A Dynamic Analysis of Interest Rate and Logging Factors in Reducing Saw Timber Procurement Costs

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ABSTRACT

Wood harvesting operations were controlled in terms of financial expenditure and material flow at three related steps in the wood procurement system -- logging, roadside inventorying, and transportation. Wood flow from sawtimber to available sawlogs in the mill yard was evaluated using the technique of dynamic programming. This program was successfully linked with data processing (input) and interactive interpretation procedures (output). The power of the algorithm was increased by implementing separable programming. In this model a nonlinear transportation function was linked to linear logging and inventorying functions.

The dynamic programming procedure was not as effective computationally as the Simplex procedure, but future trends in computer development can be expected to offer increasing computing capacity for dynamic procedures. Small tactical problems were solved more accurately as the model construction was closer to real-life systems. No interest rate effects on sawtimber allocation were observed in the sensitivity analyses conducted, but transportation allocation as a phase of material flow changed when the effect of varying volumes of logging was analyzed.

Keywords: *integrated timber allocation, tactical planning, dynamic programming, cumulative cost curve, geographical decentralizing.*

INTRODUCTION

Mechanization in wood harvesting and the proportion of truck transportation are assumed to continue to rise in Finland [11], although their relative shares are already high nationally; i.e., 65%, 61%, respectively [10]. These progressive trends were forecast by an LP model used to calculate the optimal resource consumption for different development alternatives and strategies [11]. The future situation would seem to require that logistics forecasts can be achieved only through the development of more advanced planning and management tools supporting planning and supervision efforts.

Operational models have conventionally been used for the separate allocation of timber without integrating them. However, due to logistics requirements, other more comprehensive models are being developed by the industry which are capable of managing several concurrent wood flow functions. As has been found in many studies, both in Finland and elsewhere, the integrated management of the flow of wood material results in lower total costs to the operating agent [2], [7], [9], [13].

Cash flow of the liquid funds at all organizational levels has been related to budget, and its role as an element of management has increased. Cash flow and material flow are affected by the seasonal variation in wood procurement; this can be taken into account by means of cumulative curve of procurement costs. This curve has found use as a tool illustrating the cost accumulation in integrated models [9].

Integrated management models, however, have not been developed quickly enough, as it is difficult to construct efficient models covering the entire dynamics of a wood procurement system. It has been observed that the number of variables in such a model is extremely high and the interrelations between variables and constraints are complicated in conventional approaches [7], [11]. As a result, functionally decentralized systems were introduced [7]. Decentralized decision making means that some of the decisions are left to lower echelons within organizations.

In functionally decentralized systems, general LP models or some advanced procedure based on the LP structure have been widely used as optimization routines because of their efficiency and users' familiarity with their structure. Furthermore,

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general LP routines are also available as commercial versions. Nevertheless, many recommendations have been put forward for using truly dynamic methods such as dynamic programming (DP) in solution procedures for dynamic systems [1], [3], [6], [8].

In certain cases, decentralized systems can also be established by geographical means, this being closer to the idea of independent profit centres. In order to find out if DP is suitable in an operation of such decentralized decision making, especially at a tactical planning level, an experimental system was modelled using the DP method. Thus, the general framework of this paper is aimed at tactical planning of wood procurement.

The other main reason for constructing this model was the consequence of two special factors, not included in dynamic optimization models, in reducing total costs -- the logging and interest rate variables. The allocation of logging was of special significance in this context. Interest rate is an often studied, intriguing time-dependent cost factor, and it has greatly changed the industry's profit picture during the past 10 years in Finland [5][9]. In the case of the latter factor, total costs depend greatly on productivity of logging function. The unit costs of roundwood logging by the forest industry and the Finnish Forest and Park Service (the government forest authority) in 1992 amounted to FIM 57.30 /m^3, while the costs of transportation amounted to only FIM 35.00 /m^3 [10].

In spite of numerous cost studies on logging based on static models [5], the effects of varying logging volume involving seasonal aspects have not been analyzed in regard to the allocation of other functions via a dynamic method. In practice, the time spent on allocation may be meaningful in influencing the total costs of wood procurement. This is most likely evident when the capital accumulation in inventories is included and considered in the financial system as part of cash payments. In this way separate costs can be determined and targeted more accurately on the respective resource inventory.

The hypotheses in this study were as follows:

- that the time factor influences costs and the tactical decisions operate with time, and that DP models are suitable for tactical planning;
- that the problem introduced in this study can be solved using Hadley's algorithm, and achieved by means of separable programming and a locally modelled procedure;
- that the interest rate can change the allocation of sawtimber in regard to tactical planning problems, although its share of the total costs may be low;
- that the allocation of transportation may be changed by changing logging volumes, and that this favours the use of an integrated model as opposed to the conventional, separately defined planning model.

The hypotheses were tested theoretically in the course of model construction. The model was also tested in reality through an experimental problem in which the system's inputs (e.g., mill wood orders, inventory buffer-stocks, the moment of transportation, material flow time, interest rate) were controlled in a DP formulation.

METHOD DEFINITION USING AN EXPERIMENTAL PROBLEM

Geographical decentralization is in the interest of big organizations operating over the whole country. Organization divisions are divided into independent regional departments for purchasing, logging, and transporting wood. In this study, a region of a hypothetical organization was divided into smaller district entities operating as the lowest echelons in a divisional hierarchy and managing their local purchasing, logging, and transportation operations independently. The region had the role of approving the districts' plan and of coordinating management operations via participatory planning.

The global problem could be solved by the Simplex algorithm, but the number of activities in an objective function increases greatly as every single activity has to be described as an individual variable for each planning period. Similarly, the number of decision alternatives solved by DP can also be too numerous. In practice, although the Simplex procedure can cope with fairly big cases, the fundamental assumptions for cost and capacity equations' linearity at least can be overly restrictive. Hence, a simplified experimental problem was used in analyses involving the procedures.

Only solutions achievable when using an LP model are those on a straight line (expansion path). Because of this characteristic of LP models, they cannot solve nonlinear causalities in a wood procurement system. Hence, DP was chosen as the method, and used in analysis done by the interest rate and logging as time-varying factors. Further, assuming that any model would be constructed for a half year split into two-week periods and that the model would be capable of using the Simplex algorithm, for instance, *to solve each stage separately*, it could not at all be called a tactical plan.

Results of DP are described by the symbol $A[X_i(t)]$. It is necessary to emphasize that the symbol $A[X_i(t)]$ is termed *functional*, and differs fundamentally from the composite function symbol $g[f(x)]$. In the symbol $A[X_i(t)]$, the $X_i(t)$ component as an integral unit indicates time paths and should not therefore be taken to be a function of t. Instead, it should be understood to be a function of $X_i(t-1)$; e.g., Chiang [3], Kennedy [8].

The coordination of the district plans into one tactical plan was actually made with small changes using DP, despite the difficulties in converging both procedures in the same problem. It is first necessary, however, to determine the goals with which to cope with the region's planning problem. These goals determined the experiments, method, and sub-techniques relevant to this study.

According to interviews by Keipi [7], managers have specified goals for functionally decentralized decision making. The goals used in this study were based on the managers' functional goals, but a new synthesis for geographical decentralizing was composed for tactical planning purposes; a shorter time scale of tactical planning influence on the set of suitable goals. Consequently, the district managers' goals in random order were as follows:

- satisfying qualitative and quantitative wood requirements of mills,
- sufficient mill inventories at the end of the planning period,
- minimizing transportation costs,
- minimizing mill inventory costs by keeping inventories small,
- satisfying wood needs of transportation,
- minimizing logging costs,
- sufficient roadside inventory at the end of the period,
- minimizing roadside inventory costs by keeping inventories small.

The integration of these goals was provided by a time-oriented procedure which is relevant for tactical planning in connection with wood procurement problems. When mills' formal wood orders were changed for future periods, e.g., quality requirements in response to the demands of the world market, the district managers had to also respond to the new situation and modify their own wood procurement plan in co-operation with other districts. In some cases, when a situation could not be coped with, it would be better to assemble and run the whole basic plan again for a new horizon under the supervision of the regional head.

Time and Adjustment Cost as Coordinators of Information in the System

In this study, cost minimization was used as a criterion for ranking of district managers' preferences. However, the goals of the essential capital requirements were taken into account in controlling districts' cash flow. This was done for each significant function of wood flow by transforming the cash flow value to the volume of material flow according to the buffer stock requirement.

Applying cumulative cost curves for the control of the cash flow yielded the approximation of the optimal amount of capital accumulated during the interval $[t_0, t_n]$.

$$\int_{t_0}^{t_n} Q(t)\,dt \equiv \lim_{n\to\infty} \sum_{i=1}^{n} Q(t_i)\,\Delta t_i \qquad (1)$$

In the tactical management operations, material flow has to be managed from the stump to the mill products during the defined time accumulation. Hence, in the experimental system, the material flow times of the partial functions were used. These are presented in the figure for the stumpage sales of wood procurement for the Finnish forest industry [9]. The entire time needed for the wood flow was about 10 months: four weeks for logging, nine weeks for roadside inventorying, one week for transportation and four weeks for mill inventorying.

The transportation function was omitted, but the other three partial wood flow functions were considered separately in the present study. The wood flow and the cumulative cost curves were determined using the following equations.

$$LB_{ij} = lcoff_{ij} * (D \,/\, WEEKS) * (LINV_{ij} \,/\, LINV) \qquad (2)$$

$$XB_{ij} = xcoff_{ij} * (D \,/\, WEEKS) * (XINV_{ij} \,/\, XINV) \qquad (3)$$

$$MB_{ik} = mcoff_{ik} * (D \,/\, WEEKS) * (MINV_{ik} \,/\, MINV) \qquad (4)$$

where:

LB_{ij}	is the volume (m^3) of grade *i* required for standing inventory in district *j* at the end of the planning horizon,
XB_{ij}	is the volume (m^3) of grade *i* required at the roadside in district *j* at the end of the planning horizon,
MB_{ik}	is the volume (m^3) of grade *i* required in mill inventory *k* at the end of the planning horizon,
$LINV$	is the total standing inventory,
$XINV$	is the total roadside inventory,
$MINV$	is the total mill inventory,
$LINV_{ij}$	is the standing inventory in district *j*,
$XINV_{ij}$	is the roadside inventory in district *j*,
$MINV_{ik}$	is the mill inventory in mill *k*,
D	is the mill wood demand,
$WEEKS$	is the length of the planning horizon in weeks,
$lcoff_{ij}$	is the buffer stock coefficient in weeks for the logging inventories,
$xcoff_{ij}$	is the buffer stock coefficient in weeks for the roadside inventories,
$mcoff_{ik}$	is the buffer stock coefficient in weeks for the mill inventories.

Fixed usable working capital was determined by means of these equations as the minimum level combined with fixed resources; in this study, it was the minimum volume requirement. This was a relevant assumption to make in the tactical system of wood procurement for two reasons; first, the budgeting traditions of the forest industry supported it; and second, the short-term planning horizon was subjected to the assumption of partial adjustment. Thus, the adjustment costs of fixed capital are part of the optimum costs to be taken into account when conducting a dynamic analysis.

Cost Equation for Transportation

For tactical planning, it was practical to use equations instead of average values, since regression equations make it possible to concentrate more relevant information by way of coefficients in the objective function. The transportation cost for unit volume was a function of the distance from the roadside inventory to the mill and the quality class of transport difficulty of the inventory. Thus, the equation has the following format:

$$TRANSP.fmk = VPclass.fmk + \{\alpha + (15.62 - \alpha) * \exp\,[-\beta(TRANSP.km - 5]\} \qquad (5)$$

where:

$TRANSP.fmk$	cost of transportation,
$VPclass.fmk$	is the quality class at roadside inventory,
$TRANSP.km$	is the distance from inventory to terminal,
α, β	are regression function parameters.

The validity of the solution procedure could be developed by nonlinear regression once equations were endogenously computed into the program. The equations defined the varying transportation cost, which was used as the coefficient in the objective function for each variable.

Illustrative Tactical Experiments

The problem is a hypothetical one, merely a simulation of a real-life situation, described as a series of experiments based on data provided by the Finnish Forest and Park Service (the government forest authority). The modified experiments consisted primarily of cost and quantity information covering three geographical districts, and the cost level included in the data was for the year 1991. The assessment of these experiments was restricted to the case of two sawmills. Their demands for spruce sawlogs were the main initial optimization conditions for the system, for which relationships of the system functions are described in Figure 1. The district manager's problem was to minimize the costs of the operations from weeks 36 to 43.

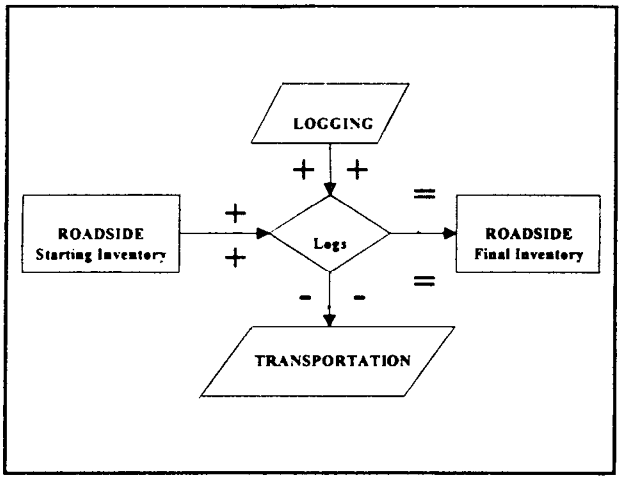

Figure 1. Cash and material flows optimized using the system including functions of logging, transportation and roadside inventorying.

The periodic wood order could be derived from the sawmills' desired production of sawn goods, but here the sawmills' (*f*) exogenous demands for sawlogs were equally divided at every stage (*t*) (Table 1); the mill demands amounted to *15 000* m^3 and *20 000* m^3 respectively in total.

Table 1. Wood orders (m^3) for planning periods.

f	t_1	t_2	t_3	t_4
1	3 750	3 750	3 750	3 750
2	5 000	5 000	5 000	5 000

Initial wood inventories of the mills were defined by the minimum (*min*) and maximum (*max*) restrictions for each stage at the beginning of the planning periods (Table 2). Shortages of raw material were prevented by using the minimum volume. The inventorying capabilities at the mill terminals were described by using the maximum volume. The final goals for the wood inventories at the end of the planning horizon were determined by the company's buffer stock requirement. These were calculated using Equation 4 of the partial wood flow. This volume was assumed to amount to four weeks raw material requirement in accordance with the mills' production levels. All storing costs in the mill inventories were assumed to be FIM 15.00 per cubic metre for the all periods.

Table 2. Mill inventories at the beginning of the planning horizon and storing capacities; both in '000s of cubic metres.

f	t_0	t_1		t_2		t_3		t_4	
		Min	Max	Min	Max	Min	Max	Min	Max
1	6	3	11	3	11	3	11	3	11
		Min	Max	Min	Max	Min	Max	Min	Max
2	6	3	11	3	11	3	11	3	11

In each district (*x*), there was also wood in roadside inventories available for transportation at the beginning of the planning horizon. Future transportation potentials were set from forecasts by district managers; their forecasts were based on both their experience, state of markets, and standing inventories (stumpage timber). These possibilities were presented by logging volumes once the buffer stock requirements of the standing inventories (Equation 2) had been subtracted from the total volume. These inventories and roadside inventories for each district are presented in Table 3.

Table 3. Inventories of wood resource.

Function	*x=1*	*x=2*	*x=3*
Roadside	10 000	13 000	3 000
Logging	31 600	34 300	24 500

The final goals for the roadside inventories were determined by using the buffer stock coefficient (Equation 3), presented by week and calculated according to the average wood order. Here, the buffer was nine weeks; the roadside inventories could not be less than this roundwood buffer.

The costs of wood procurement consisted of two separate compositions. Firstly, there were costs preceding the roadside inventorying, and these divided into ones derived from purchasing and ones derived from logging. In these systems, the logging costs also included hauling costs. In Table 4, the letter (*P*) describes the purchasing costs, and (*L*) the logging costs. The average period costs of the region (*Avr*) were calculated to include all the districts' costs. Secondly, there were the transportation costs, whose model structure was already considered in the previous section, but the model also includes an equation of wood moisture. It defines a seasonal time-varying parameter, by means of which the real volume of wood could be determined as metric tons instead of cubic metres. The costs were assumed to be valid if the buffer stocks at the end of the planning horizon exceeded the minimum requirements.

Table 4. Costs of purchasing and logging.

	t_1		t_2		t_3		t_4	
x	P	L	P	L	P	L	P	L
1	120	50	120	60	120	70	120	100
2	120	50	120	60	120	70	120	100
3	120	50	120	60	120	70	120	100
Avr	170		180		190		220	

RESULTS

The model is first illustrated with the least-cost network (Figure 2), but numerous simplifications must be made to it because of the large scale of the system for computers to handle. The format is described in Table 5 with definitions of the various characteristics. The experiments were limited to the consideration of a nonlinear, discrete-time, dynamic system having only deterministic parameters and inputs.

Figure 2 illustrates that the wood procurement problem can be viewed as a homogeneous network system. By way of a simplification, the example presents state dimensions related only to one instead of three real management districts. More precisely, the described dimension presents roadside inventories where the state alternatives for the respective week are represented by nodes. The volume of a roadside inventory, measured in cubic metres, is thus a state parameter. Homogeneous means that each state has the same number of possible state values; e.g., the same grid value was used for each dimension and all state combinations (*i.j*), were formed after reduction operations. A wood procurement alternative associated with combinations is presented by a set of direct links. Joined to each link (i_j, i_{j+1}), is the minimum stage value $a_j\{i_j, i_{j+1}\}$ also representing the choice of optimal set of interior state parameters and control variables.

Table 5. Network flow graph definitions.

TERM	DEFINITION
Node	Nodes on a network flow graph have been designated (*i.j*) where *i* is the state number and *j* is the decision stage.
Branch	Branches are unidirectional paths connecting the nodes. A decision arrow is assigned to indicate the direction of cause and effect.
Path	A path is a continuous connection of branches with unidirectional arrows.
Internode cost	Stage return $a_j\{i_j, i_{j+1}\}$ shown beside the linking decision arrow.

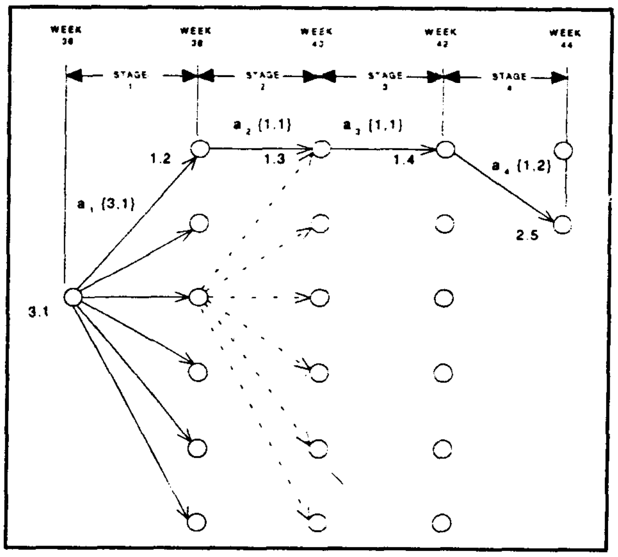

Figure 2. Network frame for resource management in a wood procurement system.

Dynamic Programming Model

The DP model was based on the experiments, but some additional assumptions had to be made to describe the dynamic system. Let us imagine that the regional manager of the wood division responsible for the districts is attempting to decide the optimal dynamic plan for the horizon. This consists of planning periods, each two weeks in length for each of the coming (T) stages. The wood demands of two mills (D_k) based on production requirements are already determined for every stage over the eight-week planning horizon. It is also assumed that the wood order (D_{ikt}) has been given, and its use in mill production has no influence on the allocation of roadside inventories.

The model was solved and considered using the backward pass-technique, selected because the solution had to be subjected to the preconditions prevailing at the beginning of the planning horizon. Using this model structure, the illustrative experiments were solved with only a slight increase in computing capacity; at the last step, $\Lambda_1(i.1)$ was computed, and the experiment for the entire range of $(i.1)$ values was solved in a straightforward manner. It was convenient to work backward in time, since the roadside inventories at stage $t = 0$ were specified exactly, while the inventories in stage $t = T + 1$ were specified by the inequalities.

The roadside inventories transported during the planning period are signed with term Y_{ijkt} and $Cy_{ijkt}(Y_{ijkt})$ was the cost function of the timber grade i, transported from area j to mill k at planning stage t. The term X_{ijt} is used to depict the starting roadside inventories. Consequently, it is possible to use X_{ij0} as the symbol for the roadside wood inventories at the beginning of the planning horizon. The term L_{ijt} describes the volume logged to roadside and $cl_{ijt}(L_{ijt})$ was the corresponding cost function. Accordingly, the costs accumulated at the roadside are calculated using the function $cx_{ijt}(X_{ijt+1} - Y_{ijkt} + L_{ijt})$. Mill inventories are described by M_{ikt} and the cost function is expressed as $cm_{ikt}(M_{ikt})$.

If the wood resources available for transportation can be allocated without limitations related to the time and stages, the model would be constructed according to previous initial assumptions and inputs. Nevertheless, systems usually have constraints which have to be encoded in the algorithm. They are used to limit the state parameters and control variables numerically when the system proceeds from one stage to the next. The dynamics of roadside inventorying, transportation, and logging depend on one another in accordance with the following material balance equation (state transition function):

$$X_{ijt} = X_{ijt+1} - Y_{ijkt} + L_{ijt}. \qquad (6)$$

The state parameter was imagined as the initial and final volume of log reserves for each planning period. In general, whatever the parameters are, they have to be determined endogenously in the model. This is why transportation is also an endogenous parameter, but only roadside inventories are used as the actual state parameter. This means that the information connected with two sequential stages is transferred and linked only by roadside inventories. Further, roadside inventories and transportation are control parameters jointly determinining the volumes of implicit logging variable.

Since the district managers' aforementioned goals had to be satisfied, it was assumed that mill inventories could be determined as the implicit volume according to the wood orders and transportation quantities. Thus, the periodic cost functions previously described are as follows.

$$f_{ijkt}(L_{ijt},M_{ikt},X_{ijt},Y_{ijkt}) = cl_{ijt}(X_{ijt} - X_{ijt+1} + Y_{ijkt}) +$$
$$cm_{ikt}(- D_{ikt} + Y_{ijkt}) + cx_{ijt}(X_{ijt}) + Cy_{ijkt}(Y_{ijkt}) \qquad (7)$$

It was assumed that inventories can be updated instantaneously at the beginning of each period. Transportation, moreover, was assumed to take place at the end of each period. Based on the information for the functions and the equations of the model, the total costs were minimized at the end of planning period using Hadley's [6] algorithm. To determine a set of optimal control variables L_{ijt}, M_{ikt}, it is necessary to find a set minimising

$$Z = \min \sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} f_{ijkt}(L_{ijt},M_{ikt},X_{ijt},Y_{ijkt}) \qquad (8)$$

The minimization was carried out subject to the parameters and variables restricted to being nonnegative integers X_{ijt}, Y_{ijkt} and L_{ijt}, M_{ikt}. These also satisfied the recursion relations which took the form of

$$\Lambda_t(X_{ijt}) =$$

$$\min \Big[\sum_{t=1}^{T} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} f_t\,(L_{ijt}, M_{ikt}, X_{ijt}, Y_{ijkt}) \qquad (9)$$

$$0 \leq X_{ijt} \leq bla$$

$$0 \leq Y_{ijkt} \leq bla$$

$$+ (l + \alpha)\Lambda_{t+1}(X_{ijt} + Y_{ijkt} - L_{ijt})\Big]$$

where

a is a number of grid values, 1...n,

b is a maximum volume of parameter,

α is the interest rate.

The combinatorial problems were the most difficult limitation of DP. This was typical for this decomposed approach. The Simplex procedure solves the problem exactly by considering only a very small percentage of the possible combinations. In the DP procedure, these combinations were eliminated by means of an approximation technique. Reduced dimensions were used and the problem of computational accuracy was solved by utilizing separable programming -- an approximation technique by which solutions are counted by using a combination of non-represented intermediate state values.

The method of linear interpolation suggested by Kennedy [8] was applied, but in three dimensions instead of one. Thus

$$X_j' = \beta_j K_j^1 + (1 - \beta_j) X_j^2 \qquad (10)$$

where

X'_j are interpolated volumes,

X_j^1 are lower volumes,

X_j^2 are upper volumes,

β_j are coefficients determined by dividing an calculated volume by difference of lower and upper volumes.

X_j^1 and X_j^2 form eight possible combinations around three state parameters (X_{ijt}) at the each period. X'_1, X'_2 and X'_3 are the interpolations of volumes representing both discrete grid values and non-representative intermediate values, then

$$\Lambda_t(X_1', X_2', X_3') = \beta_1\beta_2\beta_3\Lambda_t(X_1^1, X_2^1, X_3^1) \qquad (11)$$

$$+ (1-\beta_1)\beta_2\beta_3\Lambda_t(X_1^2, X_2^1, X_3^1)$$

$$+ \ldots + (1-\beta_1)(1-\beta_2)(1-\beta_3)\Lambda_t(X_1^2, X_2^2, X_3^2)$$

Computational Efficiency of DP Procedure

The time consumption of dynamic and linear procedures was used as the criterion describing the performance level. It was analyzed by running three programs of different sizes. The number of variables and constraints described the characteristics of the linear procedure. The number of alternatives was used to describe the size of the dynamic procedure for corresponding systems. The results are presented in Table 6.

Table 6. A comparison of computing time requirements for dynamic and linear procedures.

Var.	Constr.	Alternatives	Dynamic	Linear
61	61	256	1 min	1 min
80	82	83521	10 min	2 min
142	94	279841	50 min	4 min

The first example describes the case consisting of three districts, two mills, and one timber grade. The second differs from the first in having two timber grades. Finally, the biggest case involved three mills.

The LP procedure was not so sensitive for these changes in system size. As is known from literature, step-by-step methods like this DP procedure are more time consuming. The tests differed greatly and to such an extent that differences in bigger scale systems can be expected to be even greater. Therefore, the greatest problem would seem to be the lack of processing speed. In actual fact, the main restriction was the shortage of programming capacity on the part of the compilers in handling nested loops.

Another almost as important problem encountered was the shortage of computer memory capacity. The PC computer used in this analysis was equipped with 486SX-processor with a clock speed of 66 MHz and 8 MB of RAM available. The final DP procedure interpreting decentralized planning system was tested using a C-compiler and the program was constructed in the UNIX-operating environment.

Interest Rate as Share of Total Costs

Planning alternatives were rationalized to real-life conditions using minimized cash flow, for which the interest rate is an expense affecting companies' flow of funds and determined by the financial markets. Therefore, the user-defined exogenous rate was used in the analysis of the DP procedure.

The share of interest expenses depended on the interest rate and the value of the working capital. Figure 3 shows that the precise control of the logging operation influenced the value of the working capital. A company was assumed to operate fully on loaned funds, whereas in real-life conditions some financing of cash payments is actually arranged as a company's own investments. Therefore, the effects of varying logging volumes may be less than the many thousands of Finnish markkas of this study.

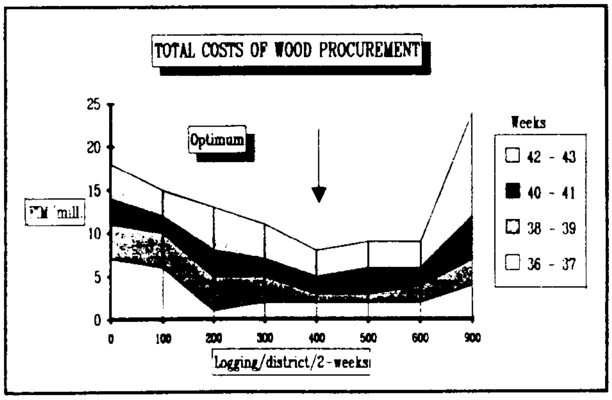

Figure 3. Total costs as a function of logging volumes.

The share of the interest expenses was found out by calculating a 16% rate of the working capital for various logging volumes. The results are presented in Figure 4. Although the absolute value varied greatly according to the respective working capital, the share of interest costs in all the logging alternatives was the same 2%. Therefore, the interest rate cannot change the allocation of sawtimber.

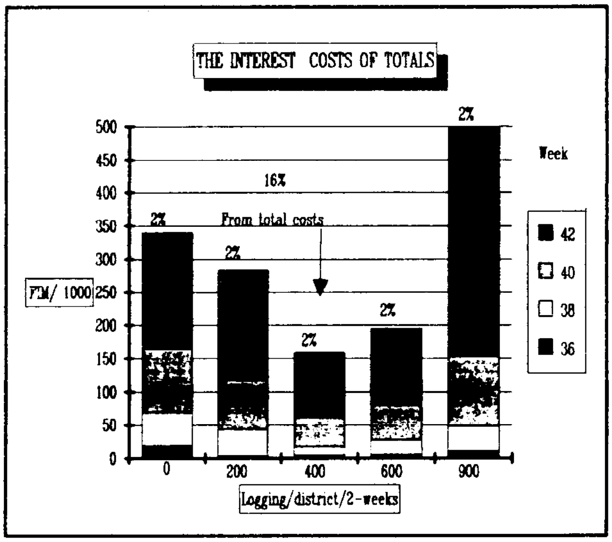

Figure 4. The interest costs of wood procurement (logging volumes constant and exogenous).

Logging Influences on Transport Decisions

Transport decisions were used as indicators describing the influence of the logging function on the integrated tactical plan. Logging volumes were set constant while the other functions were variable terms dependent on time. Actually, these time paths were considered using the sensitivity analysis described in Table 5.

Planning using the integrated dynamic model gave an allocation for the transport function differing from that when working with the more simple optimizing model. Moreover, the integrated model also gave a lower optimal cost for the wood procurement experiment. This conclusion can be drawn by comparing the results in Table 5 and Figure 3.

DISCUSSION

Solving the tactical plan by DP as compared to the LP was not competitive computationally in this case. Theoretically, however, it did offer more advanced options for integrated planning. Earlier results from the use of DP in connection with various types of problems have also indicated shortcomings in the performance of DP procedures [1], [6], [8]. In one study, even the tests showed that DP is totally out of the question in solving a general type of LP problem including a reasonable number of constraints [6]. Nevertheless, some good working procedures have been introduced [1], [8], [12].

Some studies [8] have given the impression that DP cannot be used to answer the practical questions faced by resource managers. According to these studies, one reason for the lack of DP-management tools may be institutional. The same general reason was identified in this wood procurement problem; policy, formulated within the company, unions and contracts, and because of a centralized planning method, often determines the parameters of time paths within which the planner operates at the lower level of an organization. In such organizational structures and planning environments, DP cannot be used as the operational tool.

The implementation of an integrated model can be viable in decentralized organizations [13]. When the operational unit in a firm is small enough and independently is responsible for its own operations, the environment becomes more suitable for this DP method.

Applying the tactical plan for the district units had an advantage when compared to conventional large-scale plans. The required planning program was simpler and used less computer capacity. Therefore, the experiment could in fact be formulated as a DP model. In this study, the LP constraints were handled by constructing them as internal DP constraints instead of as state parameters. However, six grid values were reasonable for use with the state parameters. This influences accuracy, and therefore, only in this case may determine precisely the optimal solution [6]. Nevertheless, linear interpolation was used. In new applications, the validity of the procedure has to be tested.

Table 5. The output of the program including the integrated plan and the analysis of changed wood allocation in transportation due to varying logging volumes.

TACTICAL PLAN FOR WEEKS 36 - 43

Norway spruce

Dstr1/M1 = From District 1 to Mill 1

WEEKS	ROADSIDE m^3		TRANSPORTATION m^3				LOGGING m^3		COSTS FIM/mill	
			Dstr1		Dstr2					
Stage	Dstr1	Dstr2	M1	M2	M1	M2	Dstr1	Dstr2	Stage	Total
36 - 37	1799	3382	170	200	300	200	400	400	2,620	8,439
38 - 39	1799	3382	170	120	300	200	400	400	2,168	5,819
40 - 41	1799	2590	170	40	300	200	400	400	1,310	3,651
42 - 43	1799	1799	170	120	170	120	400	400	1,118	2,341
44 ...	1799	1799								1,223

Transportation sensitivity (Dstr1/M1) to varying logging volumes

	0 m^3	200 m^3	400 m^3	600 m^3	900 m^3
36 - 37	300	300	170	300	300
38 - 39	400	400	220	400	400
40 - 41	320	600	320	320	600
42 - 43	400	40	220	400	400

The main reason for using discrete time and integer variables was in the faster calculation speed of available computers. Also, memory limitations had an important role in the selection of the integer-value approach. However, the results are not required instantaneously as, for example, in determining sawing patterns at a headrig. Actually, solution times of a full day (or more) are acceptable.

Scientific research results on DP have shown that there is a great variety of both linear and nonlinear problems which it can solve. However, there are severe numerical limitations to the kinds of problems that can be treated [6]. In the past, the maximum number of state parameters or control variables that could be handled by computers was three. In this study these limitations were justified once again in bigger problems when using the same algorithm three decades later. The problems requiring the determination of three state parameters, six control parameters and six implicit variables at each stage were within the realm of PC-computer feasibility. Although computational capacities have increased much, and the use of microcomputers has changed the working environment, DP in wood resource allocation continues to wait for what the future has to offer in the way of instruments.

In the method study of functionally decentralized wood procurement planning, it was expected that the discrete simulation, due to its flexibility, would facilitate the evaluation of the various decentralized planning problems [7]. Discrete simulation is a step-by-step solution technique like DP, but DP has flexibility and can also be constructed to have the discrete, finite and integer format. Some other links have also been presented between DP and simulation [8]. The lack of an optimization routine limiting the performance of discrete simulation is not a problem with DP models. The recursion relation based on Bellman's Principle of Optimality can guarantee the global optimum [5][7].

There is no unifying theory of nonlinear programming for DP as there is for LP in the field of linear theory. The computational algorithms available are only for solving very special types of problems. Therefore, the DP of procedure had to be modified accordingly to suit the actual problem.

In this study, roadside inventories were selected as the state parameters based on the dynamic structure of the wood procurement system. There could, of course, be many other possible selections available for model construction; e.g., one of the other wood procurement functions. Furthermore, there were different kinds of sub-systems within the problem as a whole, and these could be formulated as a DP model. However, after numerous tests and theoretical modelling considerations, it was difficult to imagine more appropriate and effective state parameters. According to Hadley [6], the selection of state parameters is the most subtle task. Once this is accomplished, it is usually a straight forward matter to obtain the recursion relation. This was also observed to be the case in this study, and sufficient time should be allocated to this phase of model construction.

Functions were handled in the same way, utilizing the partial timber flow equations. The mills' wood demands are usually divided into stages by using monthly grids. In this procedure, however, shortened stages were tested for practical planning purposes; the idea was to achieve a more accurate solution for wood procurement needs resulting from more frequent dynamic changes in production. Nevertheless, caution must be applied in regard to the length of the tactical planning periods so as to ensure that their length is adequate from the operational point of view. Consequently, two-week periods were preferred to one-week periods.

The particular importance of the interest rate for the control of tactical planning was analyzed, because the dynamic model operated using the time factor and other descriptive factors with the values and volumes of the local districts instead of averages of the higher echelon. Furthermore, it is common knowledge that the effects of interest rate are a nonlinear function of time, and these could be estimated more accurately by using this dynamic model.

Developing the DP procedure was completed by testing the model's inputs in reality. A case in point was the cost effect caused by the interest rate. It was a significant part (2%) of the total costs, but the interest rate seemed to have only a slight influence on the allocation of resources. These results clearly indicate that the percentages represented by these costs were not high enough to significantly influence allocation; there were more effective factors in the dynamic model. The costs were almost the same as the costs found in the first time factor study conducted in Finland using empirical data and the actual percentage [9], [11]; had FIM 6 /cubic metre been used as the average magnitude of interest costs, then the corresponding percentage would have been about 2.31.

The most obvious explanation for the lower percentage calculated in this study may be in enhanced wood allocation compared to the actual conditions, especially because the total loan capital was used during this short-term planning horizon. In a real-life study, the data were compiled by the Central Association of Finnish Forest Industries, and their own capital investments were obviously included [9]. Therefore, the results of this study must be considered as instances of the maximum cost effect of the interest rate. In practical problems the corresponding interest rate should be lower for planning operations to be done efficiently.

In one study, an integrated model, developed for allocating annual timber sales, had the potential to generate significant savings [13]. In order to find out the efficiency of logging, roadside inventorying, and transportation operations, a sensitivity analysis was developed. A comparison of the integrated and conventional modelling strategies actually identified savings opportunities. The changed allocation of transportation, by varying logging when using the integrated model, indicated an even greater accuracy of the solution as compared to using separate models.

As future extensions, the next decade may bring with it advantages in the form of DP configurations for PC computers. Also, if districts will be reorganized profit centres and their responsibilities will be assigned for themselves, then so-called information cheating [7] could be controlled and avoided. On the other hand, the major disadvantage would be the lack of the professional managers as the performance of managers would entail both operational and programming skills.

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