LOGPLAN II: A Model for Planning Logging and Regeneration Activities

R.M. Newnham
Petawawa National Forestry Institute
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ABSTRACT

LOGPLAN II is a linear-programming (LP) based model that can be used as a tool in formulating a forest company's annual operating plan. Given the resources of wood, equipment, and planting stock that are available, the model schedules harvesting and regeneration activities in such a way that the cost of meeting mill demands is minimized. The model can be used to test a number of different planning strategies to ensure that the most effective is selected.

The development of LOGPLAN since the mid-1970s is outlined. Formulae are given for the objective function and the constraints that may be imposed on the harvesting system. The method of constructing a flowchart for the system is illustrated using "Hypothetical Forest Company" as an example. Required data are entered interactively on a computer terminal and stored in tabular form on computer files that can be used for making corrections or changes. The LP input matrix is generated automatically from these files using FORTRAN programs. Optimization is accomplished using the XMP software package. The procedure for running the different programs to complete an analysis is described. Examples of input tables and output reports are given for the Hypothetical Forest Company.

RÉSUMÉ

Le LOGPLAN II, fondée sur la programmation linéaire (PL), est un modèle qui peut être un moyen de formulation pour les plans opérationnels annuels d'une compagnie forestière. Si les données sur les ressources de bois, les installations et le matériel reproductif sont à notre disposition, à l'aide de ce modèle, on est en mesure de déterminer le calendrier de récolte et de pratiques de régénération forestières. Ce procédé permet de minimiser les frais encourus lorsqu'on veut satisfaire aux demandes établies par les usines de papeterie. Il peut être aussi utilisé à vérifier de diverses stratégies de planification pour que l'on puisse choisir celle qui est la plus efficace.

Le présent article donne également un aperçu de l'évolution du LOGPLAN II depuis le milieu des années 70. Les formules sont décrites en ce qui concerne les fonctions objectives et les restrictions applicables à un système de récolte. La méthode de générer les organigrammes est illustrée en se servant de la "Compagnie forestière hypothétique" comme exemple. Les données nécessaires sont introduites, de manière interactive, à un terminal d'ordinateur, puis elles sont emmagasinées dans des fichiers informatiques en forme tabulaire, ce qui permet les corrections ou les changements. La matrice d'entrée en programmation linéaire est automatiquement générée de ces fichiers en programmant en FORTRAN. Le logiciel XMP assure l'optimalisation. Pour compléter l'analyse, le procédé d'exécuter les différents programmes est aussi décrit. Les exemples de tables d'entrée et de rapports sortants se rangent dans le cadre de la Compagnie forestière hypothéthique.

INTRODUCTION

The LOGPLAN model was developed as a tool to aid the forest manager in drawing up a one-year logging operations plan. Basically, the model took the resources of wood and of equipment that were available and scheduled the logging operations (felling, delimbing, slashing, trucking, etc.) in such a way that the cost of supplying a known (fixed) amount of wood to a company's mill, (the mill demand) was at a minimum, subject to a number of constraints. The main objective of the model was to give the planner the ability to quickly and cheaply evaluate alternative systems and strategies (to ask: "What if ...?" questions) before determining the final plan.

The original model consisted of three components: data input and matrix generation, linear programming optimization, and output report generation. It was described by Newnham (1975a), and a detailed description of the FORTRAN programs provided by Newnham (1975b). A practical example of its application was described by Newnham (1976). Further field testing showed that, in practice, harvesting systems in typical eastern Canadian operations were too complex to be "optimized" by the linear programming routines given by Newnham (1975b). Modifications were made to take advantage of the proprietary software, MPSX (International Business Machines 1972). An example of such a complex system is shown in Figure 1. The company operated in three districts, each of which supplied the bulk of the wood requirements of one or two mills. Additional supplies of roundwood and chips were purchased. The system could have been analysed on a district by district basis except for the fact that there was some cross-hauling between districts. For example, some sawlogs were trucked from District 1 to the sawmill (Mill 5) in District 3. Waste wood from the sawmill was chipped and sent to the pulp mill (Mill 1).

Although company staff, with whom the model was developed, were enthusiastic about the model's potential value, it was not accepted by the forest industry. This was because at the time there was a shortage of "computer-literate" staff, management was resistant to trying something "new", and only limited access was available to the mainframe computers that were necessary to do the analyses — as one woodlands manager later stated: "LOGPLAN was five years ahead of its time!" With the advent of a new generation of computer-literate forestry graduates, a management that is more receptive to new computer-based technology, and the general availability of personal computers and workstations that are as powerful as the main-frames of the 1970s, most of these roadblocks have been eliminated.

Recent Advances in Harvest Planning

During the 1980s much effort was expended on developing harvest planning (or scheduling) and other forest management models. This was directly due to great advances in computing technology and the concomitant development of sophisticated software for geographic information systems (GIS) and associated database management systems (DBMS). Large, detailed databases are now available that can be manipulated by GIS and DBMS to provide the data necessary for modelling.

Timber RAM (Navon 1971, Chappelle et al. 1976, Armstrong et al. 1984) was an early harvest planning model. It was a linear programming (LP) model that, given an inventory of resources on a forest management unit, could calculate the volumes cut, the cost, and revenues for up to 35 decades. This, and other more recent LP-based planning models (e.g. Hoganson and Rose 1987, Marshall 1988, Jamnick et al. 1990), can be used to test different harvesting strategies and management policies. Some LP models have been developed that address specific problems; the model of Reed and Erico (1986) studied the risk of catastrophic fire and its effect on long-term wood supply.

Linear programming has a rigid mathematical structure (Marshall 1986) that can only optimize one objective at a time. However, forest management plans often have to meet a number of objectives, not all of which can be optimal. To cope with such situations we can use modified forms of LP, such as multiple objective programming (Mendoza et al. 1987, Bare and Mendoza 1988) and fuzzy linear programming (Mendoza and Sprouse 1989). The ADHAM model (Wightman and Jordan 1990) can accommodate the subjective factors that often have to be considered in harvest planning along with the objective ones. The model does this by linking spreadsheet techniques with LP. Goal programming (e.g., Kao and Brodie 1979) has also been applied. Other researchers prefer Monte Carlo integer programming (MCIP) methods, especially when spatial constraints have to be taken into account (O'Hara et al. 1989, Clements et al. 1990). Nelson and Brodie (1990) showed that a random search algorithm could produce plans that were within three percent of the optimum produced by a mixed integer programming (MIP) solution but at a fraction of the cost. Jamnick (1990) obtained similar results when he compared an LP model with the simulation model, FORMAN.

Geographic information systems have made it possible to integrate spatial constraints into harvest planning models fairly easily. Nelson et al. (1988)

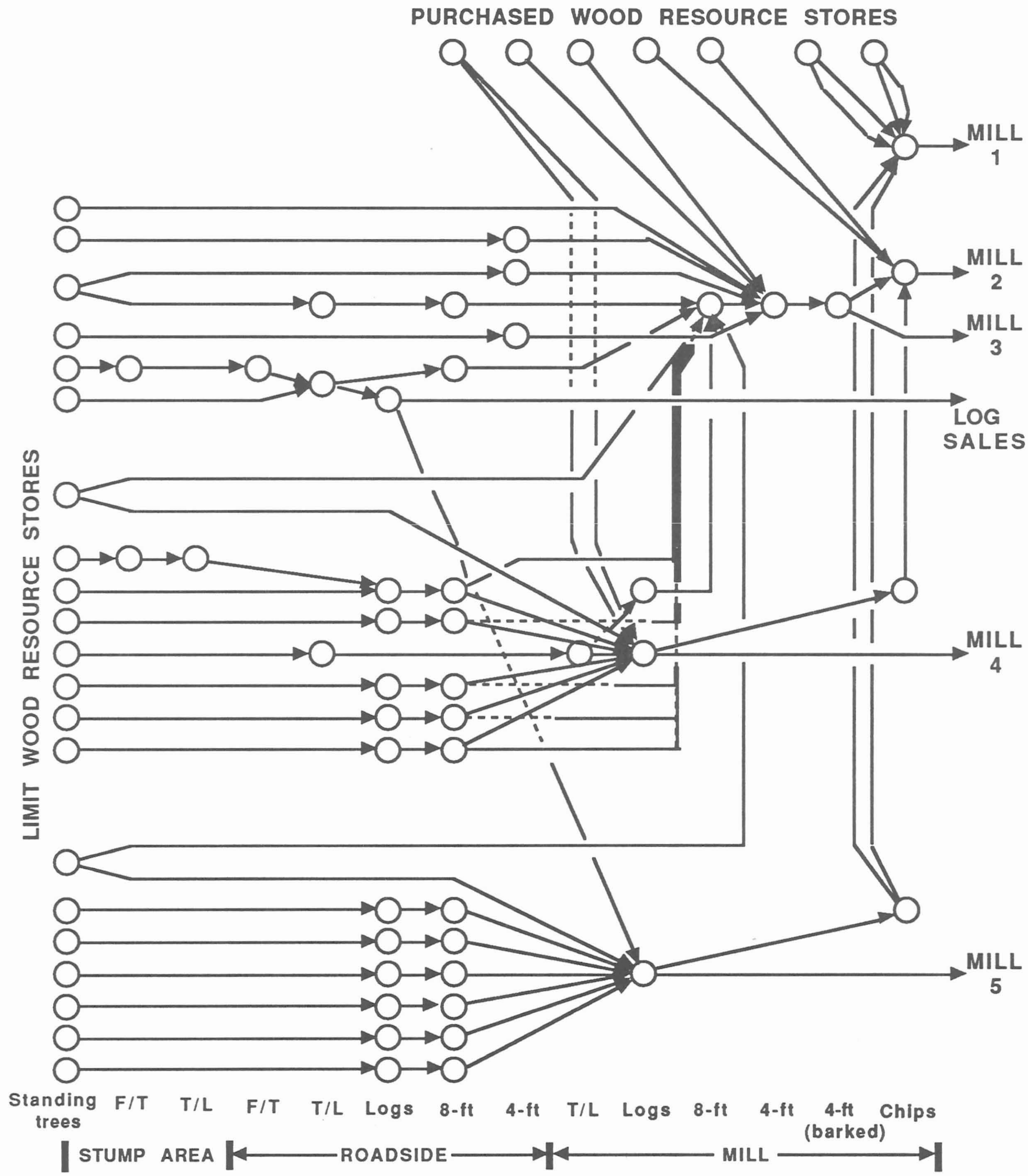

Figure 1. Flow chart of the harvesting operations at an eastern Canadian forestry company.

discussed the problems associated with building "adjacency" constraints into a planning model. Such constraints usually place restrictions on the timing of the harvest of adjacent stands to control the area of contiguous clear-cuts. Torres-Rojo and Brodie (1990) have proposed an heuristic for adjacency constraint aggregation. Other examples of the integration of GIS into harvest planning include Bobbe (1989) and Lougheed (1988). Walker and Lougheed (1989) used GIS to evaluate alternative road networks with Timber RAM to maximize volume utilization.

Erdle[1] anticipated a harvest scheduling model that tracked the development and treatment of all stands in a province. Moore and Lockwood (1990) have taken the first step in showing that this is technically feasible. Their HSG model keeps track of 28000 stands on a forest management unit in northern Ontario and develops harvest schedules for periods of five and 25 years (or longer). Adjacency constraints are not, as yet, included in the model. Lockwood[2] is investigating the simulated annealing algorithm to resolve this problem.

It can be seen that much effort has been expended on developing models that can schedule the order in which stands may be harvested. These schedules can be valuable in providing some of the input to LOGPLAN. Each scheduled stand could be considered as a "wood resource store" but, to reduce the number of such stores to a manageable level, it is usually preferable to aggregate the stands. Each wood resource store should consist of stands of similar species composition, maturity, and site class, and should be located in the same geographic area (particularly with respect to transportation distance to the mill). Using output from the HSG model, an attempt was made to automate this aggregation using cluster analysis. Although the results were fairly successful, it was felt that the forest manager should be involved in making the final selection.

Since LOGPLAN was published in the mid-1970s little further effort appears to have been made to develop logging operations planning models. The interaction of certain components of a logging operations system has been studied. Greene and Lanford (1984) used interactive simulation in a microcomputer to study a feller-buncher thinning a southern pine plantation. Gingras (1988) undertook a field study of the interaction between a feller-buncher and a grapple-skidder to determine the optimum size of bunch. Hassler et al. (1988) developed a discrete-state continuous parameter Markov process model to study the interaction between a grapple-skidder and a slasher. Similar, but more complex, interactions had been studied earlier using simulation by Newnham and Sjunnesson (1969). Walker and Priess (1988) used MIP to integrate harvesting and delivery planning (but not in the detail of a LOGPLAN analysis). Sessions and Paredes (1987) developed an alternative to MIP for locating sort yards (somewhat analogous to the LOGPLAN "sorting activities" described later). Twito et al. (1987) used a computer assisted design (CAD) system for developing harvesting and road network plans. Simulated annealing (Lockwood[2]) also appears to be a useful tool for designing road networks.

For eastern Canada, a valuable methodology for comparing the performance of harvesting machines and systems has been developed by Mellgren (1990). For each machine, production is based on ideal operating conditions but correction factors are provided for less favourable operating conditions.

LOGPLAN II Modifications

During the 1970s, in most provinces the companies were generally not responsible for regeneration following harvesting. Thus the main concern was to minimize the cost of harvesting, without considering the possible adverse effect this might have on subsequent regeneration activities. With the advent of Forest Management Agreements (FMA) in the early 1980s responsibility for regeneration was transferred to the companies. It would thus seem logical not to analyse the two sets of regeneration and harvesting activities separately but to combine them and obtain an overall optimization, a view shared by Kotak et al. (1990). This option has now been built into LOGPLAN II.

A number of other modifications, including sorting activities and store groups, have been made to LOGPLAN since the original reports (Newnham 1975a, 1975b) were published. Data are now entered interactively on a terminal with the user responding to "prompts". Because of the quantity of data that is required this is still a laborious business but, once entered for a logging system, the data are filed in an easily readable tabular form. The tables are subsequently used to generate the standard 80-column card-image input to LOGPLAN, and input errors can be corrected using a text editor. Modifications have been made to the programs to include additional constraint options and to adapt the model for use with the XMP LP software package (XMP Software Inc. 1989).

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[1] Erdle, T. 1985. Harvest scheduling and its impact on wood supply. New Brunsw. Dep. Natur. Resources, Forest Manage. Br. unpubl. rep. 16p.

[2] Lockwood, C.G. 1990. Personal communication.

THE MODEL

The Objective Function

The objective function for LOGPLAN II is the same as for the original model, namely to minimize:

$$Z = c_{11}x_{11} + c_{12}x_{12} + ... + c_{21}x_{21} + ... + c_{NM}x_{NM}$$

where:

c_{ij} = $r_{ij} + t_{ij}$
x_{ij} = production (in m^3) of activity A_i in period j
N = number of activities
M = number of periods

and

$$x_{ij} \geq 0 \text{ for } i = 1, ..., N \text{ and } j = 1, ..., M$$

r_{ij} is the sum of the fixed and variable machine operating costs ($/shift), divided by the production rate (m^3/shift) to give the cost in $/$m^3$. t_{ij} is an allowance for inventory charges associated with activity A_i. Newnham (1975a) showed that it could be calculated from the formula:

$$t_{ij} = \sum_{k=j}^{M} W_k - 0.5W_j)(c_f - c_e)$$

where:

W_k = the number of operating days in period k
c_f = the daily inventory charge ($/$m^3$) for the store being filled by activity A_i
c_e = the daily inventory charge ($/$m^3$) for the store being emptied by activity A_i

The first half of this expression indicates that interest for the current inventory is carried from the middle of the current operating period to the end of the planning period. The second half reflects the increase in the value of the wood as it is transferred between stores by the activity.

Constraints

The modifications that have been made to LOGPLAN have resulted in a number of new constraints to the LP model. These, together with the original constraints (Newnham 1975a), are described here.

Periodic Activity Production

$$x_{ij} \leq b_1$$

where b_1 is usually the maximum possible production, P_{ij}, of activity A_i in period j, except where this level would result in a negative inventory in the store, S_k, being emptied by activity A_i. The final value of b_1 is, therefore:

$$b_1 = \min\{P_{ij}, \sum_{i=1}^{N_k} \sum_{v=1}^{j} Pu_i v + I_k)\}$$

where:

u_i = number of the ith activity feeding store S_k
N_k = number of activities feeding store S_k
I_k = initial inventory of store S_k

The values of b_1 are the "BOUNDS" in the LOGPLAN.MPS file noted later in this report.

Total Activity Production

$$\sum_{j=1}^{M} x_{ij} \leq b_{2.1}$$

$$\sum_{j=1}^{M} x_{ij} \geq b_{2.2}$$

When $b_{2.1} = b_{2.2}$, the constraint becomes $\Sigma x_{ij} = b_{2.1}$. If $b_{2.2} = 0$, the minimum constraint is superfluous as all $x_{ij} \geq 0$. The values of $b_{2.1}$ are the "RHS" and the differences, $b_{2.1} - b_{2.2}$, are the "RANGES" in LOGPLAN.MPS.

Determination of the correct values of $b_{2.1}$ and $b_{2.2}$ is complicated as it depends on the size and initial inventory of all the stores that may contribute to activity A_i and also on the productivity of all the other activities that feed and empty those stores. A relatively simple example will illustrate the principles of how this is done.

Figure 2 shows part of a flowchart in which S_1 and S_2 are wood resource stores. The values of $b_{2.1}$ and $b_{2.2}$ for activity A_3 will then be:

$$b_{2.1} \leq \min \{ \sum_{j=1}^{M} P_{3j}, (1000+2000+100), (\sum_{j=1}^{M} P_{1j} + \sum_{j=1}^{M} P_{2j}+100)\}$$

and

$$b_{2.2} \geq \max \{0, [(1000-200) + (2000-500) - 400] - \sum_{j=1}^{M} P_{4j}\}$$

In simple terms, $b_{2.1}$ must be less than the total maximum production of the activity A_3 or the sum of the initial inventories in the three stores (S_1 - S_3) that could be a source of wood for A_3 or the sum of the total maximum productions for A_1 and A_2 plus the initial inventory of S_3, whichever is the least. The value of $b_{2.2}$ must be greater than the sum (800+1500=2300) of

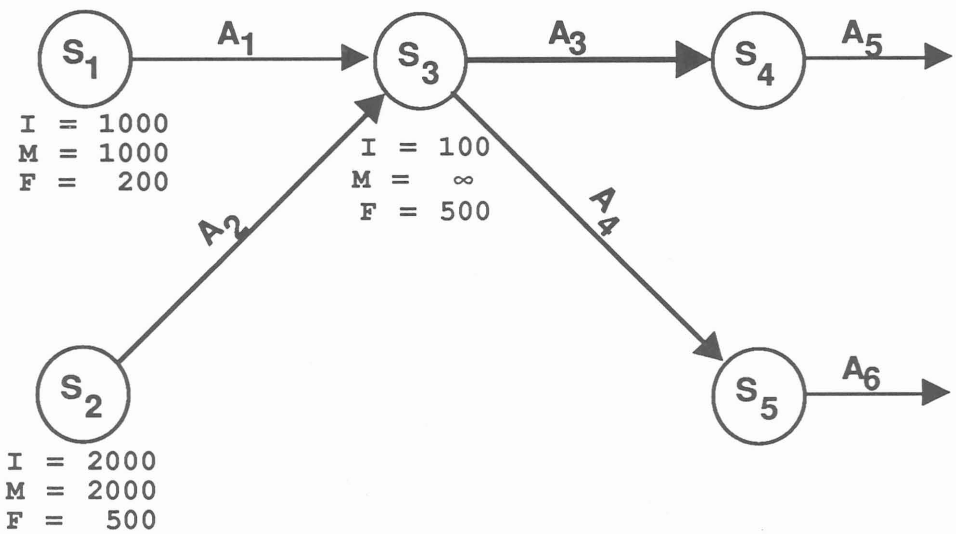

Figure 2. An example to illustrate the method of calculating the constraints on the total production of an activity. (I, M and F, are the initial, maximum, and final inventories of each store.)

volumes of wood that **must** be removed from the two wood resource stores (S_1 and S_2), less the difference (400) between the initial and final inventories of store S_3. If the result is negative, then $b_{2.2}$ is 0 and becomes superfluous. It should be noted that if $b_{2.2} > b_{2.1}$ the LP problem becomes "infeasible" and an optimum solution does not exist.

Intermediate and Mill Blockpile Stores

Store constraints ensure that the inventory in each store never falls below zero or rises above the maximum capacity of the store. They also ensure that the maximum final inventory is not exceeded or, if a fixed volume is to be left in the store at the end of the planning period, that the amount is there. For each store there may be two constraints for each period:

$$\sum_{i=1}^{M_k}\sum_{v=1}^{j} x_{u_i v} - \sum_{i=1}^{N_k}\sum_{v=1}^{j} x_{u_i v} \le b_{3.1} \text{ for } j = 1, 2, ..., M$$

$$\sum_{i=1}^{N_k}\sum_{v=1}^{j} x_{u_i v} - \sum_{i=1}^{M_k}\sum_{v=1}^{j} x_{u_i v} \le b_{3.2} \text{ for } j = 1, 2, ..., M$$

where:

M_k = number of activities emptying store S_k
N_k = number of activities filling store S_k
u_i = activity number of the ith activity emptying or filling store S_k
j = period number

If $b_{3.1} = b_{3.2}$, the two constraints are replaced by a single equality. If either b-value is negative, the inequality is reversed and both sides are multiplied by –1.

The calculation of $b_{3.1}$ and $b_{3.2}$ is also complicated but the principle can be illustrated if store S_3 in Figure 2 is used as an example. For all periods, the value of $b_{3.1}$ will be 100. In other words, the total volume of wood being removed from the store S_3 must not exceed the volume that is added to the store by more than 100, the volume of wood that was in the store at the beginning of period 1. If the final inventory, S_f, had been specified as exactly 500, rather than a maximum (i.e., $S_f = 500$ instead of $S_f \le 500$), the two constraints would have been replaced by a single equality with $b_{3.1} = 400$ (the difference between the final and initial inventories). For the first M-1 periods, the value of $b_{3.2}$ will be 800, the difference between the maximum and initial inventories. For the last period, $b_{3.2}$ will be 400. A fuller and more detailed example of the calculation of these constraints was given by Newnham (1975b).

Wood Resource Stores

Where the number of activities emptying a wood resource store is greater than 1, two constraints are required:

$$\sum_{i=1}^{M_k}\sum_{j=1}^{M} x_{k_i j} \le b_{4.1}$$

$$\sum_{i=1}^{M_k}\sum_{j=1}^{M} x_{k_i j} \ge b_{4.2}$$

where:

$b_{4.1}$	=	initial inventory of the wood resource store
$b_{4.2}$	=	difference between the initial and final inventories

When the final inventory is a fixed value or zero, the two constraints are replaced by a single equality.

The constraint for a wood resource store that is emptied by a single activity will have been covered by the second type of constraint ($b_{2.1}$ and $b_{2.2}$).

Activity Groups

The user has the option of defining groups of activities that utilize the same machines or methods of regeneration. All of these machines may be made available to each activity in the group but a constraint must be applied to ensure that, at any one time, not more than the total number of machines are assigned. This constraint is:

$$\sum_{i=1}^{L_k} x_{k_i j} / Q_{k_i j} \leq b_5$$

where:

L_k	=	the number of activities in the group
k_i	=	activity number of the ith activity in the group
Q_{k_i}	=	the maximum potential production of one machine for period j in activity A_{k_i}

It should be noted that although b_5 is an integer the solution may yield a value of x that, when divided by Q, gives a fraction. This value will have to be rounded up to the nearest whole number to indicate the minimum number of machines that will have to be assigned to that activity. To maintain the scheduled production level (x), the machines would operate in the activity for less than the full number of operating days for the period. For the balance of the period, the machines would be transferred to another activity if required.

Sorting Activities

In the original version of LOGPLAN, the composition of the wood resources stores was taken into account by "assortment" constraints (Newnham 1975a). For each wood resource store the proportion of each stand type and the proportion of each species or assortment within the stand type was specified. The volumes of each assortment that were required by the mill or mills also had to be specified. The assortment constraints ensured that the correct proportions were put into the system but did not guarantee that they reached the mills in the correct proportions.

In LOGPLAN II, groups of sorting activities may be used to ensure that mill demands are assigned assortments in the correct proportions. These groups, each of which empties a single store, can occur anywhere in the harvesting operations but, for each wood resource store, they must occur before the wood is "mixed" with wood emanating from another wood resource store (unless that store has the same composition of assortments). As well as sorting, these activities may perform other functions (e.g. slashing, trucking, etc.). For each activity in the group, the minimum and maximum proportions of total volume produced by the group must be specified. The range in production for each activity will then be:

$$r_{k_i} \leq P_{k_i j} / \sum_{m=1}^{N_k} P_{k_m j} \leq R_{k_i}$$

where:

N_k	=	the number of activities in the kth group
k_i	=	activity number of the ith activity in the group
r_{k_i}	=	the minimum proportion of the total production of the group for the ith activity in the group
R_{k_i}	=	the maximum proportion of the total production of the group for the ith activity in the group

The two constraints for the LP matrix are then:

$$P_{k_i j}/\Sigma P_{k_i j} \geq b_{6.1}$$

$$P_{k_i j}/\Sigma P_{k_i j} \geq b_{6.2}$$

where $b_{6.1} = r_{k_i}$ and $b_{6.2} = R_{k_i}$. In Figure 3, there are three groups of sorting activities: A_{24} - A_{26} and A_{33}, A_{27} - A_{29}, and A_{30} - A_{31}. All, except A_{33}, are also trucking activities.

Store Groups

It may sometimes be desirable to impose a constraint on the maximum total volume that can be present in a group of stores while not restricting the maximum volume of any store within the group. An example would be where wood is sorted into separate assortments at a landing but where the exact proportions are not known until the model is run. For the Hypothetical Forest Company, the manager does not want the volume of tree lengths stored at the roadside (stores S_{19} - S_{22}) to ever exceed 10 000 m^3,

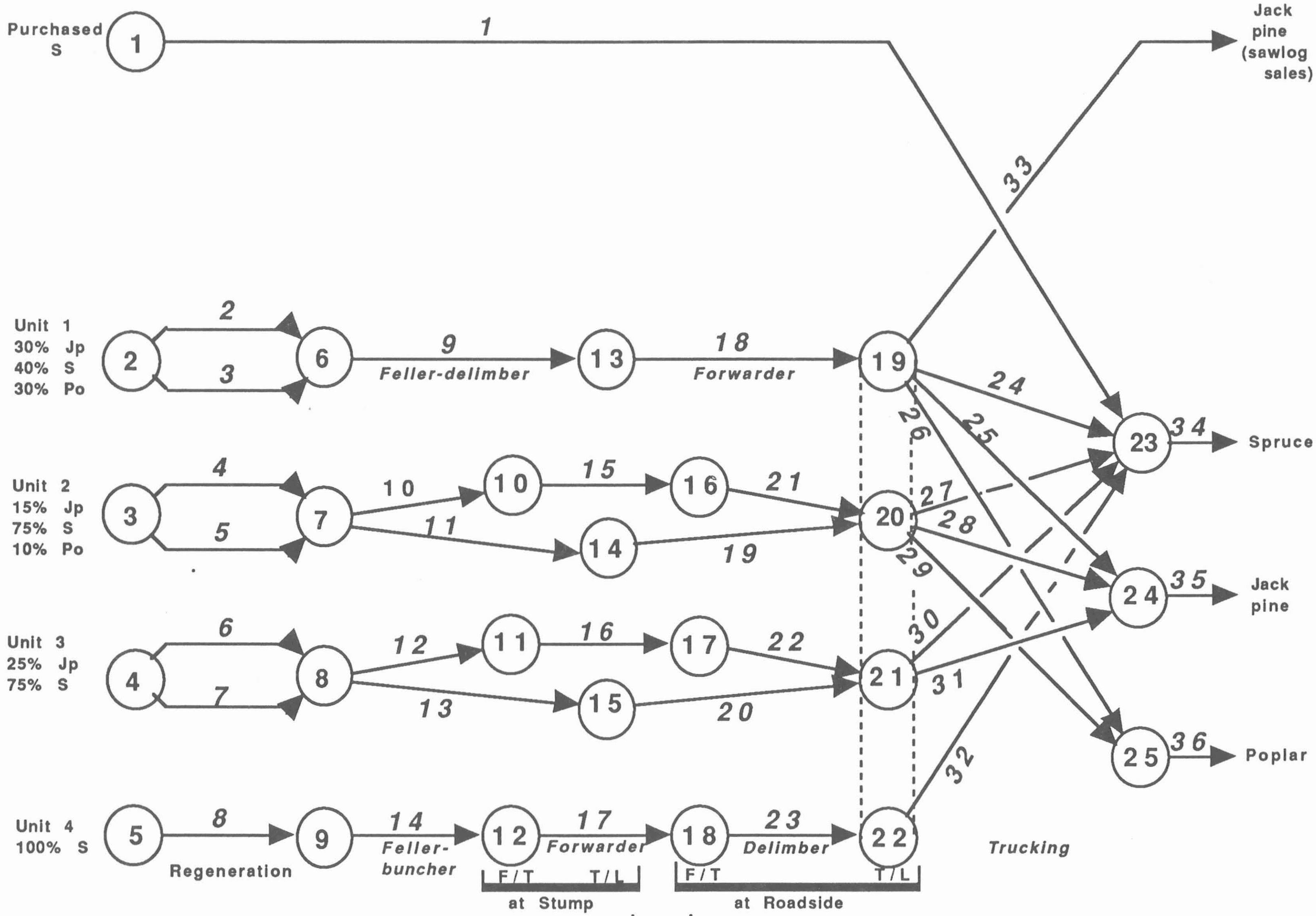

Figure 3. LOGPLAN flow chart for Hypothetical Forest Company.

but is not concerned about which store (or stores) the wood is found.

The two constraints are very similar to those for intermediate stores, except that the summations are now for all stores within the group:

$$\sum_{w=1}^{L_k} \sum_{u_i=1}^{ML_k} \sum_{v=1}^{j} x_{u_{w_i}v} - \sum_{w=1}^{L_k} \sum_{u_i=1}^{NL_k} \sum_{v=1}^{j} x_{u_{w_i}v} \geq b_{7.1}$$

$$\sum_{w=1}^{L_k} \sum_{u_i=1}^{ML_k} \sum_{v=1}^{j} x_{u_{w_i}v} - \sum_{w=1}^{L_k} \sum_{u_i=1}^{NL_k} \sum_{v=1}^{j} x_{u_{w_i}v} \leq b_{7.2}$$

where L_k = the number of stores in the group. The values of $b_{7.1}$ and $b_{7.2}$ are obtained in a similar manner to those of $b_{3.1}$ and $b_{3.2}$.

Planting Stock

In LOGPLAN II it is possible to place constraints on the number of plants (or seeds) of each type of planting stock that are available each year. For each type of stock, the constraint is:

$$\sum_{i=1}^{M_k} \sum_{j=1}^{Q} x_{k_i\theta_j} \cdot t_k / V_{L_k} \leq b_8$$

where:

θ_j	=	$(n - 1) \bullet Q + j$ for $n = 1, 2, \ldots, N_y$
N_y	=	number of years in the planning period
Q	=	number of operating periods per year
M_k	=	number of activities in the kth group of activities that have a common method of regeneration
k_i	=	activity number of the ith activity in group k
t_k	=	number of plants (or seeds) per ha
L_k	=	number of the wood resource store being emptied by activity k_i
V_{L_k}	=	volume per ha (m^3) of wood resource store L_k
b_8	=	number of plants (or seeds) that are available each year for group k

Silvicultural Budget

The LOGPLAN II user has the option of specifying an annual silvicultural budget for regeneration. To ensure that this amount is not exceeded, the constraint is:

$$\sum_{i=1}^{N_r} \sum_{j=1}^{Q} x_{k_j\theta_j} \cdot c_{k_j\theta_j} / V_{L_k} \leq b_9$$

where:

N_r	=	number of regeneration activities
b_9	=	annual silvicultural budget ($)
$c_{k_i\theta_j}$	=	cost ($/ha) of regenerating store L_k by the regeneration method used by activity k_i in period $(n - 1) \bullet Q + j$

METHOD

The procedure for using LOGPLAN II for analysing a logging operations system is as follows:

(1) Construct a flowchart of the logging operations.
(2) Using the terminal, input data for the system parameters, operating periods, stores, machines, and harvesting and regeneration activities.
(3) Correct any input errors on the summary files.

The remaining steps are done automatically by running different programs:

(4) Convert data in the summary files to 80-column format.
(5) Generate the LP input matrix.
(6) Sort the LP matrix columns in alphanumeric order.
(7) Convert the LOGPLAN II output data files to the standard MPSX format required by XMP.
(8) Optimize using XMP.
(9) Prepare reports from the XMP output.

A detailed description of these steps follows.

The Logging Operations System Flowchart

The system flowchart for a Hypothetical Forest Company is shown in Figure 3. This system illustrates many of the options available to the LOGPLAN II user while keeping the system as simple as possible. "Stores" are shown as circles and "activities", whose main function is to transfer wood from one store to the next in the system, are shown as arrows.

Wood resource stores are shown on the left of the chart. These are comprised of a single source of purchased wood (S_1) and four harvesting units (S_2 - S_5). Mill blockpiles (S_{23} - S_{25}), from which the mill demands (activities A_{34} - A_{36}) are met, are shown on the right. The following rules apply to the numbering of stores:

(1) Stores of purchased wood (if any) are numbered first.
(2) Other wood resource stores, the harvesting units, are numbered second.
(3) Mill blockpiles are numbered last.
(4) Intermediate stores may be numbered in any order but it is logical to number them in sequence from left to right.

Similar rules apply to the numbering of activities:

(1) Wood purchasing activities (if any) are numbered first.
(2) Activities emptying the other harvesting units, whether they are harvesting or regeneration activities, are numbered second.
(3) Mill demands are numbered last.
(4) Wood selling activities (if any) are numbered immediately before the mill demands.
(5) Other activities are usually numbered in sequence from left to right.

Regeneration activities (A_2 - A_8), if present, always "empty" the wood resource store (harvesting unit) that they are responsible for regenerating and each "fills" a dummy store (S_6 -S_9) that has a zero capacity. This ensures that any areas that are harvested are regenerated (subject to constraints on the silvicultural budget and the availability of planting stock). Two or more methods of regenerating a harvest unit may be used or, if no action is being taken by the company to regenerate a unit, the regeneration activity is omitted and the first harvesting activity "empties" the store. Although, in the flow chart, regeneration appears to take place before harvesting and can also occur in any season of the year, in practice the reverse is true, with regeneration occurring only in the planting season and often in the year following harvesting.

In Figure 3, certain activities are grouped to form "activity groups". Activities A_9, A_{11}, and A_{13} are feller-delimbers and A_{10}, A_{12}, and A_{14} are feller-bunchers. Forwarders are used in A_{15} - A_{20} but the first three of these forward full trees while the remainder transport tree lengths, so the production rates will differ. Activities A_{21} - A_{23} are delimbing trees at the roadside. Activities A_{24} - A_{32} are responsible for transporting wood from the roadside to the mill and are, at the same time (along with A_{33}), "sorting" activities that ensure that wood leaving stores S_{19} - S_{22} is in the proportions indicated under each unit. There is some flexibility in directing jack pine to the mill or to sawlog sales but the combined proportion must equal 30 per cent. Stores S_{19} - S_{22} form a "group of stores" for which a maximum total inventory is specified.

Although there are three mill demands (A_{34} - A_{36}), this does not necessarily infer that there are three mills; the spruce and pine might be used to make pulp and the poplar might be used for wafer board manufacture.

After completing the flowchart, subsequent steps in a LOGPLAN II analysis are made by running a number of computer programs. Except for one sorting program, currently available as a SAS procedure (SAS Institute Inc. 1988), these programs are written in FORTRAN 77 for a SUN workstation. The linkages between the different programs and their input and output files are shown in Appendix I.

Data Input

Initial data input is done interactively by running the program `logplan2_inp`. In response to prompts on the terminal screen, the user provides a job number and title and then data for general harvesting system parameters, periods (seasons), stores, machines, activities, and planting stock constraints.

General harvesting system parameters

The parameters and their values for the Hypothetical Forest Company system (Figure 3) are given in Table 1.

Table 1. System parameters and their values for the Hypothetical Forest Company

Description of system parameter	Value
Number of years in plan (max. = 5)	2
Number of operating periods per year (max. = 20*)	4
Total number of stores (max. = 50*)	25
Number of purchased-wood stores (max. = 10)	1
Number of management unit stores (max. = 8*)	4
Number of groups of stores (max. = 10)	1
Total number of activities (max. = 60*)	36
Number of wood-purchasing activities (max. = 60*)	1
Number of wood-selling activities (max. = 60*)	1
Number of activity groups (max. = 10)	6
Number of mill demands (max. = 10)	3
Number of groups of sorting activities (max. = 10)	3
Number of regeneration machine types (max. = 10)	3
Number of harvesting machine types (max. = 10)	4
Number of truck types (max. = 10)	1
Number of planting-stock constraints (max. = 10)	1
Annual silvicultural (regeneration) budget ($)	2000000

* These values may be changed by changing the PARAMETER statements in the FORTRAN programs.

Periods (Seasons)

For the first year the user is requested to give the starting and finishing date and the number of operating days for each period. It is assumed that the dates and numbers of operating days are the same in the second and subsequent years. For the current analysis, the periods are: 01 APR 1991 - 31 MAY 1991 (40 operating days), 01 JUN 1991 - 15 OCT 1991 (90), 16 OCT 1991 - 15 DEC 1991 (40), and 16 DEC 1991 - 31 MAR 1992 (50) for a total of 220 operating days in each of the two years.

Stores

An example of the data requested for a wood resource store is given in Figure 4.

```
Store No. 3  Description (Max. = 24 characters):
             >Logging Unit 2
             Initial inventory (m**3):  280000
             Maximum final inventory (m**3):100000
             Area (ha): 1350
             Average number of trees/m**3: 8.0
```

Figure 4. Input data for a wood resource store.

All volumes and areas are rounded to the nearest whole number. The average number of trees/m^3 is required, so that the option to adjust machine productivity according to tree size may be implemented. Areas and trees/m^3 are not required for purchased wood resource stores. It should be noted that the difference between the initial and final inventories is the volume of wood that **must** be removed from the store during the planning period, regardless of cost.

For intermediate stores and mill blockpiles the data required are shown in Figure 5.

```
Store No. 16  Description (Max. = 24 characters):
              >F/T at roadside
              Initial inventory (m**3):  0
              Maximum inventory (m**3):  500
              Maximum final inventory (m**3):  0
              Daily inventory charge ($/m**3):
                                            0.006
```

Figure 5. Input data for an intermediate store.

If there is no limit to the maximum volume that is allowed in the store at any one time, a value of –999 is entered for maximum inventory. If it is desired to have a specified volume of wood in the store at the end of the planning horizon, the negative of that value is entered. Unless this is done, the model tends to empty all stores at the end of the planning period. The daily interest charge is for interest on the capital tied up in the store and any maintenance charges associated with the storage area.

Store Groups. Where the planner prefers to place a constraint on the maximum inventory allowed in a group of stores, as well as on each individual store, the maximum inventory for the group and the numbers of the stores in the group have to be specified (Figure 6). For the Hypothetical Forest Company, the total volume of tree lengths at the roadside was restricted to 10 000 m^3.

```
Group No. 1  Description (Max. = 24 characters):
             >T/L at roadside
             Number of stores in group (max. =
             10): 4
             Enter the store number for each of
             the 4 stores in the group (separate
             the numbers by a space or a comma):

             19 20 21 22
             Maximum total inventory for the group
             (m**3): 10000
```

Figure 6. Input data for a store group.

Machines

There are three basic categories of machine, those required for regeneration, for harvesting, and for trucking. For some activities (particularly regeneration activities), machines may not be directly required. For example, slash burning followed by natural regeneration may not have machine input in the same way that a felling activity has. It is also sometimes possible to simplify a system by combining different machines into a single activity (e.g. loading and slashing).

The information required for a harvesting machine type is given in Figure 7.

```
Harvesting machine type  3
Description (Max. = 24 characters):
          >Forwarders
Number of units available: 7

     For the next four entries on cost, you may
     either enter values for Capital, Fixed and
     Variable costs in $/shift OR a single value
     in $/m**3 (in which case enter 0 for each of
     the three shift costs).

Capital cost ($/shift): 240

Fixed cost ($/shift): 320

Variable cost ($/shift): 200

Production (m**3/shift): 135
```

Figure 7. Input data for a harvesting machine type.

Shift costs and production rates are rounded to the nearest whole number but costs in $/$m^3$, if used, are given in dollars and cents. The capital cost is the cost of owning a machine, whether it is used or not, while the fixed cost is charged as soon as the machine is scheduled for operation. The variable cost is only charged for the proportion of the time that the machine is actually operating. The production rate is the maximum level of production that a machine could attain during a shift.

Similar information is required for the regeneration machines (units), except that production is in ha/shift.

In the original LOGPLAN model, any variations in production rates due to season, topography, or tree size could only be accommodated by varying the production rates for each activity and period at the time of data entry. In LOGPLAN II, to ease the burden of data entry, these variations are accommodated by **productivity adjustment factors** that are similar to the correction factors of Mellgren (1990). For harvesting and regeneration activities, there are three types of adjustment factors:

(1) *Tree Size*. In LOGPLAN II, the average tree size is assumed to be 0.125 m^3 (equivalent to 8 trees/m^3 -- this value can be changed in the PARAMETER statement at the start of program `logplan2_prep`). A factor of 1.3 would result in a 30 per cent increase/decrease in productivity for each doubling/halving in tree size.
(2) *Period*. Seasonal variations in productivity due to climate are controlled by a another factor that is specified for each period. Thus, a factor of 0.95 would decrease the machine's production rate in that period by five per cent.
(3) *Wood Resource Store*. Variations in productivity due to topography, volume per hectare, soil conditions, etc. can be specified for each wood resource store. A factor of 1.03 would indicate a three per cent increase in productivity.

The combined effect of the productivity factors is multiplicative. Thus for the above examples, assuming an average tree size of 0.25 m^3, the overall productivity would be increased to 1.3 x 0.95 x 1.03 = 1.27, an increase of 27 per cent. Unless otherwise specified, all productivity adjustment factors default to values of 1.0. Program `logplan2_inp` prompts ask the user for any changes to the factors from their default values, thus ensuring that such data have only to be entered where necessary. An example is given in Figure 8.

Somewhat different data are required for trucks. For each, there is a choice of two methods for determining shift productivity:

```
Are there any adjustments to be made for wood
    resource stores on the forest management unit
    [Y/N]? y

    1  Feller-bunchers

Any adjustments for any wood resource store for
    this unit [Y/N]? n

    2  Feller-delimbers

Any adjustments for any wood resource store for
    this unit [Y/N]? n

    3  Forwarders

Any adjustments for any wood resource store for
    this unit [Y/N]? y
ENTER productivity adjustment factor for each wood
    resource store:

    2 Logging Unit 1            1.00
    3 Logging Unit 2            0.95
    4 Logging Unit 3            1.00
    5 Logging Unit 4            0.90

    4  Delimbers

Any adjustments for any wood resource store for
    this unit [Y/N]? n
```

Figure 8. Input data for wood resource store productivity adjustment factors.

(1) The speed at which the truck travels along each of up to three classes of road may be entered. If this is done, the hauling distance along each road class must be entered for each activity using the truck type so that the number of roundtrips/shift can be determined.
(2) The number of roundtrips/shift can be entered directly for each activity using the truck type.

Average load size must always be entered. Figure 9 is an example of the interactive input for the trucking activities for the Hypothetical Forest Company:

```
Truck type  1  Description (max. = 24 characters):
    >Tree-length  trucks

Number of units available: 8

      For the next four entries on cost, you may
      either enter values for Capital, Fixed and
      Variable costs in $/shift OR a single value
      in $/m**3.km (in which case enter 0 for each
      of the three shift costs).

Capital cost ($/shift): 0
Fixed cost ($/shift): 600
Variable cost ($/shift): 0
Average load size (m**3): 55
Average road speed (rounded to the nearest km/h):
Class 1 roads: 70
Class 2 roads: 60
Class 3 roads: 5
```

Figure 9. Input data for a truck type.

Seasonal variation in productivity can be adjusted as with the other machine types. However, it is assumed that trucking productivity will not be affected by either tree size or the wood resource store from which the wood is trucked.

Activities.

An example of the input data for activity A_{18} is given in Figure 10.

```
Activity No. 18 Function (1 letter upper or lower
    case): h

   FMU store from which wood originated: 2
   Description (24 characters): Forwarder (T/L)
   Productivity adjustment factor (e.g. 1.05):
    1.20
   Machine type No.: 3

Number of machine-shifts available in each period
    (for purchasing, selling, and mill demand
    activities, write "1")

Are the number of machine-shifts constant for all
    periods [Y/N]? y
Number of available machine-shifts per day: 14
No. of store being emptied: 13
No. of store being filled: 19
```

Figure 10. Input data for an activity.

The codes for functions are:

P → Purchasing wood
R → Regeneration activities
H → Harvesting activities
T → Trucking
S → Selling wood
M → Mill demands

The FMU store is required so that any adjustments for the wood resource store can be made (note: this is the **store** number, not the unit number).

The productivity adjustment factor is applied to the activity and is multiplied by the product of the other adjustment factors previously described for machines. In this particular example, harvesting machine type 3 is a forwarder whose production rate was based on forwarding full trees. In activity A_{18}, the forwarders are being used to forward tree-lengths and so their production rate has been increased by 20 per cent. The number of machine-shifts is the number of machines (7) that are available multiplied by the number of shifts per day (2). If the number of machine-shifts is not constant, the user will be prompted to give the number for each period (a value of "0" will indicate that the activity cannot operate in that period). The numbers of the store being emptied and filled are required to fix the location of the activity within the harvesting system.

The data required for the other types of activity are similar, with the following exceptions:

(1) For purchasing and selling activities, the price of wood and the maximum volume of wood that can be bought or sold in any day must be given.
(2) Wood selling and mill demand activities do not fill any stores.
(3) For mill demand activities, the volume of wood required each day must be given.
(4) For trucking activities, the user either specifies the number of roundtrips/shift or, if truck speeds have been input, the distances to the mill along each of up to three road classes (from which the number of roundtrips is calculated).

For activities that share the same type of machine, it is usual to make all the machines available for each of the activities.

Sorting Activities. Some groups of activities, in addition to transporting or processing wood, also sort the wood by species or end product. For the Hypothetical Forest Company, the trucking activities (A_{24} - A_{31}) and the selling activity (A_{33}) are also sorting activities. An example of the input data required for one of these groups is given in Figure 11.

```
Sort group No. 1 No. of store being emptied: 20
    Number of activities in group (max. = 10): 4

    For each activity, enter the activity No. and
      the minimum and maximum percentages (e.g.
      "21 30 50")

    1 >24 40 40
    2 >25 20 30
    3 >26 30 30
    4 >33  0 10
```

Figure 11. Input data for a group of sorting activities.

The sum of the maximum percentages should be at least 100. Activities A_{24} and A_{26} are supplying the mill with fixed proportions of spruce (40%) and poplar (30%). The 30 per cent jack pine in Unit 1 (S_2) may all go to the mill or, if it will result in savings to the company, up to 500 m^3/day (the maximum that can be sold – A_{33}) or 10 per cent of the volume of wood leaving store S_{20} (whichever is less) can be sold as sawlogs. Where possible, some flexibility should be built into sorting activities. In this example, it must be realized that for every 40 m^3 of spruce that is harvested 30 m^3 of poplar must also be harvested. To take advantage of cheap wood of one species, this may result in expensive wood of another species having to be harvested.

Activity Groups. For any group of activities that share the same type of machine, it is usual to make all the machines available to each of the activities in the group. Without additional constraints, this could result in more machines being scheduled than are available. Figure 12 shows an example of the input data that are required to ensure that this over-scheduling does not occur.

```
Group No. 4    Description (max. = 24 characters):
               >Forwarders
               Total number of machine-shifts that
                 are available to the group: 14
               Number of activities in the group
                 (max. = 20): 6
               1 Activity No.:   15
               2 Activity No.:   16
               3 Activity No.:   17
               4 Activity No.:   18
               5 Activity No.:   19
               6 Activity No.:   20
```

Figure 12. Input data for an activity group.

Planting-stock constraints.

It has already been stated that it is possible to set a constraint on the annual budget for silviculture or regeneration. It may also be necessary to set constraints on the numbers of plants that are available each year for each type of planting stock. An example is given in Figure 13.

```
Stock type 1  Description:

       >Container plants

       Total available stock: 2000000
       Number of regeneration activities using
       this stock: 3
       1 Activity:    3
       2 Activity:    5
       3 Activity:    7
```

Figure 13. Input data for a planting-stock constraint.

If it is desired to put a constraint on the area that can be regenerated with a certain regeneration method (rather than on the planting stock), this can be simulated by by entering a value of "1" for the "number of plants/ha" for the regeneration machine type (method). The "total available stock" then becomes the maximum area that can be regenerated.

Data Correction

The interactive data input produces four files PERIODS.n, STORES.n, MACHINES.n, and ACTIVITIES.n where n is the job number. These can be concatenated and a print file (TEMPHEAD.OUT) produced using program `temphead`. For the Hypothetical Forest Company, the files are listed in Appendix II. Records that are subsequently used by the data conversion program are identified by a line number in columns 130-132. Any mistakes that were made in entering the data may be corrected in these four files using a text editor. However, care must be taken to make sure that the formats of both the data within the columns and of the line number are not changed.

If there are no changes in the flowchart, it is usually not necessary to re-enter the data interactively to test different scenarios; data changes can be made in the same way as corrections.

Data Conversion

Data conversion is done by program `logplan2_prep` that requires the user to enter only the job number. Before running the program, the symbolic constants in the PARAMETER statement should be checked to ensure that they are compatible with those for `logplan2_inp`. This PARAMETER statement has three other constants that may be set:

SCALE: a factor for scaling the elements of the LP-matrix (current value = 100.0).
PYEAR: the interest rate for discounting costs to the present (current value = 0.0).
TREEM3: the average number of trees/m^3 (the standard for calculating variations in productivity due to tree size -- current value = 8.0).
HDAY: the number of hours in each shift (used where the number of round-trips/shift are calculated from truck travel times -- current value = 8.0).

The values of these symbolic constants are seldom changed.

`logplan2_prep` takes the numbered records in the ".n" files and converts the data to 80-column records (file LOGPLAN.n), that are similar in format to the input for the original LOGPLAN (Newnham 1975b). Changes can also be made to this file although, as there are no column headings to guide the user, this is more difficult. Care must also be taken to ensure that the changes are compatible throughout the data file. For these reasons, the user is advised to make changes only on the ".n" files.

`logplan_prep` also produces a small output file, SILVIC.n, that contains data on the regeneration activities and sorting and activity groups. This information is required later for preparing the final reports and need not concern the user.

LP Matrix Generation

Matrix generation is done by program `logplan2` which is based on the original LOGPLAN FORTRAN programs (Newnham 1975b). The only input from the user is the file name, "LOGPLAN.n" (n still being the job number)* . The program will give an error message and stop if any of the array bounds are violated. The user will then have to "edit" the main program (in the UNIX system: "vi logplan2.f") and reset the values of the symbolic constants in the PARAMETER statement ("comment" statements indicate the roles of these constants). The main program will then have to be recompiled and linked with `logplan2_opha`, `logplan2_matr`, `logplan2_data`, `logplan2_opsn` and `logplan2_stock` before rerunning.

Output from `logplan2` consists of four files:

(1) LOGPLAN.INP. This contains the basic input data in the format of the original LOGPLAN model. In addition to the data contained in the four ".n" files, it also shows for each activity the operating cost in $\$/m^3$ and the elements of the objective function (also in $\$/m^3$). These latter will generally differ from the activity costs as they take into account the carrying charges for the inventory in the stores being emptied and filled by each activity. Note that data for regeneration activities have been converted from hectares to their volume equivalent. This file can be listed on a printer and is sometimes useful for checking the area conversions.

(2) LOGPLAN.STO. Contains much of the input data and is used as input later to prepare the final reports. As the data are in binary format, the file cannot be directly accessed.

(3) TEMP16.DAT. Contains the elements of the LP matrix in row order. These must later be sorted in column order.

(4) TEMP17.DAT. This contains values of the right hand side (RHS), the ranges and the bounds.

* A "change" file, CHANGE.DAT, is also required. At present, this contains zeros in every field but can be used to start the model at a time other than the first day of the first period, or to modify any of the data in LOGPLAN.n. To do this, the user must have an intimate knowledge of the program and the input variables.

Column Sorting

The columns in file TEMP16.DAT are sorted in alphanumeric order by program `logplan2_sort.sas` that uses the SAS procedure, SORT (SAS Institute Inc. 1988).

Conversion to MPSX Format

This conversion is performed by program `logplan2_conv` that requires no user input. Output is in standard MSPX format (see e.g. International Business Machines 1972) on file LOGPLAN.MPS. The first record contains the name of the objective function (always OBJ.FUNC for the LOGPLAN II analyses). ROWS, COLUMNS, RHS, RANGES, and BOUNDS follow in order. The names of rows and columns have the format: *iiijjkl, where * is a letter (A for activity, S for store, G for activity group, P for sorting activities, Z for store groups, and R for stocking constraints). The field "iii" is for the number of the activity, store or group , etc. and "jj" is for the period number. "k" and "l" are used only for proportional constraints: "k" indicates the activity number and "l" indicates whether the constraint is an equality (0), a lower bound (1), or an upper bound (2). For stocking constraints, the number has only two characters and the "jj" field is the year number. Silvicultural budget constraints have the format: SILVnn, where nn is the year number. All embedded blanks are replaced by zeros.

Optimization

Optimization is done with the XMP LP software package which is accessed through program `imp`. This program requires a LOGPLAN.SPC file, an example of which is given in Figure 14.

```
BEGIN
ROWS 1000
COLUMNS 1200
ELEMENTS 25000
MAX COLUMN 250
MINIMIZE
OBJECTIVE OBJ.FUNC
END
```

Figure 14. Example of a LOGPLAN.SPC file

This version will handle a larger system than that shown in Figure 3. The values for ROWS, COLUMNS, etc. can be changed to accommodate the problem size. The user will be requested to enter the name of the input file (without the ".MPS" suffix -- always "LOGPLAN"). For further information on the use of XMP, the users' manual (XMP Software Inc. 1989) should be consulted.

Any other software package that accepts standard MPSX format input data can be used. However, the output (on file LOGPLAN.OUT) from these packages may differ in format from that of XMP, thus requiring revisions to be made to the report-writing program `logplan2_out`.

Report Preparation

The output from the XMP optimization gives the production level for each activity in each period that will minimize the cost of meeting mill demands. Program `logplan2_out` reproduces this information in tabular form that is easily understood. Other tables show the area regenerated by each regeneration method, the inventory in each store at the end of each period, the numbers of machines and machine-shifts required for each activity and period, etc. An example of an output report is shown in Appendix III for the Hypothetical Forestry Company operations shown in Figure 3.

Before running the program, the PARAMETER statement should be checked to ensure that it is compatible with the PARAMETER statement in `logplan2`. The user will then be asked to give the job number and also if it is necessary to revise costs in the output reports. For the LP optimization, cost elements in the objective function are in $/m^3 and are based on the assumption that the fixed cost ($/shift) is only charged when a machine is actually operating. When a machine is actually scheduled to operate less than 100 per cent of a shift, the fixed cost must still be charged for the whole shift and the cost in $/m^3 will be slightly higher than used in the optimization. The user may choose this revision or use the original cost figures.

Two of the tables that are of particular interest are the production and cost summary table (Table 2) and the activity group production table (Table 3). Table 2 gives a summary of the area harvested, the volumes of wood harvested on company limits (the FMU), and the volumes purchased and sold, together with the associated costs (both actual and discounted to the present). Table 3 gives the production for each group of machines, together with per cent utilization. Feller-delimbers are fully utilized throughout the two-year planning period while feller-bunchers average only 76.7 per cent utilization. This would indicate that replacing one of the feller-bunchers by a feller-delimber might lower the overall cost of wood delivered to the mill.

CONCLUSION

This report has shown how the harvesting and regeneration operations of a forest company may be studied using the LOGPLAN II model. The method of constructing the flow chart of the operations has been described and illustrated with a simple example for a Hypothetical Forest Company. Examples are given of the method of entering the initial data and of the tabular format in which the input data are stored for correction or modification for the LOGPLAN analysis. Finally, an example of the output from a test is given.

How can LOGPLAN II help the forest manager? To a certain extent, this will depend on how flexible the manager is prepared to be in considering possible alternatives in developing an operating plan. If the manager has predetermined the order in which stands will be harvested, as well as the methods of harvesting and regenerating these stands, LOGPLAN will only give an estimate of the cost of implementing this plan -– a cost that is probably already known. The quality of the input data is also an important factor. If it is assumed that the production rate for each type of machine is constant regardless of tree size, season, and stand type, there are likely to be several optimum (or near optimum) solutions and LOGPLAN may not necessarily provide the "best". As it is recognized that formulae that relate machine productivity to the variables that affect it are often not available, LOGPLAN II uses "productivity adjustment factors". Where the appropriate formulae are known, these factors can be estimated quite accurately. Where they are not available, the manager may have a "rule of thumb" (e.g. feller-buncher productivity increases 25 per cent with every doubling in tree size), or has a "gut feeling" (e.g. skidder productivity declines 10 per cent during the winter season). Another approach is to test productivity factors over a range of values to determine their importance. If a factor is found to seriously affect the overall cost, the manager may well want to obtain accurate data about it.

Given a flexible attitude on behalf of the manager and a good database, LOGPLAN can provide the following assistance in minimizing the cost of harvesting and regeneration:

(1) It can give an estimate of this cost for the planning period that can be used as a guideline for budgeting.
(2) For each type of machine and for each operating period, it can indicate the activities in which the machines will be operating, the minimum number of machines that will be required, and the number of machine-shifts that will be operated.
(3) If the activities in which a machine type may operate are "grouped", the percentage utilization for the group is calculated. A value much less than 100 per cent would indicate that perhaps

TABLE 2. Hypothetical Forest Company : summary of production and cost

V O L U M E   A N D   C O S T   S U M M A R Y

	Discounted costs and revenues			Actual costs and revenues		
	Volume m**3	Value ($)	($/m**3)	Volume m**3	Value ($)	($/m**3)
Capital cost*		4734400.00	6.022		4734400.00	6.022
Operating costs:						
Logging**	786190	11662290.00	14.834	786190	11662290.00	14.834
Inventory***		4682.96	0.006		4682.96	0.006
Sub-total	786190	11666973.00	14.840	786190	11666973.00	14.840
Regeneration	4094~	3089374.75	3.930	4094~	3089374.75	3.930
Limit-wood total	786190	19490748.00	24.791	786190	19490748.00	24.791
Purchased wood	300000	9600000.00	32.000	300000	9600000.00	32.000
Total production	1086190	29090748.00	26.782	1086190	29090748.00	26.782
Less sales	19190	786790.00	41.000	19190	786790.00	41.000
Total mill supply	1067000	28303958.00	26.527	1067000	28303958.00	26.527

~ Area harvested and regenerated in ha

* Interest on capital invested in machines plus depreciation. This item is charged against each machine regardless or not of whether it is scheduled for operation. The cost in $/m**3 is obtained by dividing the total capital cost by the volume of wood produced on limits

** Does not include interest on capital

*** Inventory cost in $/m**3 is obtained by dividing the total inventory cost by the volume of limit wood. The charge is applied to limit wood only

Interest rate for discounting = 0.000% per year

TABLE 3. Hypothetical Forest Company: production and utilization by activity group

ACTIVITY GROUP PRODUCTION

Group No.	Description:	Total Prodn. (*)	Production (*) in period: 1	2	3	4	5	6	7	8
1	Slashburn: nat. regen.	1760	160	360	160	200	160	360	160	200
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
2	Feller-bunchers	433884	32069	100179	41674	55500	14080	96470	40932	52981
		(76.5)	(70.7)	(78.9)	(82.7)	(88.1)	(31.0)	(79.5)	(83.0)	(86.1)
3	Feller-delimbers	329536	26936	72215	29249	36561	26550	72215	29249	36561
		(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
4	Forwarders	763420	59005	172394	70923	92061	40630	168685	70181	89541
		(83.0)	(90.1)	(81.4)	(97.9)	(83.5)	(60.4)	(78.6)	(97.9)	(81.9)
5	Delimbers	433884	32069	98679	43174	54000	15580	94970	42432	52981
		(91.9)	(74.2)	(100.0)	(100.0)	(100.0)	(36.1)	(100.0)	(100.0)	(100.0)
6	Tree-length trucks	754230	63721	169694	70823	88561	39724	164085	70081	87541
		(68.9)	(67.7)	(75.6)	(68.0)	(67.8)	(42.1)	(74.2)	(70.6)	(70.6)

* ha for regeneration groups; m**3 for other groups.
(values in parentheses are percent utilization of the machines assigned to the group)

fewer machines are required. Conversely, a 100 per cent utilization would indicate that perhaps more machines are required.

(4) For each activity the production, both total and for each period, is given in m^3 or ha.

(5) For each regeneration method, the total area treated and the number of plants required are given.

(6) For each store, the inventory is given at the end of each period and also the total inventory cost.

By far the greatest value of LOGPLAN is in testing different planning strategies (asking "What if ...?" questions). An initial analysis may indicate where changes could be made to reduce the overall cost of meeting mill demands. A subsequent analysis will determine whether these changes result in cost reductions. The effect of an anticipated work stoppage can be simulated or the manager may want to test a "worst case" scenario.

What does LOGPLAN not do for the manager? The model only schedules equipment on a period (season) basis. These periods are usually from 20 to 90 operating days in duration and so are of no help in day-to-day planning (in theory, the periods could be "weeks" but this would greatly increase the size of the LP matrix and, unless there were noticeable variations in costs or production rates from week to week, would be pointless). LOGPLAN also does not assign equipment to specific stands but rather to groups of stands of similar composition in the same general area. It is thus left to the manager, or local supervisor, to implement the day-to-day scheduling, a task best left to that individual anyway.

LOGPLAN has evolved over a period of 15 years and will continue to evolve. With further field testing, requests for new options or constraints will doubtless be made and subsequently built into the model. Advances in computer hardware and software technology may also lead to improvements. However, even in its present form, LOGPLAN II can be a valuable aid to the forest manager in developing operating plans.

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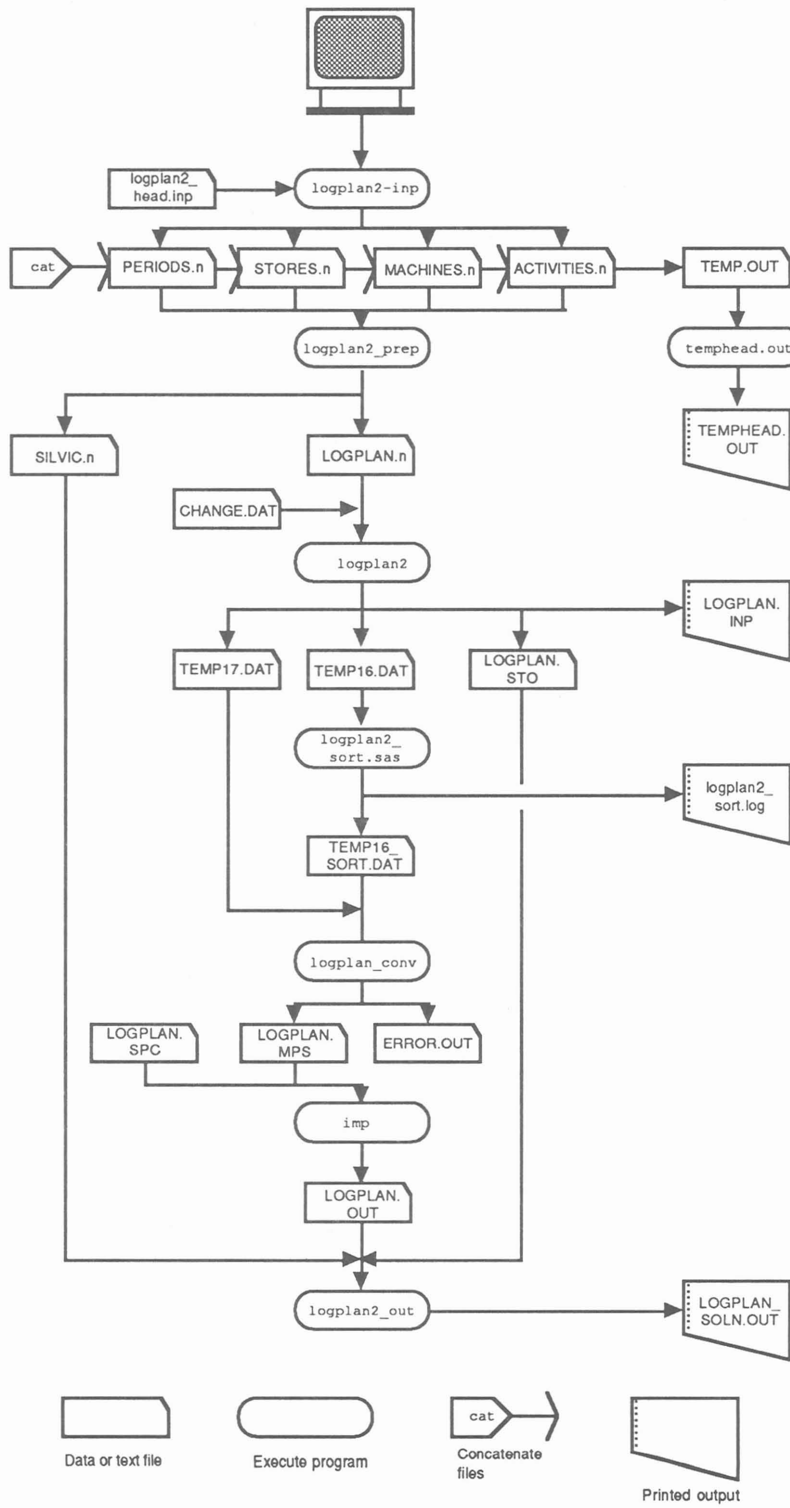
APPENDIX I

Flow chart showing the linkages among LOGPLAN II programs, and input and output files

APPENDIX I

Flow chart showing the linkages among LOGPLAN II programs, and input and output files.



APPENDIX II

Listing of the intermediate data files
(the ".n" files)

Run No. 1 Hypothetical Forest Company

Number of years in plan (max. = 5):	2	1
Number of operating periods per year - max.= 20):	4	2
Total number of stores (max. = 50):	25	3
Number of purchased-wood stores (max. = 10):	1	4
Number of mangement unit stores (max. = 8):	4	5
Number of groups of stores (max. = 10):	1	6
Total number of activities (max. = 60):	36	7
Number of wood-purchasing activities (max. = 60):	1	8
Number of wood-selling activities (max. = 60):	1	9
Number of activity groups (max. = 10):	6	10
Number of mill demands (max. = 10):	3	11
Number of groups of sorting activities (max. = 10):	3	12
Number of regeneration machine types (max.= 10):	3	13
Number of harvesting machine types (max. = 10):	4	14
Number of truck types (max. = 10):	1	15
Number of planting-stock constraints (max. = 10):	2	16
Annual silvicultural (regeneration) budget ($):	2000000	17

Run No. 1 Hypothetical Forest Company File: PERIODS.1

Number of operating days in each period (season)

Period No.	From	To	No. of days	
1	01 APR 1991	31 MAY 1991	40	18
2	01 JUN 1991	15 OCT 1991	90	19
3	16 OCT 1991	15 DEC 1991	40	20
4	16 DEC 1991	31 MAR 1991	50	21
5	01 APR 1992	31 MAY 1992	40	22
6	01 JUN 1992	15 OCT 1992	90	23
7	16 OCT 1992	15 DEC 1992	40	24
8	16 DEC 1992	31 MAR 1992	50	25

Run No. 1 Hypothetical Forest Company File: STORES.1

Number of wood resource stores: 5
Purchased wood stores: 1
Management unit stores: 4

Store No.	Type	Description:	Inventory (m**3) Initial	Final	Area (ha)	No. of trees/ (m**3)	
1	PUR	Purchased spruce	400000	100000	0	0.0	1
2	FMU	Logging Unit 1	240000	50000	1200	6.5	2
3	FMU	Logging Unit 2	280000	100000	1350	7.0	3
4	FMU	Logging Unit 3	440000	200000	2500	8.0	4
5	FMU	Logging Unit 4	300000	250000	2000	10.0	5

Run.No. 1 Hypothetical Forest Company

Total number of stores: 25
Intermediate stores: 17
Mill blockpiles: 3

Store No.	Type	Description:	Inventory (m**3) Initial	Maximum	Final	Inventory charge ($/shift)	
6	INT	Unit 1: regenerated	0	0	0	0.000	6
7	INT	Unit 2: regenerated	0	0	0	0.000	7
8	INT	Unit 3: regenerated	0	0	0	0.000	8
9	INT	Unit 4: regenerated	0	0	0	0.000	9
10	INT	Unit 2: F/T at stump	0	0	0	0.003	10
11	INT	Unit 3: F/T at stump	0	0	0	0.003	11
12	INT	Unit 4: F/T at stump	0	0	0	0.003	12
13	INT	Unit 1: T/L at stump	0	0	0	0.004	13
14	INT	Unit 2: T/L at stump	0	0	0	0.004	14
15	INT	Unit 3: T/L at stump	0	0	0	0.004	15
16	INT	Unit 2: F/T at roadside	0	500	0	0.006	16
17	INT	Unit 3: F/T at roadside	0	500	0	0.006	17
18	INT	Unit 4: F/T at roadside	0	500	0	0.006	18
19	INT	Unit 1: T/L at roadside	1900	10000	10000	0.008	19
20	INT	Unit 2: T/L at roadside	2200	10000	10000	0.008	20
21	INT	Unit 3: T/L at roadside	3500	10000	10000	0.008	21
22	INT	Unit 4: T/L at roadside	2400	10000	10000	0.008	22
23	BLK	Mill Blockpile: spruce	10000	-999	10000	0.000	23
24	BLK	Mill Blockpile: j. pine	2500	-999	2500	0.000	24
25	BLK	Mill Blockpile: poplar	750	-999	750	0.000	25

Run No. 1 Hypothetical Forest Company

Number of groups of stores: 1

Group No.	Description:	No. of stores	Maximum Inventory (m**3)	Stores in group:				
1	T/L at roadside	4	10000	19	20	21	22	26

Run No. 1 Hypothetical Forest Company File: MACHINES.1

No. of regeneration machine (or unit) types 3

Unit No.	Function	Description:	No. of Units	Operating costs ($/shift) Capital	Fixed	Variable	OR Cost ($/ha)	Production (ha/shift)	Plants or seeds/ha	
1	R	Slashburn, nat. regen.	2	0	0	0	500.00	2	0	1
2	R	Scarify, bare root	2	0	0	0	900.00	10	1200	2
3	R	Scarify, containers	3	0	0	0	1000.00	10	1500	3

Run No. 1 Hypothetical Forest Company

Tree size and periodic (seasonal) productivity
adjustment factors

Unit No.	Tree size factor	Factor in period: 1	2	3	4	5	6	7	8	
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	4
2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	5
3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	6

Resource store productivity adjustment factors

Unit No.	Factor in wood resource store: 2	3	4	5	
1	1.00	1.00	1.00	1.00	7
2	1.00	1.00	1.00	1.00	8
3	1.00	1.00	1.00	1.00	9

Run No. 1 Hypothetical Forest Company File: MACHINES.1

No. of harvesting machine (or unit) types 4

Unit No.	Function	Description:	No. of Units	Operating costs ($/shift) Capital	Fixed	Variable	OR Cost ($/m**3)	Production (m**3/shift)	
1	H	Feller-bunchers	7	240	260	200	5.11	90	10
2	H	Feller-delimbers	5	260	260	200	7.08	65	11
3	H	Forwarders	7	240	320	200	3.85	135	12
4	H	Delimbers	3	240	260	200	2.56	180	13

Run No. 1 Hypothetical Forest Company

Tree size and periodic (seasonal) productivity adjustment factors

Unit No.	Tree size factor	Factor in period: 1	2	3	4	5	6	7	8	
1	1.50	0.90	1.10	1.00	1.00	0.90	1.10	1.00	1.00	14
2	1.60	0.90	1.10	1.00	1.00	0.90	1.10	1.00	1.00	15
3	1.00	0.80	1.20	0.90	1.10	0.80	1.20	0.90	1.10	16
4	1.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	17

Resource store productivity adjustment factors

Unit No.	Factor in wood resource store: 2	3	4	5	
1	1.00	1.00	1.00	1.00	18
2	1.00	1.00	1.00	1.00	19
3	1.00	0.95	1.00	0.90	20
4	1.00	1.00	1.00	1.00	21

Run No. 1 Hypothetical Forest Company File: MACHINES.1

No. of trucking machine (or unit) types 1

Unit No.	Function	Description:	No. of Units	Load size (m**3)	Speed (km/h) on road class: 1	2	3	Operating costs ($/shift) Capital	Fixed	Variable	OR Cost ($/m**3. km)	
1	T	Tree-length trucks	8	55	70	60	5	0	600	0	0.000	22

Run No. 1 Hypothetical Forest Company

Tree size and periodic (seasonal) productivity adjustment factors

Unit No.	Tree size factor	Factor in period: 1	2	3	4	5	6	7	8	
1	1.00	0.90	1.00	1.00	1.00	0.90	1.00	1.00	1.00	23

Resource store productivity adjustment factors

Unit No.	Factor in wood resource store: 2	3	4	5	
1	1.00	1.00	1.00	1.00	24

Run No. 1   Hypothetical Forest Company   File: ACTIVITIES.1

Total No. of activities: 36

Activity No.	Function	Resource store No.	Description:	Productivity adjustment factor	Machine type No.	Store emptied	Store filled	
1	P	0	Purchasing spruce	1.00	0	1	23	1
2	R	2	Slashburn: nat. regen.	1.00	1	2	6	2
3	R	2	Scarify: containers	1.00	3	2	6	3
4	R	3	Scarify: bare root	1.00	2	3	7	4
5	R	3	Scarify: containers	1.00	3	3	7	5
6	R	4	Slashburn: nat. regen.	1.00	1	4	8	6
7	R	4	Scarify: containers	1.00	3	4	8	7
8	R	5	Scarify: bare root	1.00	2	5	9	8
9	H	2	Feller-delimber	1.00	2	6	13	9
10	H	3	Feller-buncher	1.00	1	7	10	10
11	H	3	Feller-delimber	1.00	2	7	14	11
12	H	4	Feller-buncher	1.00	1	8	11	12
13	H	4	Feller-delimber	1.00	2	8	15	13
14	H	5	Feller-buncher	1.00	1	9	12	14
15	H	3	Forwarder (F/T)	1.00	3	10	16	15
16	H	4	Forwarder (F/T)	1.00	3	11	17	16
17	H	5	Forwarder (F/T)	1.00	3	12	18	17
18	H	2	Forwarder (T/L)	1.20	3	13	19	18
19	H	3	Forwarder (T/L)	1.20	3	14	20	19
20	H	4	Forwarder (T/L)	1.20	3	15	21	20
21	H	3	Delimber	1.00	4	16	20	21
22	H	4	Delimber	1.00	4	17	21	22
23	H	5	Delimber	1.00	4	18	22	23
24	T	2	Truck spruce	1.00	1	19	23	24
25	T	2	Truck jack pine	1.00	1	19	24	25
26	T	2	Truck poplar	1.00	1	19	25	26
27	T	3	Truck spruce	1.00	1	20	23	27
28	T	3	Truck jack pine	1.00	1	20	24	28
29	T	3	Truck poplar	1.00	1	20	25	29
30	T	4	Truck spruce	1.00	1	21	23	30
31	T	4	Truck jack pine	1.00	1	21	24	31
32	T	5	Truck spruce	1.00	1	22	23	32
33	S	0	Pine saw-log sales	1.00	0	19	0	33
34	M	0	Mill demand: spruce	1.00	0	23	0	34
35	M	0	Mill demand: jack pine	1.00	0	24	0	35
36	M	0	Mill demand: poplar	1.00	0	25	0	36

Run No. 1   Hypothetical Forest Company   File: ACTIVITIES.1

Number of machine-shifts available in each period

Activity No.	Description	Period No.: 1	2	3	4	5	6	7	8	
1	Purchasing spruce	1	1	1	1	1	1	1	1	37
2	Slashburn: nat. regen.	1	1	1	1	1	1	1	1	38
3	Scarify: containers	1	1	1	1	1	1	1	1	39
4	Scarify: bare root	1	1	1	1	1	1	1	1	40
5	Scarify: containers	1	1	1	1	1	1	1	1	41
6	Slashburn: nat. regen.	1	1	1	1	1	1	1	1	42
7	Scarify: containers	1	1	1	1	1	1	1	1	43
8	Scarify: bare root	1	1	1	1	1	1	1	1	44
9	Feller-delimber	10	10	10	10	10	10	10	10	45
10	Feller-buncher	14	14	14	14	14	14	14	14	46
11	Feller-delimber	10	10	10	10	10	10	10	10	47
12	Feller-buncher	14	14	14	14	14	14	14	14	48
13	Feller-delimber	10	10	10	10	10	10	10	10	49
14	Feller-buncher	14	14	14	14	14	14	14	14	50
15	Forwarder (F/T)	14	14	14	14	14	14	14	14	51
16	Forwarder (F/T)	14	14	14	14	14	14	14	14	52
17	Forwarder (F/T)	14	14	14	14	14	14	14	14	53
18	Forwarder (T/L)	14	14	14	14	14	14	14	14	54
19	Forwarder (T/L)	14	14	14	14	14	14	14	14	55
20	Forwarder (T/L)	14	14	14	14	14	14	14	14	56
21	Delimber	6	6	6	6	6	6	6	6	57
22	Delimber	6	6	6	6	6	6	6	6	58
23	Delimber	6	6	6	6	6	6	6	6	59
24	Truck spruce	16	16	16	16	16	16	16	16	60
25	Truck jack pine	16	16	16	16	16	16	16	16	61
26	Truck poplar	16	16	16	16	16	16	16	16	62
27	Truck spruce	16	16	16	16	16	16	16	16	63
28	Truck jack pine	16	16	16	16	16	16	16	16	64
29	Truck poplar	16	16	16	16	16	16	16	16	65
30	Truck spruce	16	16	16	16	16	16	16	16	66
31	Truck jack pine	16	16	16	16	16	16	16	16	67
32	Truck spruce	0	16	16	16	0	16	16	16	68
33	Pine saw-log sales	1	1	1	1	1	1	1	1	69
34	Mill demand: spruce	1	1	1	1	1	1	1	1	70
35	Mill demand: jack pine	1	1	1	1	1	1	1	1	71
36	Mill demand: poplar	1	1	1	1	1	1	1	1	72

Run No. 1 Hypothetical Forest Company

Number of wood-purchasing activities: 1
Number of wood-selling activities: 1
Number of mill demands: 3

Activity No.	Function	Description:	Price ($/m**3)	Volume (m**3/shift)	
1	P	Purchasing spruce	32.00	1500	73
33	S	Pine saw-log sales	41.00	500	74
34	M	Mill demand: spruce	0.00	1900	75
35	M	Mill demand: jack pine	0.00	350	76
36	M	Mill demand: poplar	0.00	175	77

Run No. 1 Hypothetical Forest Company

Hauling distances for trucking activities

Number of trucking activities: 9

Activity No.	Function	Description:	Hauling distance (km) Road class:			Number of round-trips/ shift	
			1	2	3		
24	T	Truck spruce	40	10	3	0.0	78
25	T	Truck jack pine	40	10	3	0.0	79
26	T	Truck poplar	40	10	3	0.0	80
27	T	Truck spruce	60	5	2	0.0	81
28	T	Truck jack pine	60	5	2	0.0	82
29	T	Truck poplar	60	5	2	0.0	83
30	T	Truck spruce	55	10	2	0.0	84
31	T	Truck jack pine	55	10	2	0.0	85
32	T	Truck spruce	65	20	4	0.0	86

Run No. 1 Hypothetical Forest Company

Number of groups of sorting activities: 3

Group No.	Store emptied	No. of activities	Activities	Description	Percentage of total production for group		
					Minimum	Maximum	
1	19	4	24	Truck spruce	40	40	87
			25	Truck jack pine	20	30	88
			26	Truck poplar	30	30	89
			33	Pine saw-log sales	0	10	90
2	20	3	27	Truck spruce	75	75	91
			28	Truck jack pine	15	15	92
			29	Truck poplar	10	10	93
3	21	2	30	Truck spruce	75	75	94
			31	Truck jack pine	25	25	95

Run No. 1 Hypothetical Forest Company

Number of activity groups: 6

Group No.	Description:	Total No. of machines	No. of activities	Activity No.	Description:	
1	Slashburn: nat. regen.	2	2	2	Slashburn: nat. regen.	96
				6	Slashburn: nat. regen.	97
2	Feller-bunchers	14	3	10	Feller-buncher	98
				12	Feller-buncher	99
				14	Feller-buncher	100
3	Feller-delimbers	10	3	9	Feller-delimber	101
				11	Feller-delimber	102
				13	Feller-delimber	103
4	Forwarders	14	6	15	Forwarder (F/T)	104
				16	Forwarder (F/T)	105
				17	Forwarder (F/T)	106
				18	Forwarder (T/L)	107
				19	Forwarder (T/L)	108
				20	Forwarder (T/L)	109
5	Delimbers	6	3	21	Delimber	110
				22	Delimber	111
				23	Delimber	112
6	Tree-length trucks	16	9	24	Truck spruce	113
				25	Truck jack pine	114
				26	Truck poplar	115
				27	Truck spruce	116
				28	Truck jack pine	117
				29	Truck poplar	118
				30	Truck spruce	119
				31	Truck jack pine	120
				32	Truck spruce	121

Run No. 1 Hypothetical Forest Company

Number of planting stock constraints: 2

Stock type	Description	Total No. of plants or seeds	No. of activities	Activity No.	Description	
1	Container plants	2000000	3	3	Scarify: containers	122
				5	Scarify: containers	123
				7	Scarify: containers	124
2	Bare root plants	1500000	2	4	Scarify: bare root	125
				8	Scarify: bare root	126

APPENDIX III

An example of the LOGPLAN II output reports for the
Hypothetical Forest Company

Job No. 1 Run No. 1

Hypothetical Forest Company

L I N E A R   P R O G R A M M I N G   S O L U T I O N

SCHEDULED PRODUCTION PER PERIOD

Activity No.	Total Production (m**3)	Production (m**3) in period: 1	2	3	4	5	6	7	8
1	300000	26139	78861	60000	75000	60000	0	0	0
9	190000	26936	35999	16000	20000	19065	35999	16000	20000
10	49864	0	48864	0	500	0	500	0	0
11	139536	0	36216	13249	16561	7485	36216	13249	16561
12	334020	32069	37212	41674	54500	14080	75971	34451	44063
14	50000	0	14102	0	500	0	19998	6482	8917
15	49864	0	48864	0	500	0	500	0	0
16	334020	32069	37212	41674	54500	14080	75971	34451	44063
17	50000	0	14102	0	500	0	19998	6482	8917
18	190000	26936	35999	16000	20000	19065	35999	16000	20000
19	139536	0	36216	13249	16561	7485	36216	13249	16561
21	49864	0	48364	500	0	500	0	500	0
22	334020	32069	36712	42174	54000	14580	75471	34951	44063
23	50000	0	13602	500	0	500	19498	6982	8917
24	76760	11534	14400	6400	8000	7626	14400	6400	8000
25	38380	5767	7200	3200	4000	3813	7200	3200	4000
26	57570	8651	10800	4800	6000	5720	10800	4800	6000
27	143700	1650	63435	10312	12421	5989	27162	10312	12421
28	28740	330	12687	2062	2484	1198	5432	2062	2484
29	19160	220	8458	1375	1656	798	3622	1375	1656
30	253140	26677	27534	31630	40500	10935	56603	26213	33048
31	84380	8892	9178	10543	13500	3645	18868	8738	11016
32	52400	0	16002	500	0	0	19998	6982	8917
33	19190	2884	3600	1600	2000	1907	3600	1600	2000
34	836000	76000	171000	76000	95000	76000	171000	76000	95000
35	154000	14000	31500	14000	17500	14000	31500	14000	17500
36	77000	7000	15750	7000	8750	7000	15750	7000	8750

Job No. 1 Run No. 1

AREAS HARVESTED AND REGENERATED

Activity No.	Total area (ha)	Area harvested (ha) in period:							
		1	2	3	4	5	6	7	8
2	880	80	179	79	100	80	179	79	100
3	70	54	0	0	0	15	0	0	0
4	913	0	410	63	82	36	177	63	79
6	880	79	179	80	100	79	179	80	100
7	1018	102	31	156	209	0	251	115	150
8	333	0	94	0	3	0	133	43	59

AREAS TREATED BY REGENERATION METHOD

Method No.	Regeneration method:	Area treated (ha)	No. of plants ('000s)
1	Slashburn, nat. regen.	1759	0
2	Scarify, bare root	1246	1496
3	Scarify, containers	1087	1632

Job No. 1 Run No. 1

V O L U M E   A N D   C O S T   S U M M A R Y

	Discounted costs and revenues			Actual costs and revenues		
	Volume m**3	Value ($)	($/m**3)	Volume m**3	Value ($)	($/m**3)
Capital cost*		4734400.00	6.022		4734400.00	6.022
Operating costs:						
Logging**	786190	11662290.00	14.834	786190	11662290.00	14.834
Inventory***		4682.96	0.006		4682.96	0.006
Sub-total	786190	11666973.00	14.840	786190	11666973.00	14.840
Regeneration	4094~	3089374.75	3.930	4094~	3089374.75	3.930
Limit-wood total	786190	19490748.00	24.791	786190	19490748.00	24.791
Purchased wood	300000	9600000.00	32.000	300000	9600000.00	32.000
Total production	1086190	29090748.00	26.782	1086190	29090748.00	26.782
Less sales	19190	786790.00	41.000	19190	786790.00	41.000
Total mill supply	1067000	28303958.00	26.527	1067000	28303958.00	26.527

~ Area harvested and regenerated in ha

* Interest on capital invested in machines plus depreciation. This item is charged against each machine regardless or not of whether it is scheduled for operation. The cost in $/m**3 is obtained by dividing the total capital cost by the volume of wood produced on limits

** Does not include interest on capital

*** Inventory cost in $/m**3 is obtained by dividing the total inventory cost by the volume of limit wood. The charge is applied to limit wood only

Interest rate for discounting = 0.000% per year

Job No. 1 Run No. 1

STORE INVENTORIES

Store	Total inventory cost ($) discounted	Total inventory cost ($) actual	Maximum inventory (m**3)	Initial inventory (m**3)	Inventory (m**3) at end of period: 1	2	3	4	5	6	7	8
1	0.00	0.00	400000	400000	373861	295000	235000	160000	100000	100000	100000	100000
2	0.00	0.00	240000	240000	213064	177065	161065	141065	121999	86000	70000	50000
3	0.00	0.00	280000	280000	280000	194920	181671	164610	157125	120410	107161	90600
4	0.00	0.00	440000	440000	407931	370719	329045	274545	260465	184494	150043	105980
5	0.00	0.00	300000	300000	300000	285898	285898	285397	285397	265399	258917	250000
16	525.00	525.00	500	0	0	500	0	500	0	500	0	0
17	525.00	525.00	500	0	0	500	0	500	0	500	0	0
18	525.00	525.00	500	0	0	500	0	500	0	500	0	0
22	1892.00	1892.00	10000	2400	2400	0	0	0	500	0	0	0
23	0.00	0.00	-999	10000	0	29232	62074	102995	111545	58708	32615	0
24	0.00	0.00	-999	2500	3489	1054	2860	5344	0	0	0	0
25	0.00	0.00	-999	750	2621	6129	5303	4210	3728	2399	1574	480

Job No. 1 Run No. 1

M A C H I N E   A L L O C A T I O N

Activity	No. of machines in period:							
	1	2	3	4	5	6	7	8
1 Purchasing spruce	1	1	1	1	1	0	0	0
2 Slashburn: nat. regen.	1	1	1	1	1	1	1	1
3 Scarify: containers	1	0	0	0	1	0	0	0
4 Scarify: bare root	0	1	1	1	1	1	1	1
6 Slashburn: nat. regen.	1	1	1	1	1	1	1	1
7 Scarify: containers	1	1	1	1	0	1	1	1
8 Scarify: bare root	0	1	0	1	0	1	1	1
9 Feller-delimber	10	5	6	6	8	5	6	6
10 Feller-buncher	0	6	0	1	0	1	0	0
11 Feller-delimber	0	6	5	5	3	6	5	5
12 Feller-buncher	10	5	12	13	5	9	10	10
14 Feller-buncher	0	2	0	1	0	3	3	3
15 Forwarder (F/T)	0	4	0	1	0	1	0	0
16 Forwarder (F/T)	8	3	9	8	4	6	8	6
17 Forwarder (F/T)	0	2	0	1	0	2	2	2
18 Forwarder (T/L)	6	3	3	3	4	3	3	3
19 Forwarder (T/L)	0	3	3	2	2	3	3	2
21 Delimber	0	3	1	0	1	0	1	0
22 Delimber	5	3	6	6	3	5	5	5
23 Delimber	0	1	1	0	1	2	2	2
24 Truck spruce	2	1	1	1	2	1	1	1
25 Truck jack pine	1	1	1	1	1	1	1	1
26 Truck poplar	2	1	1	1	1	1	1	1
27 Truck spruce	1	5	2	2	2	2	2	2
28 Truck jack pine	1	1	1	1	1	1	1	1
29 Truck poplar	1	1	1	1	1	1	1	1
30 Truck spruce	5	2	5	5	2	4	5	5
31 Truck jack pine	2	1	2	2	1	2	2	2
32 Truck spruce	0	2	1	0	0	3	2	2
33 Pine saw-log sales	1	1	1	1	1	1	1	1
34 Mill demand: spruce	1	1	1	1	1	1	1	1
35 Mill demand: jack pine	1	1	1	1	1	1	1	1
36 Mill demand: poplar	1	1	1	1	1	1	1	1

M A C H I N E - S H I F T   R E Q U I R E M E N T S

Activity	No. of machine-shifts in period:							
	1	2	3	4	5	6	7	8
1 Purchasing spruce	17.4	52.6	40.0	50.0	40.0	0.0	0.0	0.0
2 Slashburn: nat. regen.	0.2	0.4	0.2	0.2	0.2	0.4	0.2	0.2
3 Scarify: containers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 Scarify: bare root	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0
6 Slashburn: nat. regen.	0.2	0.5	0.2	0.3	0.2	0.5	0.2	0.3
7 Scarify: containers	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
8 Scarify: bare root	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
9 Feller-delimber	400.0	437.4	213.8	267.3	283.1	437.4	213.8	267.3
10 Feller-buncher	0.0	456.5	0.0	5.1	0.0	4.7	0.0	0.0
11 Feller-delimber	0.0	462.6	186.2	232.7	116.9	462.6	186.2	232.7
12 Feller-buncher	395.9	375.9	463.0	605.6	173.8	767.4	382.8	489.6
14 Feller-buncher	0.0	162.3	0.0	6.3	0.0	230.2	82.1	112.9
15 Forwarder (F/T)	0.0	317.5	0.0	3.5	0.0	3.2	0.0	0.0
16 Forwarder (F/T)	296.9	229.7	343.0	367.0	130.4	469.0	283.5	296.7
17 Forwarder (F/T)	0.0	96.7	0.0	3.7	0.0	137.2	59.3	66.7
18 Forwarder (T/L)	207.8	185.2	109.7	112.2	147.1	185.2	109.7	112.2
19 Forwarder (T/L)	0.0	196.1	95.7	97.8	60.8	196.1	95.7	97.8
21 Delimber	0.0	251.8	2.6	0.0	2.6	0.0	2.6	0.0
22 Delimber	178.2	204.0	234.3	300.0	81.0	419.3	194.2	244.8
23 Delimber	0.0	84.2	3.1	0.0	3.1	120.7	43.2	55.2
24 Truck spruce	78.0	87.6	38.9	48.7	51.5	87.6	38.9	48.7
25 Truck jack pine	39.0	43.8	19.5	24.3	25.8	43.8	19.5	24.3
26 Truck poplar	58.5	65.7	29.2	36.5	38.7	65.7	29.2	36.5
27 Truck spruce	11.2	386.5	62.8	75.7	40.5	165.5	62.8	75.7
28 Truck jack pine	2.2	77.3	12.6	15.1	8.1	33.1	12.6	15.1
29 Truck poplar	1.5	51.5	8.4	10.1	5.4	22.1	8.4	10.1
30 Truck spruce	182.2	169.3	194.4	249.0	74.7	347.9	161.1	203.1
31 Truck jack pine	60.7	56.4	64.8	83.0	24.9	116.0	53.7	67.7
32 Truck spruce	0.0	150.0	4.7	0.0	0.0	187.4	65.4	83.6
33 Pine saw-log sales	5.8	7.2	3.2	4.0	3.8	7.2	3.2	4.0
34 Mill demand: spruce	40.0	90.0	40.0	50.0	40.0	90.0	40.0	50.0
35 Mill demand: jack pine	40.0	90.0	40.0	50.0	40.0	90.0	40.0	50.0
36 Mill demand: poplar	40.0	90.0	40.0	50.0	40.0	90.0	40.0	50.0

Job No. 1 Run No. 1

STORE GROUP INVENTORIES

Group No.	Description:	No. of stores	Maximum inventory (m**3)	Inventory in period: 1	2	3	4	5	6	7	8
1	T/L at roadside	4	10000	2400	0	0	0	500	0	0	0

Job No. 1 Run No. 1

SORTING ACTIVITIES

Group No.	Store emptied	Description:	Activities	Percentage of total production: Prescribed Minimum	Prescribed Maximum	Scheduled
1	19	Forwarder (T/L)	24	40	40	40.00
			25	20	30	20.00
			26	30	30	30.00
			33	0	10	10.00
1	20	Forwarder (T/L)	27	75	75	75.00
			28	15	15	15.00
			29	10	10	10.00
1	21	Delimber	30	75	75	75.00
			31	25	25	25.00

Job No. 1 Run No. 1

ACTIVITY GROUP PRODUCTION

Group No.	Description:	Total Prodn. (*)	Production (*) in period: 1	2	3	4	5	6	7	8
1	Slashburn: nat. regen.	1760	160	360	160	200	160	360	160	200
		(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
2	Feller-bunchers	433884	32069	100179	41674	55500	14080	96470	40932	52981
		(76.5)	(70.7)	(78.9)	(82.7)	(88.1)	(31.0)	(79.5)	(83.0)	(86.1)
3	Feller-delimbers	329536	26936	72215	29249	36561	26550	72215	29249	36561
		(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
4	Forwarders	763420	59005	172394	70923	92061	40630	168685	70181	89541
		(83.0)	(90.1)	(81.4)	(97.9)	(83.5)	(60.4)	(78.6)	(97.9)	(81.9)
5	Delimbers	433884	32069	98679	43174	54000	15580	94970	42432	52981
		(91.9)	(74.2)	(100.0)	(100.0)	(100.0)	(36.1)	(100.0)	(100.0)	(100.0)
6	Tree-length trucks	754230	63721	169694	70823	88561	39724	164085	70081	87541
		(68.9)	(67.7)	(75.6)	(68.0)	(67.8)	(42.1)	(74.2)	(70.6)	(70.6)

* ha for regeneration groups; m**3 for other groups.
(values in parentheses are percent utilization of the machines assigned to the group)