAT.CPL.
/*
&ARGS CONTROL
&S R_UNIT := [OPEN_FILE %CONTROL% -MODE R OK]
&IF %OK% = 1 &THEN &DO
  TYPE
  TYPE Error : Could not open %CONTROL% for reading
  TYPE
  &RETURN
&END
/*
/* Initialize arrays to null values.
/*
&DO I := 1 &TO 5
  &S T%I% := 0
&END
&DO I := 1 &TO 20
  &S SP%I% := ' '
  &S SN%I% := ' '
  &S INV%I% := ' '
  &S REL%I% := ' '
  &S BP%I% := ' '
  &S BN%I% := ' '
&END
/*
/* Variable Definitions:
/* RP - pathname of road coverage
/* ROAD - name of road coverage
/* VO...V5 - haul speeds: VO - access road
/*                        V1 - road class 1 etc.
/* N - number of forest access points
/*T1...T5 - fixed plus variable two-way travel time (minutes)
/*                between mill gate and forest access point
/* SRCHTOL - maximum access road length (map units)
/* BMNUM - number of stand coverage basemaps
/* SP1...SP20 - pathname of stand coverage
/* SN1...SN20 - name of stand coverage
/* INV1...INV20 - name of inventory file
/* REL1...REL20 - relate-item between SN%I%.PAT and REL%I%
/* BP1...BP20 - pathname of barrier coverage
/* BN...BN20 - name of barrier coverage
/*
```

```
&S RP := [READ_FILE %R_UNIT% OK]
&S ROAD := [READ_FILE %R_UNIT% OK]
&S V1 := [READ_FILE %R_UNIT% OK]
&S V2 := [READ_FILE %R_UNIT% OK]
&S V3 := [READ_FILE %R_UNIT% OK]
&S V4 := [READ_FILE %R_UNIT% OK]
&S V5 := [READ_FILE %R_UNIT% OK]
&S V0 := [READ_FILE %R_UNIT% OK]
&S N  := [READ_FILE %R_UNIT% OK]
&DO I := 1 &TO %N%
  &S T%I% := [READ_FILE %R_UNIT% OK]
&END
&S SRCHTOL := [READ_FILE %R_UNIT% OK]
&S BMNUM := [READ_FILE %R_UNIT% OK]
&DO I := 1 &TO %BMNUM%
  &S SP%I% := [READ_FILE %R_UNIT% OK]
  &S SN%I% := [READ_FILE %R_UNIT% OK]
  &S INV%I% := [READ_FILE %R_UNIT% OK]
  &S REL%I% := [READ_FILE %R_UNIT% OK]
  &S BP%I% := [READ_FILE %R_UNIT% OK]
  &S BN%I% := [READ_FILE %R_UNIT% OK]
&END
CLOSE -UNIT %R_UNIT%
/*
/* Start command output file.
/*
&S TAG := [DATE -TAG]
COMO HAUL_%TAG%
TYPE
TYPE CONTROL FILE: %CONTROL%
TYPE
TIME
/*
/* Skip creation of MINARC coverages if road coverage and same search
/* tolerance used in a previous run.
/*
&IF [EXISTS %ROAD%_%SRCHTOL%] &THEN &DO
A %RP%>%ROAD%_%SRCHTOL%
&DATA ARC INFO
&DO I := 1 &TO 5
SEL CENTER%I%.LUT
ERASE CENTER%I%.LUT
Y
&END
Q STOP
&END
&DO I := 1 &TO 5
ARC KILL SAVCENT%I%
&END
&GOTO RERUN
&END
/*
```

```
/* Create and attach to run directory.
/*
ARC CREATEWORKSPACE %ROAD%_%SRCHTOL%
A *>%ROAD%_%SRCHTOL%
/*
/* Parse input coverage %ROAD% into ROAD1...ROAD5 and CENTER.
/*
&DATA ARC ARCEDIT
GRAPHIC OFF
EDITCOVERAGE %RP%>%ROAD%
EDITFEATURE ARCS
SELECT ALL
CALC %ROAD%-ID = %ROAD%-ID * 1000
PUT ROAD5
RESELECT %ROAD%-ID LE 45000
PUT ROAD4
RESELECT %ROAD%-ID LE 35000
PUT ROAD3
RESELECT %ROAD%-ID LE 25000
PUT ROAD2
RESELECT %ROAD%-ID LE 15000
PUT ROAD1
EDITFEATURE LABELS
SELECT ALL
&DO I := 1 &TO 5
&S J := 6 - %I%
RESELECT %ROAD%-ID LE %J%
PUT CENTER%J%
&END
Q
N
&END
TIME
/*
/* BUILD ROAD1...ROAD5 and CENTER, add LIMIT to CENTER.PAT for ALLOCATE.
/*
&DO I := 1 &TO 5
ARC BUILD ROAD%I% LINE
ARC BUILD CENTER%I% POINT
ARC ADDITEM CENTER%I%.PAT CENTER%I%.PAT ~
LIMIT 4 12 F 3
&END
TIME
/*
&DATA ARC INFO
&DO I := 1 &TO 5
SEL CENTER%I%.PAT
CALC LIMIT = 999999
&END
Q STOP
&END
TIME
```

```
/*
/* Run MINARC.F77 to create minimum distance coverages.
/*
&DATA R HUGH>PRJ016>MINARC>MINARC
ROAD1
ROAD2
ROAD3
ROAD4
ROAD5
%BMNUM%
%SRCHTOL%
%SP1%>%SN1%
%SP2%>%SN2%
%SP3%>%SN3%
%SP4%>%SN4%
%SP5%>%SN5%
%SP6%>%SN6%
%SP7%>%SN7%
%SP8%>%SN8%
%SP9%>%SN9%
%SP10%>%SN10%
%SP11%>%SN11%
%SP12%>%SN12%
%SP13%>%SN13%
%SP14%>%SN14%
%SP15%>%SN15%
%SP16%>%SN16%
%SP17%>%SN17%
%SP18%>%SN18%
%SP19%>%SN19%
%SP20%>%SN20%
%BP1%>%BN1%
%BP2%>%BN2%
%BP3%>%BN3%
%BP4%>%BN4%
%BP5%>%BN5%
%BP6%>%BN6%
%BP7%>%BN7%
%BP8%>%BN8%
%BP9%>%BN9%
%BP10%>%BN10%
%BP11%>%BN11%
%BP12%>%BN12%
%BP13%>%BN13%
%BP14%>%BN14%
%BP15%>%BN15%
%BP16%>%BN16%
%BP17%>%BN17%
%BP18%>%BN18%
%BP19%>%BN19%
%BP20%>%BN20%
&END
```

```
TIME
/*
/* GENERATE, CLEAN and BUILD MINARC coverages from MINDST files.
/*
&DO I := 1 &TO 5
&DATA ARC GENERATE MINARC%I%
COPYTICS %RP%>%ROAD%
INPUT MINDST%I%
LINES
Q
&END
TIME
ARC CLEAN MINARC%I% # 0.0 0.0
TIME
ARC BUILD MINARC%I% LINE
TIME
&END
/*
/* Run PREPIT.F77 to add items to %SNx%.PAT, MINARCx.AAT, and INVx for
/* ALLOCATE and storage of analysis results.
/*
&DATA R HUGH>PRJ016>MINARC>PREPIT
%BMNUM%
%SP1%>%SN1%
%INV1%
%SP2%>%SN2%
%INV2%
%SP3%>%SN3%
%INV3%
%SP4%>%SN4%
%INV4%
%SP5%>%SN5%
%INV5%
%SP6%>%SN6%
%INV6%
%SP7%>%SN7%
%INV7%
%SP8%>%SN8%
%INV8%
%SP9%>%SN9%
%INV9%
%SP10%>%SN10%
%INV10%
%SP11%>%SN11%
%INV11%
%SP12%>%SN12%
%INV12%
%SP13%>%SN13%
%INV13%
%SP14%>%SN14%
%INV14%
%SP15%>%SN15%
```

```
%INV15%
%SP16%>%SN16%
%INV16%
%SP17%>%SN17%
%INV17%
%SP18%>%SN18%
%INV18%
%SP19%>%SN19%
%INV19%
%SP20%>%SN20%
%INV20%
MINARC1
MINARC2
MINARC3
MINARC4
MINARC5
&END
TIME
/*
A %RP%>%ROAD%_%SRCHTOL%
/*
&LABEL RERUN
/*
/* Prepare MINARCx coverages for ALLOCATE.
/*
&DATA ARC INFO
&DO I := 1 &TO 5
SELECT MINARC%I%.AAT
CALC RELITEM = MINARC%I%-ID
REDEFINE
34,RC,1,1,I

CALC IMPEDANCE = LENGTH / ( %V0% * 16.667 )
RESEL MINARC%I%-ID LE 55000
RESEL RC LE 5
CALC IMPEDANCE = LENGTH / ( %V5% * 16.667 )
RESEL RC LE 4
CALC IMPEDANCE = LENGTH / ( %V4% * 16.667 )
RESEL RC LE 3
CALC IMPEDANCE = LENGTH / ( %V3% * 16.667 )
RESEL RC LE 2
CALC IMPEDANCE = LENGTH / ( %V2% * 16.667 )
RESEL RC LE 1
CALC IMPEDANCE = LENGTH / ( %V1% * 16.667 )
&END
Q STOP
&END
TIME
/*
/* Perform ALLOCATE on MINARCx coverages.  Results written to
/* MINARCx.AAT files.
/*
```

```
&DATA ARC ALLOCATE
&DO I := 1 &TO 5
READNETWORK MINARC%I% IMPEDANCE IMPEDANCE
READCENTER CENTER%I% # LIMIT
SAVECENTER SAVCENT%I%
RUN
WRITEALLOCATION CENTER CUMIMP
RESET
&END
Q
&END
TIME
/*
/* Define CENTER.LUT.
/*
&DATA ARC INFO
ADIR HUGH>PRJ016>MINARC>INFO
TAKE DATA ARC COST
&DO I := 1 &TO 5
DEFINE CENTER%I%.LUT
SAVCENT%I%#,4,5,B
CENTER,4,5,B
TIME,4,12,F,3

ADD
1
0
%T1%
2
0
%T2%
3
0
%T3%
4
0
%T4%
5
0
%T5%

SEL CENTER%I%.LUT
REL SAVCENT%I%.PAT 1 BY SAVCENT%I%#
CALC CENTER = $1SAVCENT%I%-ID
/*
/* CENTER.LUT (look-up table for forest access point travel times) and
/* CUMIMP (from ALLOCATE) used to calculate round-trip travel times.
/* COST.PG (INFO program) used to calculate haul cost ($/m3) for each
arc.
/*
SEL MINARC%I%.AAT
REL CENTER%I%.LUT 1 BY CENTER
```

```
CALC TIME = ( 2 * CUMIMP ) + $1TIME
RUN COST
&END
Q STOP
&END
TIME
/*
/* PULLITEMS RELITEM and COST from MINARCx.AAT files (TAKE not permitted
/* for extended datafiles).
/*
&DO I := 1 &TO 5
&DATA ARC PULLITEMS MINARC%I%.AAT MINARC%I%.TAB
RELITEM
COST
END
&END
TIME
&END
&DATA ARC INFO
&DO I := 1 &TO 5
SEL MINARC%I%.TAB
SORT ON RELITEM
SAVE %RP%>%ROAD%_%SRCHTOL%>MINARC%I%.TAB INIT
&END
Q STOP
&END
TIME
/*
/*  Initialize CALLS to ROUTINE RELATE.
/*
&S NUM := 1
&S SP := %SP1%
&S SN := %SN1%
&S INV := %INV1%
&S REL := %REL1%
&CALL RELATE
&IF %BMNUM% = 1 &THEN &GOTO QUIT
&S NUM := 2
&S SP := %SP2%
&S SN := %SN2%
&S INV := %INV2%
&S REL := %REL2%
&CALL RELATE
&IF %BMNUM% = 2 &THEN &GOTO QUIT
&S NUM := 3
&S SP := %SP3%
&S SN := %SN3%
&S INV := %INV3%
&S REL := %REL3%
&CALL RELATE
&IF %BMNUM% = 3 &THEN &GOTO QUIT
&S NUM := 4
```

```
&S SP := %SP4%
&S SN := %SN4%
&S INV := %INV4%
&S REL := %REL4%
&CALL RELATE
&IF %BMNUM% = 4 &THEN &GOTO QUIT
&S NUM := 5
&S SP := %SP5%
&S SN := %SN5%
&S INV := %INV5%
&S REL := %REL5%
&CALL RELATE
&IF %BMNUM% = 5 &THEN &GOTO QUIT
&S NUM := 6
&S SP := %SP6%
&S SN := %SN6%
&S INV := %INV6%
&S REL := %REL6%
&CALL RELATE
&IF %BMNUM% = 6 &THEN &GOTO QUIT
&S NUM := 7
&S SP := %SP7%
&S SN := %SN7%
&S INV := %INV7%
&S REL := %REL7%
&CALL RELATE
&IF %BMNUM% = 7 &THEN &GOTO QUIT
&S NUM := 8
&S SP := %SP8%
&S SN := %SN8%
&S INV := %INV8%
&S REL := %REL8%
&CALL RELATE
&IF %BMNUM% = 8 &THEN &GOTO QUIT
&S NUM := 9
&S SP := %SP9%
&S SN := %SN9%
&S INV := %INV9%
&S REL := %REL9%
&CALL RELATE
&IF %BMNUM% = 9 &THEN &GOTO QUIT
&S NUM := 10
&S SP := %SP10%
&S SN := %SN10%
&S INV := %INV10%
&S REL := %REL10%
&CALL RELATE
&IF %BMNUM% = 10 &THEN &GOTO QUIT
&S NUM := 11
&S SP := %SP11%
&S SN := %SN11%
&S INV := %INV11%
```

```
&S NUM := 19
&S SP := %SP19%
&S SN := %SN19%
&S INV := %INV19%
&S REL := %REL19%
&CALL RELATE
&IF %BMNUM% = 19 &THEN &GOTO QUIT
&S NUM := 20
&S SP := %SP20%
&S SN := %SN20%
&S INV := %INV20%
&S REL := %REL20%
&CALL RELATE
/*
/* End command output file, quit HAULCOST.CPL.
/*
&LABEL QUIT
TYPE
TYPE Leaving HAULCOST...
TYPE
COMO -E
&RETURN
/*
/* Routine defines item templates for MINARCx.TAB, and declares the
/* external pathname to the MINARCx.TAB datafile.  Sets up RELATES
/* between INV and MINARCx.TAB files.  The INV relate-item, RELITEM,
/* calculated from %SN%# (same number used for MINARCx.TAB arc ids in
/* MINARC.F77).  Runs TRANSFER.PG, which attaches the minimum cost
/* period (MCP) and minimum cost (MC) values to the INV file.
/*
&ROUTINE RELATE
A %SP%
&DATA ARC INFO
CALC $NM = 1
SEL %INV%
SORT ON %REL%
SEL %SN%.PAT
RESEL %SN%-ID LT 900
SORT ON %REL%
REL %INV% 1 BY %REL% SEQ NUM
CALC $1RELITEM = %SN%# + %NUM%00000
REL
SEL %SN%.PAT
SORT ON %SN%#
SEL %INV%
&DO I := 1 &TO 5
SEL MINARC%I%.TAB
Y
EXTERNAL
Y

ERASE MINARC%I%.TAB
```

```
Y
DEFINE MINARC%I%.TAB
RELITEM,9,9,I
COST,4,12,F,3

SEL MINARC%I%.TAB
EXTERNAL
%RP%>%ROAD%_%SRCHTOL%>MINARC%I%.TAB
&END
SEL %INV%
SORT ON RELITEM
&DO I := 1 &TO 5
REL MINARC%I%.TAB %I% BY RELITEM SEQ
&END
ADIR HUGH>PRJ016>MINARC>INFO
TAKE DATA ARC TRANSFER
RUN TRANSFER
SEL %INV%
SORT ON %REL%
Q STOP
&END
TIME
&RETURN
```

```
C  ******************************************************************
C
C  Program:          MINARC.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             13 July 1987
C  Modified:         January 1988
C  Status:           Operational
C
C  ******************************************************************
C
C  Read input from HAULCOST.CPL.
C
C  SUBROUTINES:
C
C    CENTRE - calculates centre coordinates and maximum radii of
C             BARFIL polygons
C
C    GETLAB - reads label coordinates and poly# for STDFIL polygons
C
C    BAROPN - opens BARFIL .PAL and .ARC files
C
C    BARCLS - closes BARFIL .PAL and .ARC files
C
C    MINOPN - opens file unit 45
C
C    MINCLS - writes 'END' and closes file unit 45
C
C    ARCDST - calculates minimum distance from STDFIL label points
C             to ROADFIL arcs
C
C    BARRIER - deletes segments of minimum distance arcs that pass
C              through barriers
C            - sets flag to write intersected barriers to MINDST file
C
C    ADDBAR - writes intersected barriers to MINDST file
C
C    ADROAD - writes ROADFIL arcs to MINDST file
C
C  ******************************************************************
C
$INSERT CMN.CMN
C
      INTEGER IERR
      REAL SRCHTOL
      REAL*8 NUMIN
      CHARACTER*5 LIST
      CHARACTER*128 ROADFIL(5),STDFIL(20),MINFIL(5),BARFIL(20)
C
      LIST='12345'
C
C  Initialize ARC modules.
```

```
C
      CALL TTINIT
      CALL MINIT
      CALL LUNINI
      CALL VINIT
      CALL INFINT
C
C  Read control file created in DEFBAT.CPL.
C
      CALL TTYOFF
      DO 100 I=1,5
        CALL TTRLIN(128,ROADFIL(I),IERR)
100   CONTINUE
      CALL TTRNUM(NUMIN,IERR)
      BMNUM=IDINT(NUMIN)
      CALL TTRNUM(NUMIN,IERR)
      SRCHTOL=SNGL(NUMIN)
      DO 110 I=1,20
        CALL TTRLIN(128,STDFIL(I),IERR)
110   CONTINUE
      DO 120 I=1,20
        CALL TTRLIN(128,BARFIL(I),IERR)
120   CONTINUE
      CALL TTYON
C
C  Call subroutines to read initial ARC data.
C
      CALL CENTRE(BARFIL)
      CALL GETLAB(STDFIL)
      CALL BAROPN(BARFIL)
C
C  Perform MINARC algorithm.
C
      DO 200 I=1,5
        MINFIL(I)='MINDST'//LIST(I:I)
        CALL MINOPN(MINFIL(I))
        CALL ARCDST(ROADFIL(I),SRCHTOL)
        CALL BARRIER
        CALL ADDBAR(BARFIL)
        CALL ADROAD(I,ROADFIL(I))
        CALL MINCLS
200   CONTINUE
      CALL BARCLS
C
      STOP
      END
```

```
C   ********************************************************************
C
C   CMN.CMN - $INSERT
C
C   Variable definitions:
C
C   LAB(i,j) - i=1, x coordinate of mindst point in ROADFIL
C              i=2, y coordinate of mindst point in ROADFIL
C              i=3, x coordinate of STDFIL label point
C              i=4, y coordinate of STDFIL label point
C              j=polygon number
C
C   XSHIFT(i) - x coordinate of centre of ith polygon in BARFIL
C   YSHIFT(i) - y coordinate of centre of ith polygon in BARFIL
C   RADIUS(i) - length from centre to furthest point on polygon perimeter
C
C   MLIN(i) - slope of mindst arc i
C   B(i) - y-intercept of mindst arc i
C
C   NUMLAB - number of label points in STDFIL
C   NUMCIR - number of polygons in BARFIL
C   BARWRT(i) - print flag for BARFIL polygon i, 1=intersection=write
C   JBARPAL,KBARARC - channel numbers for BARFIL PAL and ARC files
C   LABID(i) - label id of polygon i
C   BMNUM - number of basemaps in forest
C
C   ********************************************************************

C
      REAL LAB(4,2500,20),XSHIFT(2500,20),YSHIFT(2500,20),
     &     RADIUS(2500,20),MLIN(2500,20),B(2500,20)
      INTEGER*4 NUMLAB(20),NUMCIR(20),BARWRT(2500,20),
     &          JBARPAL(20),KBARARC(20),LABID(2500,20),BMNUM
      COMMON /ONE/ NUMLAB,LAB,NUMCIR,XSHIFT,YSHIFT,RADIUS,BARWRT,
     &             MLIN,B,JBARPAL,KBARARC,LABID,BMNUM
```

```
      SUBROUTINE CENTRE(BARFIL)
C  *****************************************************************
C
C  Program:          CENTRE.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             13 July 1987
C  Status:           Operational
C
C  *****************************************************************
C
C  Open BARFIL .PAL for reading.C
C  Store, in CMN.CMN, for each BARFIL polygon:
C     1) XSHIFT and YSHIFT, x-y coordinates of polygon centre
C
C     2) RADIUS, the length from the centre to the furthest
C        point on the polygon
C
C  *****************************************************************
C
$INSERT CMN.CMN
$INSERT SOFTARC>INSERTS>PALREC.DEF
C
      INTEGER IERR,IFMREC,JCHAN,JKIND,JWRITE,JACCES,JRECL
      REAL LX,LY
      CHARACTER*128 BARFIL(20),PALNAM
      DATA JACCES,JWRITE /2,2/
C
      DO 100 I=1,BMNUM
        CALL ANAME(BARFIL(I),PALNAM,11)
        CALL VOPEN(JCHAN,PALNAM,JKIND,JWRITE,JACCES,JRECL,IERR)
C
200     CONTINUE
        CALL VREAD(JCHAN,IFMREC,IPBUFF,LPBUFF,IERR)
        IF(IERR.EQ.-1) GOTO 300
        NUMCIR(I)=IFMREC
C
C  BOXPAL coordinates:        (3),(4)
C                       (1),(2)          lower left, upper right
C
        LX=(BOXPAL(3)-BOXPAL(1))/2.0
        LY=(BOXPAL(4)-BOXPAL(2))/2.0
        XSHIFT(IFMREC,I)=BOXPAL(1)+LX
        YSHIFT(IFMREC,I)=BOXPAL(2)+LY
        RADIUS(IFMREC,I)=SQRT(LX**2+LY**2)
        GOTO 200
C
300     CONTINUE
        CALL VCLOSE(JCHAN)
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GETLAB(STDFIL)
C  *****************************************************************
C
C  Program:           GETLAB.F77
C  Written by:        W.H. Lougheed
C  Computer:          PR1ME 550-II
C  Date:              15 July 1987
C  Status:            Operational
C
C  *****************************************************************
C
C  For each STDFIL polygon, store in CMN.CMN:
C     1) LAB(3:4,j) = x-y coordinates of label point
C     2) LABID(j) = polygon number (POLY#)
C
C  *****************************************************************
C
$INSERT SOFTARC>INSERTS>LABREC.DEF
$INSERT CMN.CMN
C
      INTEGER IERR,JKIND,JRECL,JACCES,JWRITE,JCHAN,LLBUFF
      CHARACTER*128 STDFIL(20),LABNAM
      DATA JWRITE,JACCES /2,2/
C
      DO 100 I=1,BMNUM
C
C  Open STDFIL .LAB file for reading.
C
        CALL ANAME(STDFIL(I),LABNAM,2)
        CALL VOPEN(JCHAN,LABNAM,JKIND,JWRITE,JACCES,JRECL,IERR)
        IF(IERR.NE.0) CALL FATAL('*** ERROR OPENING LAB FILE ***',30)
        NUMLAB(I)=0
200     CONTINUE
          CALL VREAD(JCHAN,IFMREC,ILBUFF,LLBUFF,IERR)
          IF(IERR.EQ.-1) GOTO 300
C
C  Stand polygon user-ids between 1 and 899.
C
          IF(NAMPOL.LT.900) THEN
            NUMLAB(I)=NUMLAB(I)+1
            LAB(3,NUMLAB(I),I)=TIE(1)
            LAB(4,NUMLAB(I),I)=TIE(2)
C
C  LABID coded for unique identification of stands.
C
            LABID(NUMLAB(I),I)=IDPOL+(I*100000)
          ENDIF
        GOTO 200
300     CALL VCLOSE(JCHAN)
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BAROPN(BARFIL)
C  *****************************************************************
C
C  Program:         BAROPN.F77
C  Written by:      W.H. Lougheed
C  Computer:        PR1ME 550-II
C  Date:            14 July 1987
C  Status:          Operational
C
C  *****************************************************************
C
C  Open BARFIL .ARC and .PAL files.
C
C  *****************************************************************
C
$INSERT CMN.CMN
C
      INTEGER IERR,JKIND,JWRITE,JACCES,JRECL
     &              KKIND,KWRITE,KACCES,KRECL
      CHARACTER*128 BARFIL(20),PALNAM,ARCNAM
      DATA JWRITE,JACCES,KWRITE,KACCES /4*2/
C
      DO 100 I=1,BMNUM
        CALL ANAME(BARFIL(I),PALNAM,11)
        CALL VOPEN(JBARPAL(I),PALNAM,JKIND,JWRITE,JACCES,JRECL,IERR)
        CALL ANAME(BARFIL(I),ARCNAM,1)
        CALL VOPEN(KBARARC(I),ARCNAM,KKIND,KWRITE,KACCES,KRECL,IERR)
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BARCLS
C  ********************************************************************
C
C  Program:          BARCLS.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             14 July 1987
C  Status:           Operational
C
C  ********************************************************************
C
C  VREC Utilitiy VCLOSE to CLOSE BARFIL.ARC and BARFIL.PAL.
C
C  ********************************************************************
C
$INSERT CMN.CMN
C
      DO 100 I=1,BMNUM
        CALL VCLOSE(JBARPAL(I))
        CALL VCLOSE(KBARARC(I))
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MINOPN(MINFIL)
C  ****************************************************************
C
C  Program:          MINOPN.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             13 July 1987
C  Status:           Operational
C
C  ****************************************************************
C
C  Open file 'MINFIL' on unit 45.
C
C  ****************************************************************
C
      CHARACTER*128 MINFIL
      OPEN(45,FILE=MINFIL)
      RETURN
      END


      SUBROUTINE MINCLS
C  ****************************************************************
C
C  Program:          MINCLS.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             07 January 1987
C  Status:           Operational
C
C  ****************************************************************
C
C  Write 'END' to unit 45, close unit 45.
C
C  ****************************************************************
C
      WRITE(45,'(A)') 'END'
      CLOSE(45)
      RETURN
      END
```

```
      SUBROUTINE ARCDST(ROADFIL,SRCHTOL)
C  *****************************************************************
C
C  Program:         ARCDST.F77
C  Written by:      W.H. Lougheed
C  Computer:        PR1ME 550-II
C  Date:            13 July 1987
C  Modified:        January 1988
C  Status:          Operational
C
C  *****************************************************************
C
C
C  ARCDST:  Accesses file ROADFIL.ARC with VREC utility subroutines
C           (VOPEN,VREAD,VREWND,VCLOSE) [ARC Programmers Manual]
C
C           1) Sequentially read through .ARC file, store coordinate
C              of the shortest distance between STDFIL labels
C              LAB(3:4,j) and ROADFIL arcs in LAB(1:2,j), replacing
C              coordinate when a shorter distance found.
C              ** to avoid using SQRT, relative distance used **
C              If minimum distance found is greater than SRCHTOL,
C              flag LAB(3:4,j) with -1, inaccessible.
C
C           2) Rewind ROADFIL.ARC file
C
C           3) Process next STDFIL label as per 1)
C
C  *****************************************************************
C
$INSERT SOFTARC>INSERTS>ARCREC.DEF
$INSERT CMN.CMN
C
      INTEGER ICHAN,ITYPE,IWRITE,IACCES,IRECL,IERR
      REAL DISTSQ,MINDST,SRCHTOL
      CHARACTER*128 ROADFIL,ARCNAM
      DATA IWRITE,IACCES /2,2/
C
C  Open ROADFIL .ARC file for reading.
C
      CALL ANAME(ROADFIL,ARCNAM,1)
      CALL VOPEN(ICHAN,ARCNAM,ITYPE,IWRITE,IACCES,IRECL,IERR)
      DO 100 I=1,BMNUM
        DO 200 J=1,NUMLAB(I)
          L=1
300       CONTINUE
C
C  Read arc, test for minimum relative length.
C
            CALL VREAD(ICHAN,IREC,IABUFF,LABUFF,IERR)
            IF(IERR.EQ.-1) GOTO 400
            DO 500 K=1,NPNTS
```

```
              DISTSQ=(PNTS(1,K)-LAB(3,J,I))**2+(PNTS(2,K)-LAB(4,J,I))**2
              IF(L.EQ.1) THEN
                MINDST=DISTSQ
                L=0
              ENDIF
C
C  Store coordinates of closest road vertex in LAB(1:2,j).
C
              IF(MINDST.GE.DISTSQ) THEN
                MINDST=DISTSQ
                LAB(1,J,I)=PNTS(1,K)
                LAB(2,J,I)=PNTS(2,K)
               ENDIF
500          CONTINUE
          GOTO 300
C
400       CALL VREWND(ICHAN)
C
C  Test whether MINDST is less than SRCHTOL, if not flag LAB(1:2,j)
C  to indicate stand not accessible (label is ignored in further
C  processing)
C
          MINDST=SQRT(MINDST)
          IF(MINDST.GT.SRCHTOL) THEN
            LAB(1,J,I)=-1.0
            LAB(2,J,I)=-1.0
          ENDIF
200     CONTINUE
100   CONTINUE
      CALL VCLOSE(ICHAN)
      RETURN
      END
```

```
      SUBROUTINE BARRIER
C   ******************************************************************
C
C  Program:          BARRIER.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             13 July 1987
C  Status:           Operational
C
C   ******************************************************************
C
C  Each MINDST arc checked for intersection with BARFIL polygons:
C
C      1)  CALL XCIRCL, XNO = number of potential intersections
C                       PNO(XNO) = polygon numbers
C
C      2)  CALL XPOLY, called XNO times for each MINDST arc, returning
C          N intecepts in array T
C
C      3)  Sort intersections to determine land/barrier/land sequence
C
C      4)  CALL PUTARC to write mindst endpoints, with barrier
C          segments excluded
C
C   ******************************************************************
C
$INSERT CMN.CMN
C
      REAL T(4,20),BINT(4,20),TEMP
      INTEGER PNO(100),MNO(100),FLAG,XNO
C
      DO 50 I=1,BMNUM
        DO 50 J=1,NUMCIR(I)
          BARWRT(J,I)=0
50    CONTINUE
C
      DO 100 I=1,BMNUM
        DO 200 J=1,NUMLAB(I)
          IF(LAB(1,J,I).EQ.-1.0) GOTO 200
          CALL XCIRCL(I,J,XNO,PNO,MNO)
          IF(XNO.EQ.0) THEN
            CALL PUTARC(I,J,LABID(J,I),LAB(1,J,I),
     &                  LAB(2,J,I),LAB(3,J,I),LAB(4,J,I))
            GOTO 200
          ENDIF
C
C  Call S/R XPOLY XNO times, returning N intercepts in array T
C
C    KEY: T(1:2,y) - x,y coordinate of first intercept with polygon I
C         T(3:4,y) - x,y coordinate of second     "       "     "    "
C         1-3 = barrier  |
C         3-5 = land     | sorted
```

```
C          5-7 = barrier   |
C
           N=0
           DO 300 L=1,XNO
             CALL XPOLY(I,J,PNO(L),MNO(L),T,N1)
             IF(N1.NE.0) THEN
               DO 301 M=1,N1
               N=N+1
                 DO 302 M1=1,4
                   BINT(M1,N)=T(M1,M)
302              CONTINUE
301            CONTINUE
             ENDIF
300        CONTINUE
C
           IF(N.EQ.0) THEN
             CALL PUTARC(I,J,LABID(J,I),LAB(1,J,I),
     &                   LAB(2,J,I),LAB(3,J,I),LAB(4,J,I))
             GOTO 200
           ENDIF
C
C  Sort BINT, increasing if road vertex < centriod
C             decreasing if    centriod < road vertex
C
           IF(LAB(1,J,I).LT.LAB(3,J,I)) THEN
C
C  Sort intersections, increasing.
C
400          FLAG=0
             DO 500 K=1,(N-1)
               IF(BINT(1,K).GT.BINT(1,K+1)) THEN
                 DO 501 L=1,4
                   TEMP=BINT(L,K)
                   BINT(L,K)=BINT(L,K+1)
                   BINT(L,K+1)=TEMP
501              CONTINUE
               FLAG=1
               ENDIF
500          CONTINUE
             IF(FLAG.EQ.1) GOTO 400
           ELSE
C
C  Sort intersections, decreasing.
C
600          FLAG=0
             DO 700 K=1,(N-1)
               IF(BINT(1,K).LT.BINT(1,K+1)) THEN
                 DO 701 L=1,4
                   TEMP=BINT(L,K)
                   BINT(L,K)=BINT(L,K+1)
                   BINT(L,K+1)=TEMP
701              CONTINUE
```

```
              FLAG=1
              ENDIF
700         CONTINUE
            IF(FLAG.EQ.1) GOTO 600
          ENDIF
C
C  Write arc endpoints to MINFIL.
C
          CALL PUTARC(I,J,999999,LAB(1,J,I),LAB(2,J,I),
     &                BINT(1,1),BINT(2,1))
          DO 800 K=1,N-1
            CALL PUTARC(I,J,999999,BINT(3,K),BINT(4,K),
     &                  BINT(1,K+1),BINT(2,K+1))
800       CONTINUE
          CALL PUTARC(I,J,LABID(J,I),BINT(3,N),BINT(4,N),
     &                LAB(3,J,I),LAB(4,J,I))
200     CONTINUE
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XCIRCL(I,J,XNO,PNO,MNO)
C   ******************************************************************
C
C   Program:          XCIRCL.F77
C   Written by:       W.H. Lougheed
C   Computer:         PR1ME 550-II
C   Date:             13 July 1987
C   Status:           Operational
C
C   ******************************************************************
C
C   Screen arcs for possible intersection with a polygon by:
C
C   1) Calculate slope of arc.
C
C   2) Calculate root of quadratic equation for arc and each BARFIL
C      bounding circle (see CENTRE.F77), positive root indicates
C      possible intersection with BARFIL polygon.
C
C   3) Return number of possible intersections (XNO), and associated
C      BARFIL polygon numbers (PNO).
C
C
C   ******************************************************************
C
$INSERT CMN.CMN
C
      INTEGER I,J,K,L,XNO,PNO(100),MNO(100)
      REAL T,QA,QB,QC
C
      XNO=0
      IF(LAB(3,J,I).EQ.LAB(4,J,I)) THEN
        MLIN(J,I)=9.99 E25
      ELSE
        MLIN(J,I)=(LAB(4,J,I)-LAB(2,J,I))/(LAB(3,J,I)-LAB(1,J,I))
      ENDIF
C
C   Calculate root of quadratic equation.
C
      B(J,I)=LAB(4,J,I)-(LAB(3,J,I)*MLIN(J,I))
      DO 100 K=1,BMNUM
        DO 100 L=2,NUMCIR(I)
        QA=(MLIN(J,I)**2+1.0)
        QB=2.0*(MLIN(J,I)*(B(J,I)-YSHIFT(L,K))-XSHIFT(L,K))
        QC=(B(J,I)-YSHIFT(L,K))**2+(XSHIFT(L,K)**2)-RADIUS(L,K)**2
        T=QB**2-(4.0*QA*QC)
C
C   If root is positive, store poly#.
C
        IF(T.GT.0.0) THEN
          XNO=XNO+1
          PNO(XNO)=L
```

```
          MNO(XNO)=K
        ENDIF
C
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XPOLY(I,J,XPOLY,XMAP,T,N)
C  ******************************************************************
C
C  Program:          XPOLY.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             13 July 1987
C  Modified:         January 1988
C  Status:           Operational
C
C  ******************************************************************
C
C     1) Check for intersection of two lines, one being the MINDST
C        arc, the other being the line between two vertices in the
C        arc forming the BARFIL perimeter.
C
C     2) Return sorted intersections in array L.
C
C     3) Switch flag BARWRT to 1 if intersections found.
C
C  ******************************************************************
C
$INSERT SOFTARC>INSERTS>ARCREC.DEF
$INSERT SOFTARC>INSERTS>PALREC.DEF
$INSERT CMN.CMN
C
      INTEGER I,J,IERR,XPOLY,XMAP,N,FLAG,FLAG1
      REAL MARC,BARC,T(4,20),TEMP,X(40),Y(40)
C
C  Read .PAL for list of bounding arcs.
C
      CALL VREADR(JBARPAL(XMAP),XPOLY,IPBUFF,LPBUFF,IERR)
      N=0
      DO 100 K=1,NPAL
        IF(IPAL(1,K).EQ.0) GOTO 900
        IARCREC=IABS(IPAL(1,K))
C
C  Read .ARC for vertex coordinates.
C
        CALL VREADR(KBARARC(XMAP),IARCREC,IABUFF,LABUFF,IERR)
        DO 200 L=1,NPNTS-1
          IF(PNTS(1,L+1).EQ.PNTS(1,L)) THEN
            MARC=9.99 E25
          ELSE
            MARC=(PNTS(2,L+1)-PNTS(2,L))/(PNTS(1,L+1)-PNTS(1,L))
          ENDIF
          BARC=PNTS(2,L)-(MARC*PNTS(1,L))
C
C  Calculate X intersection point.
C
          TEMP=MARC-MLIN(J,I)
          IF((MARC.EQ.MLIN(J,I)).OR.TEMP.EQ.0.0)  GOTO 200
```

```
          XX=(B(J,I)-BARC)/(MARC-MLIN(J,I))
          IF(((XX.GT.PNTS(1,L).AND.XX.LT.PNTS(1,L+1)).OR.
     1      (XX.LT.PNTS(1,L).AND.XX.GT.PNTS(1,L+1))).AND.
     2      ((XX.GT.LAB(1,J,I).AND.XX.LT.LAB(3,J,I)).OR.
     3      (XX.LT.LAB(1,J,I).AND.XX.GT.LAB(3,J,I)))) THEN
            N=N+1
            Y(N)=MLIN(J,I)*XX+B(J,I)
            X(N)=XX
          ENDIF
200     CONTINUE
100   CONTINUE
900   IF(N.EQ.0.OR.N.EQ.1) THEN
        N=0
        GOTO 300
      ENDIF
      FLAG1=0
      DO 101 L=3,19,2
        IF(N.EQ.L) FLAG1=1
101   CONTINUE
      IF(LAB(1,J,I).LT.LAB(3,J,I)) THEN
C
C  Sort intersections, increasing
C
400     FLAG=0
        DO 500 K=1,N-1
          IF(X(K).GT.X(K+1)) THEN
              TEMP=X(K)
              X(K)=X(K+1)
              X(K+1)=TEMP
              TEMP=Y(K)
              Y(K)=Y(K+1)
              Y(K+1)=TEMP
              FLAG=1
          ENDIF
500     CONTINUE
        IF(FLAG.EQ.1) GOTO 400
      ELSE
C
C  Sort each intersection, decreasing
C
600     FLAG=0
        DO 700 K=1,N-1
          IF(X(K).LT.X(K+1)) THEN
              TEMP=X(K)
              X(K)=X(K+1)
              X(K+1)=TEMP
              TEMP=Y(K)
              Y(K)=Y(K+1)
              Y(K+1)=TEMP
              FLAG=1
          ENDIF
700     CONTINUE
```

```
      IF(FLAG.EQ.1) GOTO 600
      ENDIF
C
C  Sequentially assign endpoint coordinates to T.
C
      IF(FLAG1.EQ.1) THEN
        T(1,1)=X(1)
        T(2,1)=Y(1)
        T(3,1)=X(N)
        T(4,1)=Y(N)
        N=2
      ELSE
        L=0
        DO 800 K=1,N-1,2
        L=L+1
          T(1,L)=X(K)
          T(2,L)=Y(K)
          T(3,L)=X(K+1)
          T(4,L)=Y(K+1)
800     CONTINUE
      ENDIF
      BARWRT(XPOLY,I)=1
      N=N/2
C
300   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADDBAR(BARFIL)
C  *******************************************************************
C
C  Program:         ADDBAR.F77
C  Written by:      W.H. Lougheed
C  Computer:        PR1ME 550-II
C  Date:            13 July 1987
C  Status:          Operational
C
C  *******************************************************************
C
C  CALL PUTARC to write BARFIL polygon if flag BARWRT(poly#) = 1
C
C  *******************************************************************
C
$INSERT SOFTARC>INSERTS>ARCREC.DEF
$INSERT SOFTARC>INSERTS>PALREC.DEF
$INSERT PRJ016>MINARC>CMN.CMN
C
      INTEGER IARCREC,IERR
      CHARACTER*128 BARFIL(20)
C
      DO 100 I=1,BMNUM
        DO 200 J=2,NUMCIR(I)
          IF(BARWRT(J,I).EQ.1) THEN
C
C  Read PAL record for polygon to find number (NPAL) and id (IPAL)
C  of bounding arcs.
C
            CALL VREADR(JBARPAL(I),J,IPBUFF,LPBUFF,IERR)
            DO 300 K=1,NPAL
              IARCREC=IABS(IPAL(1,K))
              IF(IPAL(1,K).EQ.0) GOTO 900
C
C  Read ARC record for arc vertices.
C
              CALL VREADR(KBARARC(I),IARCREC,IABUFF,LABUFF,IERR)
              DO 400 L=1,NPNTS-1
C
C  CALL PUTARC to write vertex.
C
                CALL PUTARC(I,NUMLAB(I)+1,999999,PNTS(1,L),PNTS(2,L),
     &                            PNTS(1,L+1),PNTS(2,L+1))
400           CONTINUE
300         CONTINUE
900       ENDIF
200     CONTINUE
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ADROAD(I,ROADFIL)
C   *****************************************************************
C
C   Program:          ADROAD.F77
C   Written by:       W.H. Lougheed
C   Computer:         PR1ME 550-II
C   Date:             13 July 1987
C   Status:           Operational
C
C   *****************************************************************
C
C   CALL PUTARC to write ROADFIL arcs to MINDST files.
C
C   *****************************************************************
C
$INSERT SOFTARC>INSERTS>ARCREC.DEF
$INSERT CMN.CMN
C
      INTEGER IERR,ICHAN,IKIND,IWRITE,IACCES,IRECL
      CHARACTER*128 ROADFIL,ARCNAM
      DATA IWRITE,IACCES /2,2/
C
C   Open ROADFIL .ARC file.
C
      CALL ANAME(ROADFIL,ARCNAM,1)
      CALL VOPEN(ICHAN,ARCNAM,IKIND,IWRITE,IACCES,IRECL,IERR)
100   CONTINUE
C
C   Read .ARC record for ROADFIL vertices.
C
      CALL VREAD(ICHAN,IFMREC,IABUFF,LABUFF,IERR)
      IF(IERR.EQ.-1) GOTO 300
      DO 200 J=1,NPNTS-1
C
C   CALL PUTARC to write vertices to MINDST file.
C
        CALL PUTARC(I,NUMLAB(I)+1,NAME,PNTS(1,J),PNTS(2,J),
     &                PNTS(1,J+1),PNTS(2,J+1))
200   CONTINUE
      GOTO 100
300   CONTINUE
      CALL VCLOSE(ICHAN)
      RETURN
      END
```

```
      SUBROUTINE PUTARC(MAP,NO,ID,X1,Y1,X2,Y2)
C   ******************************************************************
C
C   Program:          PUTARC.F77
C   Written by:       W.H. Lougheed
C   Computer:         PR1ME 550-II
C   Date:             13 July 1987
C   Status:           Operational
C
C   ******************************************************************
C
C
C   1) Check each arc for similarity, if found, shift endpoint.
C
C   2) Write arc id and endpoint coordinates to MINFIL in
C      ARC GENERATE format
C
C   ******************************************************************
C
$INSERT CMN.CMN
      REAL X1,X2,Y1,Y2,MTST,MI
      INTEGER MAP,NO,ID
C
C   Test for duplicate arcs.  If found move X2+1/1000th*X2
C
C   MAP= basemap number
C   NO = label number of arc to be checked for similarity
C   ID = 999999 assumed to be road or barrier, not checked for similarity
C
      IF((ID.NE.999999).AND.(NO.LE.NUMLAB(MAP))) THEN
        IF((LAB(3,NO,MAP)-LAB(1,NO,MAP)).NE.0.0) THEN
          MTST=((LAB(4,NO,MAP)-LAB(2,NO,MAP))/
     &          (LAB(3,NO,MAP)-LAB(1,NO,MAP))*1000.0)
        ELSE
          MTST=9.99 E25
        ENDIF
        DO 100 I=1,BMNUM
          DO 200 J=1,NUMLAB(I)
            IF((LAB(3,J,I)-LAB(1,J,I)).NE.0.0) THEN
              MI=((LAB(4,J,I)-LAB(2,J,I))/
     &             (LAB(3,J,I)-LAB(1,J,I))*1000.0)
            ELSE
              MI=9.99 E25
            ENDIF
            IF((LAB(1,NO,MAP).EQ.LAB(1,J,I)).AND.
     &         (NO.NE.J).AND.
     &         (MTST.EQ.MI)) THEN
              X2=X2+(X2/1000.0)
              LAB(3,NO,MAP)=X2
            ENDIF
200       CONTINUE
100     CONTINUE
```

```
      ENDIF
C
C  Write arc id and endpoint coordinates to MINFIL.
C
        WRITE(45,'(I8)') ID
        WRITE(45,'(2F12.3)') X1,Y1
        WRITE(45,'(2F12.3)') X2,Y2
        WRITE(45,'(A)') 'END'
      RETURN
      END
```

```
C   *******************************************************************
C
C   Program:          PREPIT.F77
C   Written by:       W.H. Lougheed
C   Computer:         PR1ME 550-II
C   Date:             13 July 1987
C   Modified:         January 1988
C   Status:           Operational
C
C   *******************************************************************
C
C   PREPIT.F77 uses ISP Utilities [ARC Programmers Manual] to add
C   items to INV for RELATE and MINARCi for ARC ALLOCATE.
C
C   *******************************************************************
C
      INTEGER IW,OW,NDEC,IERR,IWI1,IWI9,OWI1,OWI9,NDECI,ACCES,
     &        FNUM,NUMREC,RECLEN,ITEMAR(4),EXISTS
      REAL*8 NUMIN
      REAL BMNUM
      CHARACTER*1 TYPE,TYPEI
      CHARACTER*8 USER
      CHARACTER*16 ITEM
      CHARACTER*32 COVER,AFTER,AATNAM,PATNAM
      CHARACTER*128 DIRECT,BM(20),MINARC(5),INV(20)
C
      DATA AFTER /'                                '/
      DATA IW,OW,TYPE,NDEC /4,12,'F',3/
      DATA IWI1,OWI1,IWI9,OWI9,TYPEI,NDECI /1,1,9,9,'I',0/
      DATA ACCES /1/
C
C   Initialize ARC modules.
C
      CALL MINIT
      CALL LUNINI
      CALL TTINIT
      CALL INFINT
C
      CALL TTYOFF
C
C   Read input coverage names.
C
      CALL TTRNUM(NUMIN,IERR)
      BMNUM=IDINT(NUMIN)
      DO 100 I=1,20
        CALL TTRLIN(128,BM(I),IERR)
        CALL TTRLIN(128,INV(I),IERR)
100   CONTINUE
      DO 200 I=1,5
        CALL TTRLIN(128,MINARC(I),IERR)
200   CONTINUE
      CALL TTYON
```

```
C
C  Add items to INV(i).
C
         DO 150 I=1,BMNUM
           CALL INFARC(BM(I),DIRECT,USER,COVER)
           ITEM='RELITEM'//AFTER(1:9)
           CALL ADDIT(INV(I),DIRECT,USER,INV(I),DIRECT,USER,ITEM,
     &                IWI9,OWI9,TYPEI,NDECI,AFTER,IERR)
           ITEM='MCP'//AFTER(1:13)
           CALL ADDIT(INV(I),DIRECT,USER,INV(I),DIRECT,USER,ITEM,
     &                IWI1,OWI1,TYPEI,NDECI,AFTER,IERR)
           ITEM='MC'//AFTER(1:14)
           CALL ADDIT(INV(I),DIRECT,USER,INV(I),DIRECT,USER,ITEM,
     &                IW,OW,TYPE,NDEC,AFTER,IERR)
150      CONTINUE
C
       CALL INFARC(MINARC(1),DIRECT,USER,COVER)
       CALL INFNAM(COVER,2,AATNAM)
       CALL INFOPN(AATNAM,DIRECT,USER,ACCES,FNUM,NUMREC,RECLEN,IERR)
       ITEM='RELITEM'//AFTER(1:9)
       CALL INFEXI(FNUM,ITEM,ITEMAR,EXISTS)
       CALL INFCLS(FNUM)
C
C  If items do not exist, add items to MINARC coverages.
C
       IF(EXISTS.EQ.0) THEN
         DO 300 I=1,5
           CALL INFARC(MINARC(I),DIRECT,USER,COVER)
           CALL INFNAM(COVER,2,AATNAM)
           ITEM='RELITEM'//AFTER(1:9)
           CALL ADDIT(AATNAM,DIRECT,USER,AATNAM,DIRECT,USER,ITEM,
     &                IWI9,OWI9,TYPEI,NDECI,AFTER,IERR)
           ITEM='IMPEDANCE'//AFTER(1:7)
           CALL ADDIT(AATNAM,DIRECT,USER,AATNAM,DIRECT,USER,ITEM,
     &                IW,OW,TYPE,NDEC,AFTER,IERR)
           ITEM='TIME'//AFTER(1:12)
           CALL ADDIT(AATNAM,DIRECT,USER,AATNAM,DIRECT,USER,ITEM,
     &                IW,OW,TYPE,NDEC,AFTER,IERR)
           ITEM='COST'//AFTER(1:12)
           CALL ADDIT(AATNAM,DIRECT,USER,AATNAM,DIRECT,USER,ITEM,
     &                IW,OW,TYPE,NDEC,AFTER,IERR)
300      CONTINUE
       ENDIF
C
       STOP
       END
```

```
 PROGRAM NAME: COST
10000  PROGRAM SECTION ONE
  10001 FORMAT $NUM1,8,16,F,2
  10002 FORMAT $NUM2,8,16,F,2
  10003 FORMAT $NUM3,8,16,F,2
  10004 FORMAT $NUM4,8,16,F,2
  10005 FORMAT $NUM5,8,8,I
  10006 FORMAT $NUM6,8,16,F,2
  10007 FORMAT $NUM7,8,16,F,2
  10008 CALC $NUM1 = ( 15.86 + 0.20 ) * 8
  10009 CALC $NUM2 = ( 15.86 + 0.20 ) * 1.5
  10010 CALC $NUM3 = 42
  10011 CALC $NUM4 = 50
  20000 PROGRAM SECTION TWO
  20001 IF TIME GT 360
  20002   CALC $NUM5 = 1
  20003 ELSE
  20004   CALC $NUM5 = 570 / TIME
  20005 ENDIF
  20006 CALC $NUM6 = ( TIME / 60 ) * $NUM5
  20007 CALC $NUM7 = $NUM6 * $NUM3
  20008 IF $NUM6 GT 8
  20009   CALC $NUM6 = ( ( $NUM6 + 0.25 ) - 8 ) * $NUM2
  20010 ELSE
  20011   CALC $NUM6 = $NUM2 * 0.5
  20012 ENDIF
  20013 CALC COST = ( $NUM1 + $NUM6 + $NUM7 ) / ( $NUM4 * $NUM5 )
  30000 PROGRAN SECTION THREE
  30001 END
```

```
PROGRAM NAME: TRANSFER
 10000  PROGRAM SECTION ONE
 20000 PROGRAM SECTION TWO
 20001 CALC MCP = 0
 20002 CALC MC = 999999
 20003 IF $1COST GT 0
 20004   CALC MCP = 1
 20005   CALC MC = $1COST
 20006 ENDIF
 20007 IF $2COST GT 0
 20008   IF $2COST LT MC
 20009     CALC MCP = 2
 20010     CALC MC = $2COST
 20011   ENDIF
 20012 ENDIF
 20013 IF $3COST GT 0
 20014   IF $3COST LT MC
 20015     CALC MCP = 3
 20016     CALC MC = $3COST
 20017   ENDIF
 20018 ENDIF
 20019 IF $4COST GT 0
 20020   IF $4COST LT MC
 20021     CALC MCP = 4
 20022     CALC MC = $4COST
 20023   ENDIF
 20024 ENDIF
 20025 IF $5COST GT 0
 20026   IF $5COST LT MC
 20027     CALC MCP = 5
 20028     CALC MC = $5COST
 20029   ENDIF
 20030 ENDIF
 30000 PROGRAM SECTION THREE
 30001 END
```

APPENDIX II

TIMBER RAM RUNSTREAMS

```
/*  ==================================================================
/*          TIMBER RAM - RAMGEN RUNSTREAM
/*
/*   PROGRAM NAME:   STEP1.CPL
/*
/*         PURPOSE:  EXECUTION OF MATRIX GENERATOR (RAMGEN)
/*
/*        DATASETS:  USED (U), CREATED (C), DELETED (D)
/*
/*                   U  RAMGEN       - TIMBER RAM MATRIX GENERATOR
/*                   U  %FIL%        - INPUT DATA FILE
/*                   C  NT1          - MANAGEMENT ALTERNATIVES
/*                   C  %FIL.MPS     - MPS-FORMAT LP INPUT FILE
/*                   C  NT3          - REPORT DATA (BINARY)
/*                   C  NT4          - SPECIAL ACTIVITIES
/*               C/U/D  NT5          - SCRATCH
/*               C/U/D  IT1          - VOLUME CLASSES DATA
/*               C/U/D  IT2          - ECONOMIC CLASSES DATA
/*               C/U/D  SCR1         - SCRATCH
/*               C/U/D  SCR2         - SCRATCH
/*
/*  WRITTEN:  860501
/*  AUTHOR:   W.H. LOUGHEED
/*  REVISION: 860717 & 880226
/*
/*  ==================================================================
/*
&ARGS FIL
OPEN %FIL% 1 0001
CREATE D_%FIL%
G D_%FIL%
COMO STEP1.COMO
DATE
TIME
/*
/*  OPEN FILES AND EXECUTE RAMGEN
/*
TIME
OPEN NT1 12 0003
OPEN %FIL%.MPS 13 0003
OPEN NT3 14 0003
OPEN NT4 15 0003
OPEN NT5 4 0003
OPEN IT1 5 0003
OPEN IT2 6 0003
OPEN SCR1 7 0003
OPEN SCR2 10 0003
OPEN RAMGEN.OUT 2 0003
R HUGH>TIMBRAM>TRAM>RAMGEN
/*
/*  CLOSE FILES AND DELETE SCRATCH
/*
```

```
CLOSE 1 2 4 5 6 7 10 12 13 14 15
DELETE NT5
DELETE IT1
DELETE IT2
DELETE SCR1
DELETE SCR2
TIME
COMO -E
/*
```

```
/*  ==============================================================
/*              TIMBER RAM - XMP/ZOOM RUNSTREAM
/*
/*  PROGRAM NAME:  STEP2.CPL
/*
/*       PURPOSE:  SOLVE LP INPUT MATRIX USING XMP
/*
/*       DATASETS:  USED (U), CREATED (C), DELETED (D)
/*
/*                  U  ZOOM         - XMP LP PROGRAM ZOOM
/*                  U  %FIL%.MPS    - MPS-FORMAT LP INPUT FILE
/*                  U  %TYPE%.HOT   - MATRIX FROM PREVIOUS SOLUTION
/*                  C  %TYPE%.BSF   - MATRIX OF PRESENT SOLUTION
/*                  U  %TYPE%.SPC   - SPECS FILE ZOOM CONTROL,
/*                                    SEE ZOOM DOCUMENTATION
/*                C/U  ZOOM.OUT     - ZOOM ITERATION LOG AND BASIS
/*                  U  TRANS        - TRANSFORM ZOOM BASIS TO MPS
/*                  C  BASIS.DAT    - MPS FORMAT BASIS
/*
/*  WRITTEN:  860601
/*  AUTHOR:   W.H. LOUGHEED
/*  REVISION: 860717 & 880226 WHL
/*
/*  ==============================================================
/*
&ARGS FIL; TYPE
&S HOME := [DIR [PATHNAME *]]
G D_%FIL%
&IF [EXISTS %TYPE%.BSF] &THEN &DO
DELETE %TYPE%.BSF
&END
CREATE %TYPE%
G %TYPE%
COMO STEP2.COMO
DATE
TIME
/*
/*  EXECUTE ZOOM
/*
&DATA R HUGH>TIMBRAM>XMPLIB>ZOOM
%HOME%>D_%FIL%>%TYPE%.MPS
%HOME%>D_%FIL%>%TYPE%.SPC
ZOOM.OUT
%HOME%>D_%FIL%>%TYPE%.BSF
%HOME%>D_%FIL%>%TYPE%.HOT
&END
CLOSE 21 22 23 24 26
/*
/* TRANSFORM ZOOM OUTPUT TO MPS STANDARD FORMAT
/*
OPEN ZOOM.OUT 21 0001
OPEN BASIS.DAT 22 0002
```

```
R HUGH>TIMBRAM>TRANS
CLOSE 21 22
TIME
COMO -E
/*
```

```
C  *******************************************************************
C
C  Program:          TRANS.F77
C  Written by:       W.H. Lougheed
C  Computer:         PR1ME 550-II
C  Date:             June 1986
C  Status:           Operational
C
C  *******************************************************************
C
C  TRANS.F77 - Translates XMP output file to MPS-format basis.
C
C  *******************************************************************
C
      CHARACTER * 1 ONE1
      CHARACTER * 5 ONE5,TWO
      REAL VAL
      INTEGER IN,OUT
      IN=29
      OUT=30
5     READ(IN,10,END=99) ONE5,TWO
10    FORMAT(5X,A5,11X,A5)
        IF(ONE5.EQ.'RIGHT') GOTO 99
        IF(TWO.EQ.'BASIC') THEN
          BACKSPACE IN
          READ(IN,15) ONE5,ONE1,VAL
15        FORMAT(9X,A5,A1,15X,D14.8)
          IF(ONE1.EQ.' ') GOTO 5
          WRITE(OUT,20) ONE5,ONE1,VAL
20        FORMAT(4X,A5,A1,14X,F14.8)
        END IF
      GOTO 5
99    WRITE(OUT,30)
30    FORMAT(1X,'END')
      STOP
      END
```

```
/*  ========================================================
/*
/*            TIMBER RAM - REPORT RUNSTREAM
/*
/*  PROGRAM NAME:  STEP3.CPL
/*
/*       PURPOSE:  EXECUTION OF REPORT-WRITER (RWAGLFP)
/*
/*  DISC DATASETS:  USED (U), CREATED (C), DELETED (D)
/*
/*                    U  RWAGLFP    - REPORT-WRITER
/*                    U  RWA.DAT    - REPORT FORMAT CONTROL
/*                    U  BASIS.DAT - MPS FORMAT BASIS
/*                    U  NT0        - SCRATCH UNIT
/*                    U  NT1        - SCRATCH UNIT
/*                    U  NT3        - REPORT DATA (BINARY, STEP1)
/*                    C  %FIL%_%TYPE%.OUT - OUTPUT FILE
/*
/*  WRITTEN: 860601
/*  AUTHOR:  W.H.LOUGHEED
/*  REVISION: 860717 & 880226 WHL
/*
/* ========================================================
/*
&ARGS FIL; TYPE
G D_%FIL%
OPEN NT3 24 0003
G %TYPE%
COMO STEP3.COMO
DATE
TIME
/*
/*  OPEN FILES AND EXECUTE RWAGLFP
/*
OPEN RWA.DAT 1 0001
OPEN NT0 21 0003
OPEN NT1 25 0003
OPEN BASIS.DAT 23 0001
OPEN %FIL%_%TYPE%.OUT 2 0003
R HUGH>TIMBRAM>TRAM>RWAGLFP
/*
/*  CLOSE FILES AND DELETE SCRATCH
/*
CLOSE 1 2 21 23 24 25
DELETE NT0
DELETE NT1
TIME
COMO -E
```

APPENDIX III

STRATA VOLUME AND ECONOMIC TABLES

Table A. Spruce Site Class 1a (S1a).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost (\$/m^3)
50	82.18	8.50	11.42	102.10	26.12
55	96.62	9.13	12.63	118.38	24.72
60	109.27	9.64	13.62	132.53	23.15
65	121.01	10.04	14.50	145.54	21.78
70	131.84	10.31	15.16	157.32	20.65
75	141.32	10.51	15.66	167.49	19.74
80	150.35	10.67	16.03	177.05	19.12
85	158.48	10.75	16.32	185.55	18.38
90	165.25	10.83	16.53	192.61	17.82
95	171.58	10.86	16.66	199.10	17.31
100	176.99	10.86	16.74	204.60	16.99
105	181.51	9.78	15.06	206.35	16.65
110	185.57	8.69	13.39	207.66	16.39
115	188.73	7.61	11.72	208.06	16.19
120	191.44	6.52	10.04	208.00	16.06
125	193.70	5.43	8.37	207.50	15.90
130	195.96	4.35	6.70	207.00	16.00
135	197.76	3.26	5.02	206.04	15.86
140	199.12	2.17	3.35	204.64	15.83
145	200.47	1.09	1.67	203.23	15.89
150	201.38	0.00	0.00	201.38	15.95
155	181.24	0.00	0.00	181.24	15.95
160	161.10	0.00	0.00	161.10	15.95
165	140.96	0.00	0.00	140.96	15.95
170	120.83	0.00	0.00	120.83	15.95
175	100.69	0.00	0.00	100.69	15.95
180	80.55	0.00	0.00	80.55	15.95
185	60.41	0.00	0.00	60.41	15.95
190	40.28	0.00	0.00	40.28	15.95
195	20.14	0.00	0.00	20.14	15.95
200	0.00	0.00	0.00	0.00	0.00

Table B. Spruce Site Class 1 (S1).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($\$/m^3$)
75	72.75	5.61	4.11	82.46	20.15
80	79.89	5.69	4.21	89.79	19.52
85	87.03	5.74	4.28	97.04	18.76
90	93.72	5.78	4.34	103.84	18.19
95	100.42	5.80	4.37	110.58	17.67
100	106.22	5.80	4.39	116.41	17.34
105	111.57	5.22	3.95	120.74	16.96
110	116.48	4.64	3.51	124.63	16.65
115	120.94	4.06	3.07	128.08	16.42
120	124.52	3.48	2.63	130.63	16.25
125	127.19	2.90	2.20	132.29	16.06
130	128.98	2.32	1.76	133.05	16.12
135	130.32	1.74	1.32	133.37	15.95
140	131.21	1.16	0.88	133.25	15.89
145	131.66	0.58	0.44	132.67	15.92
150	132.10	0.00	0.00	132.10	15.95
155	118.89	0.00	0.00	118.89	15.95
160	105.68	0.00	0.00	105.68	15.95
165	92.47	0.00	0.00	92.47	15.95
170	79.26	0.00	0.00	79.26	15.95
175	66.05	0.00	0.00	66.05	15.95
180	52.84	0.00	0.00	52.84	15.95
185	39.63	0.00	0.00	39.63	15.95
190	26.42	0.00	0.00	26.42	15.95
195	13.21	0.00	0.00	13.21	15.95
200	0.00	0.00	0.00	0.00	0.00

Table C. Spruce Site Class 2 (S2).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
70					
75					
80					
85					
90	50.45	1.38	0.67	52.50	25.14
95	56.81	1.39	0.67	58.87	23.57
100	61.90	1.40	0.67	63.97	23.10
105	66.98	1.26	0.61	68.85	22.16
110	71.65	1.12	0.54	73.30	21.39
115	75.89	0.98	0.47	77.34	21.04
120	79.28	0.84	0.40	80.52	20.62
125	82.67	0.70	0.34	83.71	20.03
130	85.21	0.56	0.27	86.04	19.82
135	87.33	0.42	0.20	87.96	19.54
140	89.45	0.28	0.13	89.87	19.29
145	90.73	0.14	0.07	90.93	19.18
150	92.00	0.00	0.00	92.00	19.16
155	82.80	0.00	0.00	82.80	19.16
160	73.60	0.00	0.00	73.60	19.16
165	64.40	0.00	0.00	64.40	19.16
170	55.20	0.00	0.00	55.20	19.16
175	46.00	0.00	0.00	46.00	19.16
180	36.80	0.00	0.00	36.80	19.16
185	27.60	0.00	0.00	27.60	19.16
190	18.40	0.00	0.00	18.40	19.16
195	9.20	0.00	0.00	9.20	19.16
200	0.00	0.00	0.00	0.00	0.00

Table D. Spruce Site Class 3 (S3).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
80					
85					
90	20.82	1.77	13.32	35.91	29.07
95	25.82	1.79	13.32	40.93	27.75
100	30.82	1.80	13.15	45.77	26.43
105	34.98	1.62	11.84	48.44	26.01
110	39.15	1.44	10.52	51.11	25.13
115	42.90	1.26	9.21	53.36	24.81
120	46.23	1.08	7.89	55.20	24.60
125	49.14	0.90	6.58	56.62	24.40
130	51.64	0.72	5.26	57.62	24.16
135	53.72	0.54	3.95	58.21	24.20
140	55.39	0.36	2.63	58.38	24.20
145	57.05	0.18	1.32	58.55	23.93
150	58.30	0.00	0.00	58.30	24.16
155	52.47	0.00	0.00	52.47	24.16
160	46.64	0.00	0.00	46.64	24.16
165	40.81	0.00	0.00	40.81	24.16
170	34.98	0.00	0.00	34.98	24.16
175	29.15	0.00	0.00	29.15	24.16
180	23.32	0.00	0.00	23.32	24.16
185	17.49	0.00	0.00	17.49	24.16
190	11.66	0.00	0.00	11.66	24.16
195	5.83	0.00	0.00	5.83	24.16
200	0.00	0.00	0.00	0.00	0.00

Table E. Pine Site Class 1 (P1).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
55	11.18	166.21	20.56	197.95	15.04
60	13.34	175.52	22.18	211.05	14.66
65	15.39	182.69	23.60	221.68	14.30
70	17.55	187.70	24.69	229.94	14.05
75	19.59	191.28	25.50	236.38	13.85
80	21.52	194.15	26.11	241.77	13.67
85	23.44	195.58	26.58	245.60	13.51
90	25.24	197.01	26.92	249.18	13.39
95	27.05	197.73	27.12	251.90	13.25
100	28.61	197.73	27.26	253.60	13.18
105	30.05	177.96	24.53	232.54	13.21
110	31.37	158.18	21.81	211.36	13.24
115	32.58	138.41	19.08	190.07	13.29
120	33.54	118.64	16.35	168.53	13.36
125	34.26	98.87	13.63	146.75	13.44
130	34.74	79.09	10.90	124.74	13.61
135	35.10	59.32	8.18	102.60	13.77
140	35.34	39.55	5.45	80.34	14.07
145	35.46	19.77	2.73	57.96	14.65
150	35.58	0.00	0.00	35.58	15.95

Table F. Pine Site Class 2 (P2).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
65	5.79	101.64	35.54	142.97	16.45
70	8.53	106.96	37.34	152.82	16.17
75	11.42	111.21	38.77	161.41	15.92
80	14.16	114.94	39.85	168.95	15.64
85	16.73	116.54	40.57	173.84	15.48
90	19.15	117.60	41.17	177.91	15.37
95	21.56	118.66	41.17	181.39	15.26
100	23.49	119.20	41.17	183.85	15.22
105	25.42	107.28	37.05	169.75	15.27
110	27.19	95.36	32.93	155.48	15.34
115	28.80	83.44	28.82	141.05	15.48
120	30.09	71.52	24.70	126.31	15.62
125	31.37	59.60	20.58	111.56	15.73
130	32.34	47.68	16.47	96.48	15.98
135	33.14	35.76	12.35	81.25	16.29
140	33.95	23.84	8.23	66.02	16.74
145	34.43	11.92	4.12	50.47	17.55
150	34.91	0.00	0.00	34.91	19.16

Table G. Pine Site Class 3 (P3).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
75	0.00	75.80	31.63	107.43	16.10
80	5.09	78.85	32.60	116.55	17.98
85	7.74	81.39	33.16	122.29	17.80
90	10.18	82.92	33.30	126.40	17.69
95	12.63	83.94	33.30	129.86	17.69
100	15.07	84.45	32.88	132.40	17.63
105	17.11	76.00	29.59	122.70	17.80
110	19.14	67.56	26.31	113.01	17.89
115	20.98	59.11	23.02	103.11	18.11
120	22.61	50.67	19.73	93.00	18.38
125	24.03	42.22	16.44	82.70	18.70
130	25.25	33.78	13.15	72.18	19.09
135	26.27	25.33	9.86	61.47	19.71
140	27.09	16.89	6.58	50.55	20.56
145	27.90	8.44	3.29	39.63	21.68
150	28.51	0.00	0.00	28.51	24.16

Table H. Aspen Site Class 1 (A1).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
35	2.04	0.00	2.46	4.50	24.74
40	3.54	0.00	3.12	6.66	24.58
45	5.14	0.00	3.70	8.84	23.89
50	6.64	0.00	4.23	10.87	22.57
55	8.24	0.00	4.67	12.91	21.73
60	9.83	0.00	5.04	14.88	20.69
65	11.34	0.00	5.36	16.70	19.71
70	12.94	0.00	5.61	18.54	18.91
75	14.44	0.00	5.79	20.24	18.24
80	15.86	0.00	5.93	21.79	17.79
85	17.28	0.00	6.04	23.32	17.22
90	18.61	0.00	6.12	24.72	16.79
95	19.93	0.00	6.16	26.10	16.41
100	21.09	0.00	6.19	27.28	16.16
105	22.15	0.00	5.57	27.72	15.96
110	23.12	0.00	4.95	28.08	15.81
115	24.01	0.00	4.34	28.35	15.72
120	24.72	0.00	3.72	28.43	15.67
125	25.25	0.00	3.10	28.35	15.58
130	25.60	0.00	2.48	28.08	15.74
135	25.87	0.00	1.86	27.73	15.67
140	26.05	0.00	1.24	27.29	15.69
145	26.14	0.00	0.62	26.76	15.82
150	26.22	0.00	0.00	26.22	15.95

Table I. Aspen Site Class 2 (A2).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost ($/$m^3$)
40	0.00	2.40	43.79	46.19	15.12
45	0.00	2.93	55.47	58.41	13.88
50	0.00	3.47	65.40	68.87	13.08
55	0.00	3.93	73.87	77.79	12.67
60	3.37	4.32	80.87	88.56	14.68
65	5.78	4.63	86.71	97.13	14.34
70	8.51	4.87	91.09	104.48	14.13
75	11.41	5.07	94.60	111.07	13.97
80	14.14	5.24	97.22	116.60	13.75
85	16.71	5.31	98.97	120.99	13.60
90	19.12	5.36	100.43	124.91	13.48
95	21.53	5.41	100.43	127.37	13.37
100	23.45	5.43	100.43	129.32	13.41
105	25.38	4.89	90.39	120.66	13.55
110	27.15	4.34	80.35	111.84	13.71
115	28.75	3.80	70.30	102.86	13.99
120	30.04	3.26	60.26	93.56	14.26
125	31.33	2.72	50.22	84.26	14.51
130	32.29	2.17	40.17	74.63	14.95
135	33.09	1.63	30.13	64.85	15.47
140	33.90	1.09	20.09	55.07	16.19
145	34.38	0.54	10.04	44.96	17.31
150	34.86	0.00	0.00	34.86	19.16

Table J. Aspen Site Class 3 (A3).

Age Class	Volume (m^3/ha) Spruce	Pine	Aspen	Total	Harvest Cost (\$/m^3)
50	0.00	7.18	38.17	45.35	17.41
55	0.00	8.56	49.82	58.38	15.50
60	0.00	9.86	59.20	69.06	14.57
65	0.00	11.07	65.67	76.74	13.99
70	0.00	12.11	70.52	82.63	13.74
75	0.00	12.89	73.44	86.32	13.54
80	4.80	13.41	75.70	93.91	15.94
85	7.29	13.84	76.99	98.13	15.82
90	9.60	14.10	77.32	101.01	15.82
95	11.90	14.27	77.32	103.49	15.84
100	14.20	14.36	76.35	104.91	15.83
105	16.12	12.92	68.71	97.76	16.10
110	18.04	11.49	61.08	90.60	16.28
115	19.77	10.05	53.44	83.26	16.60
120	21.30	8.62	45.81	75.73	17.01
125	22.64	7.18	38.17	68.00	17.48
130	23.80	5.74	30.54	60.08	18.02
135	24.76	4.31	22.90	51.97	18.86
140	25.52	2.87	15.27	43.66	19.96
145	26.29	1.44	7.63	35.36	21.38
150	26.87	0.00	0.00	26.87	24.16