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	PRODUCT	TION FORECASTS	BY CON	APUTER MODELS
Abstra	act approve	:d:		

John E. O'Leary

Potentially large savings can be realized within the forest industry by improved machine scheduling, labour scheduling, machine investment, inventory management, and the maximization of wood value. Forecasting must change within the forest industry from "guesstimates" to more efficient production forecasting models. Much work needs to be done with data collection and the establishment of production standards prior to any reasonable production planning. Once the standards are derived, production planning can be done by numerous operations research techniques. Linear programming, critical path scheduling, and PERT Simulation are suggested as methods of allocation, scheduling, and controlling resource inputs.

An Introduction to the Formulation of Logging Production Forecasts by Computer Models

by

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AN INTRODUCTION TO THE FORMULATION OF LOGGING PRODUCTION FORECASTS BY COMPUTER MODELS

I. INTRODUCTION

The concept of production forecasting and scheduling on a decision-making model basis is relatively new in the application to logging. Some theoretical work has been attempted on specific logging operations in Eastern Canada (Lussier, 1959) and in British Columbia (Boyd, 1969), but little work has been done on the total logging system analysis from the standing tree to the jackladder of the mill.

To date, little importance has been placed on optimization of logging costs and production for a manufacturing market demand. Instead, history has dictated a "cut out and get out" management objective, with maximum production for minimum cost of each individual logging activity. Effort has been directed towards reducing each operational cost with neglect for the total wood production function. Minimal attempt has been made to optimize the total wood cost and maximum return.

Forestry is just beginning a progressive era of change. Increasing demands of labour, the public, financiers, government forestry policy, and machinery investment are forcing the forester to utilize smaller wood and invest greater amounts of money in mechanization and land. Labour is demanding more monetary income and fringe benefits to compete with other labour organizations and to meet an increased cost of living. The public is demanding more protection, conservation, and preservation of its natural resources in addition to increased unrestricted recreational areas. Financiers, amidst greater capital costs and returns, are demanding more return on their investments. Government forestry policy, with increased pressures from the public and tighter fiscal policies, are exerting their demands on the forest industry by more restrictive environmental quality legislation, greater wood utilization, and higher taxes. Finally, greater monetary costs and the increased cost of living are raising the necessary capitalization expenditures. With this smaller wood, increased mechanization, and increased demands, the forester must become more efficient in log production. In the near future, there will be no room for "guesstimate" production forecasts that do not optimize the market conditions, labour supply, machinery, and natural resources.

Technologically, the forest companies are progressing with improved harvesting methods and utilization techniques. The tree shears, grapple yarders, articulated four-wheel skidders, Beloit tree harvesters, combines, and chip-harvesters are all inventions of the last ten years that make harvesting more efficient. Utilization techniques like the cambio debarker and the chip-n-saw were designed to

economically cut small logs (four inch tops) into lumber. With these many new and varied techniques of logging, the optimization of inputs has become more complicated. No longer can the practical experience of one engineer optimize the production and scheduling of the log production department with the demands of the manufacturing and sales department.

It is the opinion of the author that production forecasting and scheduling to a demand function is seriously lacking in the forest industry. From visual observations of idle equipment, the use of wrong equipment, unnecessary moving, and production of the wrong type of wood (i. e., sawing peeler logs, pulping high quality sawlogs), it is obvious that a potentially large savings can be made by instituting new and dynamic production management techniques.

This paper will attempt to outline only an introductory, practical log production forecasting and scheduling model. Until the methodology is actually utilized in log production forecasting with sufficient control, numerous errors will persist. Only with the application of the model can the needed corrections and new systems be incorporated. It is hoped that the model is just a simple beginning of a potentially complex system that could incorporate many other variables. Also, the analysis could be improved by utilizing more complex models such as non linear programming, dynamic programming, and simulation. However, it is important to remember that this type of model is

highly dependent on cooperation by the line supervisors and the workers. Complexity in the model before any data has even been collected will only increase the difficulties of incorporating the model into the log production system.

II. OBJECTIVES OF THE STUDY

The objectives of the study are:

- to study the needs and benefits of a log production forecasting model.
- to study the assumptions and requirements for the application of a model.
- to examine the present system of production forecasting and scheduling.
- 4) to establish the methodology of an improved production forecasting system for immediate implementation.
- 5) to illustrate, by example, how this proposed system will function.
- 6) to suggest further refined improvements that can be made.

III. THE NEEDS AND BENEFITS OF A LOG PRODUCTION FORECASTING MODEL

The function of any company is profit making--the maximization of production with a corresponding minimization of costs. In forestry, the need exists to improve this profit making amidst increasing pressures and demands. One area of improvement is generally increased operational efficiency of the log production system on both a total and specific operational basis.

Improved log production forecasting is needed to improve the operational efficiency by the following methods:

- 1) better balancing of the work load
- optimization of the monetary returns from different grades of logs in the different manufacturing processes
- reduction in the manufactured, partially manufactured, and log inventory costs, i.e., reduction in felled and bucked inventories
- 4) reduction in material waste
- 5) improvement in customer delivery
- 6) greater utilization of machinery
- 7) better coordination of different activities
- ·8) better harvesting system layouts
- better adaption of the harvesting schedule to seasonal constraints
- 10) reduction in waiting time

The needed improvements in log production planning and scheduling can result in the following savings:

- 1) lower extraction costs
- 2) lower supervision costs
- 3) reduction of fixed charges, i.e., set up charges
- 4) deferring of capital expenditures
- 5) improved investment analysis

Potential savings that can be made by incorporating operations research techniques and computer programming in log production forecasting can only be roughly estimated. It is estimated that a conservative minimal potential savings of five percent can be made to logging costs. O'Brien (1965) estimates conservatively an average 8.5 percent savings on construction projects using only advanced critical path scheduling. In addition O'Brien estimates from experience in the construction industry that a 20 to 50 percent savings can be made in the period from a non-controlled preconstruction phase to the finished construction phase by utilizing planning. Thus, large potential savings amounting to millions of dollars can be realized when one applies the small percentage savings to the large production prevalent in the larger forest companies.

It has been observed that in many industries like the forest industry, there is a notable lack of cost consciousness among the engineers and managers responsible for designing and operating systems (Flagle, Huggins and Roy, 1960). Often high production and low costs in one activity appear to be more challenging and interesting to some engineers and managers than the objective of striving for high production and low costs on the total operational basis. Of notable interest are the forest engineering costs. The engineering cost in most companies in British Columbia is less than one percent of the total wood cost. The engineers brag about this low cost, but they fail to realize that this low engineering cost, this substandard engineering, raises the yarding cost an estimated 20 percent or the total wood cost five percent.

To bring this system-cost problem under control will require a major reorientation in thinking in many organizations; both among management and among engineers. One example of changes in viewpoint required is the concept of the computer. Computer modeling and simulation can provide valuable aids to general management in forecasting, scheduling and planning log production, labour, and machinery resources without in any way substituting for it, and without really causing any major change in management's mode of operation. Computer models provide greater speed of information analysis, the capacity to weigh many more alternative courses of action, and the ability to appraise in much greater detail the possible alternatives and examine more comprehensively the consequences of each as well as the probabilities of their occurrence. In short, they provide managers and engineers with five critical aids to profit and decision-making--speed, accuracy, discipline, versatility, and probability of risk--that they have-

not had in such degree before.

IV. APPLICATION OF THE MODEL

The log production model described in this report can be applied in any company that is interested in improved efficiency. Application of the system will be particularly advantageous in companies operating under the following conditions:

- 1) company operates a small computer
- 2) company has annual production in excess of 50,000 cunits
- structure of marketing is a modified oligopoly or perfect competition structure
- 4) company has both horizontal and vertical integration
- 5) machinery is not standardized
- 6) employees are educated in operations research and computer technology
- 7) a desire to utilize model making techniques by all levels of employees exists
- 8) divisions are equipped with computer consoles
- 9) optimal planning, scheduling, and forecasting decisions are difficult to do manually when all of the major variables are considered

V. THE PRESENT PRODUCTION PLANNING SYSTEM

The following outline of the present production planning system is specifically for one particular anonymous forest company. However, general application can be made of this system to other forest companies with only minor alterations.

The present logging production forecast is made by each divisional engineer and combined with other divisions to form the total forecast for the company. The marketing organization, by using this forecast, attempts to budget sales of lumber, pulp, and raw logs. The forecasts are compiled every three months giving monthly production units for the following two years. The engineer decides from inventory maps what areas are to be logged and chooses from his own experience the monthly production, machine scheduling, and cost estimate. Little effort is made to correlate the factors of production with actual production.

In most cases the forecast is wrong before it has been printed because of changes in management decisions, weather, timber damage caused by fire and insects, and non-correlated forecast techniques. Management decisions like logging a particular setting, moving machinery to other divisions, and the purchase of new machinery are sometimes made without consultation of the production forecaster. Weather, fire, and insect attack can make the production forecast in error overnight. Finally, the variables of logging are not optimized in making the forecast. Production standards are virtually nonexistent in the harvesting operations. Managers cannot predict how a certain machine, be it a yarder or a piece of road construction equipment, will perform under given environmental and sociological factors.

A flow chart of the present production system and its variables and the role that production forecasting plays in the company is shown in Figure 1.

Timber Inventory

Machine Availability Labour Inputs

Logging Production Forecasting & Scheduling

Sales Demand Forecast _____ Log ___ Management Policy Changes Decision of Destination ____ Production ____ Weather, Fire, & of Log Insect Attack Log Inventory Purchase of Logs ____ Manufacturing of Log From Outside Market (Pulp, Sawmill) Manufacturing Inventory Sales



Major inputs of log quality, management policy changes, and sales forecasts come after logging production forecasting. In the present system, major emphasis is placed on log production rather than on the logging production forecasts. Minimal attempt is made to coordinate log production of particular species with the manufacturing and market demand functions. Rarely are logs optimized for end use according to log grade.

Presently, the accounting system provides monthly budgets and actual costs for each division. This costing is divided into total fixed and variable operational costs and the total fixed overhead costs. Information related to machine availability, down time, productivity, labour and other variables of production is not standardized, if at all even recorded. Communication to provide comprehensive production data is limited between the accountants and the logging managers. For example, depreciation is often subjectively assigned on a monthly departmental basis rather than as a variable usage cost. Improvements must be made to the accounting system in order to determine suitable production standards.

VI. THE PROPOSED PRODUCTION PLANNING SYSTEM

1. General System

A more efficient production system is possible by utilizing

production standards, planning or integration of the standards, and control. Almost all of the major environmental and sociological variables of harvesting can be accounted for in simplified mathematical models that can greatly aid in production forecasting. Those variables that are not included in the logging model will put the system out of control if they are necessary. The emphasis and coordination of all the phases of harvesting around log production should be changed to logging production forecasting.

Perhaps the most important point with the adoption of a model system is that the output data is only as good as the minimal quality factor of the input data.

It is recommended that the general production planning system should be changed from the present system outlined in Figure 1 to the proposed system shown in Figure 2. Emphasis should be changed from log production to logging production forecasting where active logging does not govern the sales and log manufacture.

A brief mention should be made of sales forecasting and timber inventory before discussing the actual logging production forecast.

2. Sales Forecast

The sales forecast should relate to the log production department the amount of species, grade, and size of wood that will be demanded in a given month to maximize the economic returns from the

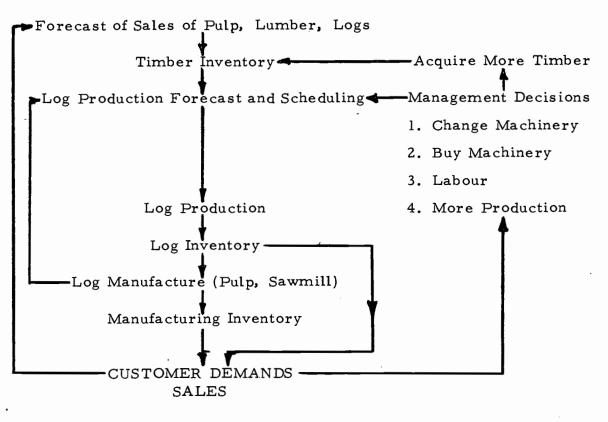


Figure 2. The Proposed Production System Flow Chart.

manufactured products and log production. Computer programs that integrate the available quality of timber and the market conditions are being used by the Weyerhaeuser and Boise Cascade Corporations. The sales forecast of pulp, lumber, and raw logs could be done using moving average, exponential smoothing or leading series techniques. In the future, these forecast functions could be simulated to provide more reliable information.

3. Timber Inventory

Timber inventory is an important part of the production planning system; it indicates how much timber by species, grade, and size is available for processing. From this inventory, one can determine the optimum end use of the wood, given a demand and price function derived from the sales forecast. Also, management can determine whether to acquire more timber from the data.

Presently, the inventory cruise is the only statistical cruise performed. Operational cruises of timber stands that are to be harvested in the near future are done by the engineer strictly as a visual estimate of a large area. Generally, he records a volume per acre with a percentage breakdown by species. No attempt is made to grade the species or estimate the tree size. Little optimization of the interrelated sales forecast, inventory and log production can be made without this information.

It is recommended that an operational cruise employing statistical and mensurational techniques be done prior to logging planning to establish inventory data that can be used in model making.

4. Engineering

The responsibilities and practices of the engineering department under the new system will have to change to incorporate new data collection. Cruising, topographic, and production data collection are the responsibility of the engineer.

Initially, the engineer will be responsible for establishing which settings are to be logged. However, in the near future, a model that

optimizes log quality in standing timber to the market demand functions could be developed. This model could then assist the engineer in deciding which timber to cut.

The engineer will also be responsible for improving his data collection of yarding and road construction operations in order that more reliable production standards can be established. Increased emphasis will have to be placed on more comprehensive engineering of route locations and settings. Without this dynamic progressive change, this engineering data will be of minimal quality used in the establishment of production standards.

VII. LOG PRODUCTION FORECASTING AND SCHEDULING

Log production forecasting and scheduling is most complex because of the great number of factors and intangibles that usually influence an operations performance. This increasing complexity of forecasting is forcing the forester to improve his decision-making process.

Decision-making can be improved with the use of operations research or "the science of the preparation of decisions," (Lussier and Tardif, 1967). Fundamentally, this "OR" includes four steps:

1) Observation of facts

2) Formulation of an hypothesis

of loaders to different settings. PERT simulation can then be applied to schedule the different loaders to the yarder's production. The scheduling model becomes more complex but manageable when there are fewer loaders than yarders. Costs of loading should be derived by the method used for yarding.

9. Hauling

Initially, the problem of truck distribution and hauling is complex without sufficient detailed production standards. The main problem with a hauling model is to account for the tremendous variation in productive time, truck capacity, hauling rates and yarding rates. In the proposed model of monthly forecasting log production, trucking should be combined with yarding and loading to indicate the number of trucks that will be required to haul the logs. In the distant future, a constantly updated simulation or linear program might be used to provide an hourly or daily hauling schedule.

10. Other Operations

Similar model-making techniques should be applied to the other logging operations listed on the sequence of logging production forecasts in Figure 3. Some of these operations are shown below:

> Dumping - standardized daily production and cost Sorting and Booming - multiple regression Towing - linear programming

Overhead Costs - daily or monthly standardized cost

Thus, at the end of the program, production forecasts, cost budgets, and scheduling of men and machinery will be produced. The linear programs will minimize the variable wood cost or rent by allocating the most optimal machine to each setting given certain constraints. PERT Simulation will schedule the men and machinery within some defined scheduling constraints. Also, the PERT will provide control over the production forecast and give a probability of completion times. Each machine will have control limits derived from the production standards to indicate when the machine is overproducing, underproducing or the model is out of tune.

VIII. LOGGING PRODUCTION MODEL

1. Problem

The production yarding model which is presented below is designed to be simple and specific in nature. However, this model is feasible on a much more complex level; with further research more exact and dynamic models may be derived. The purpose in this report is only to show that such a model can be derived and be applicable to the logging industry.

The problem is to develop a model to forecast and plan log production, forecast cost budgets and to schedule men and machines

for a period of one year for the area described below. The objective is to optimally allocate the available equipment within the defined constraints and production standards to settings with the objective of cost minimization and profit maximization.

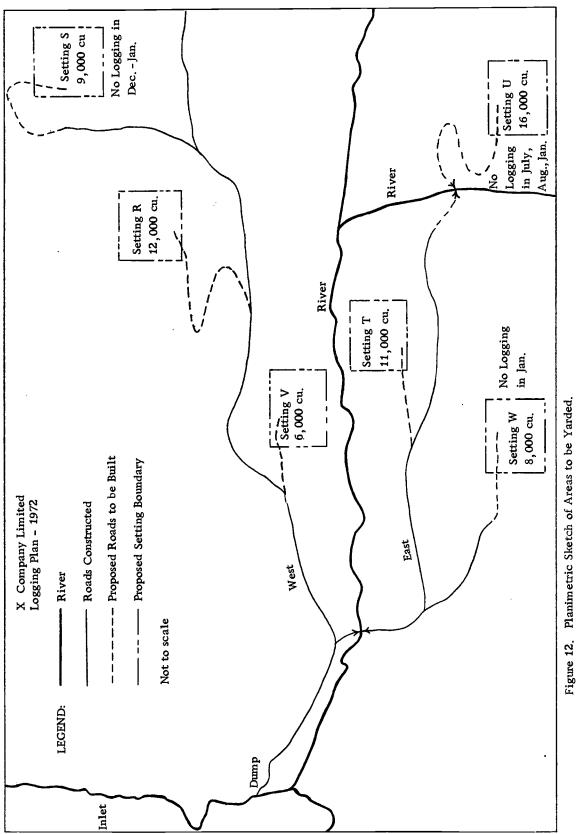
2. Given Data

A planimetric sketch of the settings to be yarded as defined by the engineer are shown in Figure 12. The diagram also notes some of the yarding constraints that must be applied to the yarding allocation and scheduling.

Cruising and topographic data for each setting is accumulated by the forest engineer. Each setting is defined according to the cruising and topographic classifications shown in Appendix I and II.

TABLE I. CRUISING DATA

Setting R 1W - F1 H6 C3 - 9 - 3 - 80 - 150 - 80 - Sa2 - S15 - PU3 - A1 B1 C4 D4
Setting S 2W - F3 H4 C3 - 9 - 2 - 90 - 130 - 70 - Sa4 - S15 - PU1 - Ao B2 C6 D2
Setting T 3E - F3 H5 S2 - 9 - 1 - 90 - 150 - 69 - Pe3 - Sa4 - S12 - PU1 - A0 B1 C3 D6
Setting U 4E - Fl H4 C5 - 9 - 3 - 100 - 160 - 100 - Sa2 - S14 - PU4 - Al B2 C5 D2
Setting V 5W - F2 H5 C3 - 9 - 3 - 90 - 100 - 60 - Sa2 - S15 - PU3 - A0 B2 C5 D3
Setting W 6W-F1H5C4-9-2-80-130-60-Sa3-S15-PU2-A0B0C6D4



Setting R 1W - 40 - S - 3 - 0 - 800 - NE - GC - M
Setting S 2W - 20 - B - 2 - 2 - 1400 - S - GC - C
Setting T 3E - 0 - F - 6 - 0 - 400 - W - GP - D
Setting U 4E - 70 - R - 1 - 1 - 1800 - SW - GW - C
Setting V 5W - (-10) - F - 6 - 0 - 300 - E - GP - D
Setting W 6W - 30 - S - 2 - 1 - 800 - W - GC - M

 Setting
 Volume of Wood

 R
 12,000 Cunits

 S
 9,000 Cunits

 T
 11,000 Cunits

 U
 16,000 Cunits

 V
 6,000 Cunits

 W
 8,000 Cunits

TABLE III. SETTING VOLUMES

In the model, three yarding machines are assumed available. Production standards for the available yarding machines are given in terms of production rates on each setting. These standards were obtained by regression analysis with past and present data. TABLE IV. MACHINE DATA

Machine A -	1960 SKAGIT PORTABLE SPAR 110 foot tower Production costs: \$360/Day (either variable costs or rent costs)
Machine B -	1969 SKAGIT PORTABLE SPAR 110 foot tower Production costs: \$400/Day
Machine C -	1968 Articulated four-wheel skidder 130 Horsepower Production costs: \$115/Day

Assume: Established production standards of the above machines yield the following production rates on the various settings.

Setting	Machine A Rate Cunits/day	Machine B Rate Cunits/day	Machine C Rate Cunits/day
R	80	90	10
S	70	75	20
Т	110	120	70
U .	60	70	1
v	75	80	40
W	80	85	20

TABLE V. PRODUCTION RATES

Standard costs per day are used as given above and revenue figures are obtained from an analysis of the contents of the cruising data on each setting and consideration of the current and forecasted log market prices.

Setting	Revenue per Cunit
R	\$30.00
S	\$32.00
Т	\$37.00
U	\$27.00
v	\$31.00
W	\$29.00

TABLE VI. SETTING REVENUES

TABLE VII. ACTIVITY TIMES

Time Activity Most Likely Minimum Maximum Engineer Road to Setting R S т U v w Engineer Setting R S т U v W Road Construction to R Setting S т U v w Falling & Bucking R Setting S т U v W (Continued on next page)

• .

Activity		Time		
Activity		Most Likely	Minimum	Maximum
Slack Time Setting	R	21	21	21
-	S	21	21	21
•	т	21	21	21
	U	21	21	21
	v	21	21	21
	W	21	21	21

TABLE VII. (Continued)

3. Constraints

The following constraints were placed on the model to optimally allocate and schedule the available machines and men.

- 1) Two yarders cannot be on the same setting at the same time
- 2) Seasonal logging constraints are shown on the planimetric sketch
- 3) Only one set of road construction equipment is available
- 4) Only one engineering crew is available
- 5) All yarding machines must be utilized
- 6) Logging production forecast is for one year
- 7) Only one set of fallers is employed
- 8) Setting must be felled 21 days before yarding

What has been presented to this point in this model is the minimum requirements of input data. This in fact will be the most difficult part of the whole model - collecting setting data and calculating production standards. Only the summary of the data was shown here. When more comprehensive data is collected and more accurate production standards produced, then the model can be made more detailed and dynamic.

4. Linear Program

The basic model, as described previously, consists of a linear program for allocation of machinery, a critical path for scheduling machinery within the given constraints, and a PERT Simulation for scheduling associated activities. Three different approaches were taken in establishing the linear program to determine a model that would best optimize the conditions within the given parameter constraints. Discussion of these approaches is presented below and the computer outputs of their results are presented at the end of this report (see Appendix III).

Definition of the variables used in the linear programming equations are as follows:

- 1) AR, AS, AT, AU, AV, and AW represent the number of days that machine A will yard on settings R through W.
- 2) BR, BS, BT, BU, BV, and BW represent the number of days that machine B will yard on settings R through W.
- 3) CR, CS, CT, CU, CV, and CW represent the number of days that machine C will yard on settings R through W.
- 4) R, S, T, U, V, and W represent the amount of wood which is

to be yarded on settings R through W respectively.

5) AI, BI, and CI represent the number of days that machine A through C are idle.

In the first linear programming model cost was minimized in yarding every setting completely. No limit was placed on a specific number of available working days for each machine. The derived equations used were:

2) 70 AS + 75 BS + 20 CS = 9,000 3) 110 AT + 120 BT + 70 CT = 11,000 4) 60 AU + 70 BU + CU = 16,000 5) 75 AV + 80 BV + 40 CV = 6,000 6) 80 AW + 85 BW + 20 CW = 8,000 7) AR + AS + AT + AU + AV + AW \ge 0 8) BR + BS + BT + BU + BV + BW \ge 0 9) CR + CS + CT + CU + CV + CW \ge 0 10) Objective : minimize	1)	80 AR + 90 BR + 10 CR = 12,000
4) 60 AU + 70 BU + CU = 16,000 5) 75 AV + 80 BV + 40 CV = 6,000 6) 80 AW + 85 BW + 20 CW = 8,000 7) AR + AS + AT + AU + AV + AW \ge 0 8) BR + BS + BT + BU + BV + BW \ge 0 9) CR + CS + CT + CU + CV + CW \ge 0	2)	70 AS + 75 BS + 20 CS = 9,000
5) 75 AV + 80 BV + 40 CV = 6,000 6) 80 AW + 85 BW + 20 CW = 8,000 7) AR + AS + AT + AU + AV + AW \geq 0 8) BR + BS + BT + BU + BV + BW \geq 0 9) CR + CS + CT + CU + CV + CW \geq 0	3)	110 AT + 120 BT + 70 CT = 11,000
6) 80 AW + 85 BW + 20 CW = 8,000 7) AR + AS + AT + AU + AV + AW ≥ 0 8) BR + BS + BT + BU + BV + BW ≥ 0 9) CR + CS + CT + CU + CV + CW ≥ 0	4)	60 AU + 70 BU + CU = 16,000
7) AR + AS + AT + AU + AV + AW ≥ 0 8) BR + BS + BT + BU + BV + BW ≥ 0 9) CR + CS + CT + CU + CV + CW ≥ 0	5)	75 AV + 80 BV + 40 CV = 6,000
8) BR + BS + BT + BU + BV + BW ≥ 0 9) CR + CS + CT + CU + CV + CW ≥ 0	6)	80 A.W + 85 BW + 20 CW = 8,000
9) CR + CS + CT + CU + CV + CW \geq 0	7)	$AR + AS + AT + AU + AV + AW \ge 0$
	8)	$BR + BS + BT + BU + BV + BW \ge 0$
10) Objective : minimize	9)	$CR + CS + CT + CU + CV + CW \ge 0$
	10)	Objective : minimize

360 (AR + AS + AT + AU + AV + AW) +400 (BR + BS + BT + BU + BV + BW) +115 (CR + CS + CT + CU + CV + CW)

Equations 1-9 define the available and restricted capacity of each machine and setting. Equations 7, 8, and 9 give each available machine an unlimited amount of time to log each setting; with this constraint it would be possible for one machine to log all settings if it were economically feasible to do so. For example, equation 7 states that the number of days available for machine A to yard settings R through W is unlimited (\geq); the same reasoning applies to equations 8 and 9 for machines B and C.

Equations 1 through 6 define the rates of each machine on each setting and limit the total production on any setting to the amount of wood available. For example, equation 1 states,

The rate machine A yards setting R times the number of days it is on setting R plus the rate machine B yards setting R times the number of days it is on setting R plus the rate machine C yards setting R times the number of days it is on setting R must equal the cunits of wood on setting R.

(80 Cunits/day) (AR days) + (90 Cunits/day) (BR days) +

(10 Cunits/day) (CR days) = 12,000 Cunits.

Equations 2 through 6 may be interpreted in a similar manner for settings S through W.

The objective equation minimizes the cost of yarding while optimizing the machines to settings by comparing the cost of each machine per day on each setting where the yarding production per day is determined by the machine's rate; i. e., the variable cost or rent is \$360 per day to use machine A, \$400 per day to use machine B and \$115 per day to use machine C no matter which setting is yarded.

The last page of the computer output for model 1 illustrates the data that can be used in the critical path method. Note that in this case the amount each machine yards on each setting is such that there will be only one machine yarding each setting; this does not satisfy our constraint that all machines be kept busy because machine A yards for 229 days, machine B for 361 days and machine C for 307 days; i. e., there exists periods where machine A and C will be idle. An attempt to define idle time within the constraining equations is given in a different approach.

This straight cost minimization model is presented here to show its inherent weaknesses for forecasting purposes. It should be obvious that the solution which this model yields is only one of many solutions which will satisfy the given constraints and give the same cost factor; i.e., there are many combinations in this problem which will yield the same cost minimization. There is a need for further constraints which are defined in the following model.

In model II a profit function was introduced in order to obtain a unique solution. Also, a limit was set on the number of days each machine was available for yarding in order to staisfy the production forecast constraint of one year.

The derived equations are:

1) 80 AR + 90BR + 10 CR - R = 0
2) 70 AS + 75 BS + 20 CS - S = 0
3) 110 AT + 120 BT + 70 CT - T = 0
4) 60 AU + 70 BU + CU - U = 0
5) 75 AV + 80 BV + 40 CV - V = 0
6) 80 AW + 85 BW + 20 CW - W = 0
7) $R \leq 12,000$
8) $s \leq 9,000$
9) $T \leq 11,000$
10) $U \leq 16,000$
11) $V \leq 6,000$
12) $W \le 8,000$
13) AR + AS + AT + AU + AV + AW ≤ 250
14) BR + BS + BT + BU + BV + BW \leq 250
15) CR + CS + CT + CU + CV + CW \leq 220
16) Objective: maximize
(30 R - 360 AR - 400 BR - 115 CR) +
(32 S - 360 AS - 400 BS - 115 CS) +
(37 T - 360 AT - 400 BT - 115 CT) +
(27 U - 360 AU - 400 BU - 115 CU) +
(31 V - 360 AV - 400 BV - 115 CV) +
(29 W - 360 AW - 400 BW - 115 CW)

Equations 7 through 12 state that the amount of wood to be yarded

on each setting may be less than or equal to the total amount of wood on that setting. For example, there are 12,000 cunits of wood on setting R; any portion of that amount may be yarded subject to the constraints placed on the yarding machines.

Since the production forecast is to be for one year, a limit should be placed on the number of days a machine may yard and hence optimize available yarding time, cost, and profit. Equations 13 through 15 limit each machine to a less than or equal to working time relationship. For example, machine A is available for work only 250 days, machine B for 250 days and since the skidder is less productive because of delays and weather it is limited to 220 days. These are approximately the number of working days in a year taking into consideration weekends, holidays, and weather conditions. If this limit is not large enough to log all the settings, as is the case in this model, the output results will indicate which settings were not completely yarded. This may indicate a need for overtime work. The linear program will optimize the available hours in terms of profit maximization and cost minimization.

If the setting that is forecast not to be yarded in the year is not yarded by overtime, then some continuous function must be made to pursue the yarding in the following year. The simplest method to initiate a continuous function is to reduce the cost of yarding in the continuing year for that setting to a nominal amount of one dollar per

cunit. The linear program will then maximize production for that one setting.

Equations 1 through 6 set up the relationship for comparing the cost of yarding a setting with the profit obtained from the wood on that setting. For example, equation 1 states:

(80 Cunits/day) (AR days) + (90 Cunits/day) (BR days)+
(10 Cunits/day) (CR days) - (R number of cunits logged)
must equal zero - where R is bound by less than or equal
to 12,000 cunits.

The objective equation compares the cost of logging a variable number of units on all settings with the profit derived from those units and in the process optimally allocates available machines to appropriate settings. That is, the objective equation states that the profit derived from X cunits of wood minus the cost of yarding that wood is to be maximized.

The last page of the computer output for model II yields the results that can be utilized. Note that all the available machine yarding time was consumed in the yarding process and also that setting U was not completely yarded. Also, note that the profit derived from the wood on setting U is the lowest of any of the settings. One may imply from this that the model is optimizing machines to settings where the most profit and lowest cost may be obtained. In the third model an attempt was made to minimize idle time and to assign costs of this time to the various machines in addition to the objectives outlined in model II. The assigned costs were as follows:

> Machine A - \$250/day Machine B - \$275/day Machine C - \$ 80/day

The idle time can be incorporated in the model by altering the time available to each machine from an inequality to an equality and adding a slack variable, idle time. The objective function can then be altered to include idle time costs.

Equations 13 through 15 in model II can be altered to:

13) AR + AS + AT + AU + AV + AW + AI = 250
14) BR + BS + BT + BU + BV + BW + BI = 250
15) CR + CS + ST + CU + CV + CW + CI = 220

The objective equation can be altered to:

(30 R - 360 AR - 400 BR - 115 CR) + (32 S - 360 AS - 400 BS - 115 CS) + (37 T - 360 AT - 400 BT - 115 CT) + (27 U - 360 AU - 400 BU - 115 CU) + (31 V - 360 AV - 400 BV - 115 CV) + (29 W - 360 AW - 400 BW - 115 CW) +

- 250 AI - 275 BI - 80 CI

The constraints and objective equations in matrix form are shown in Table VIII.

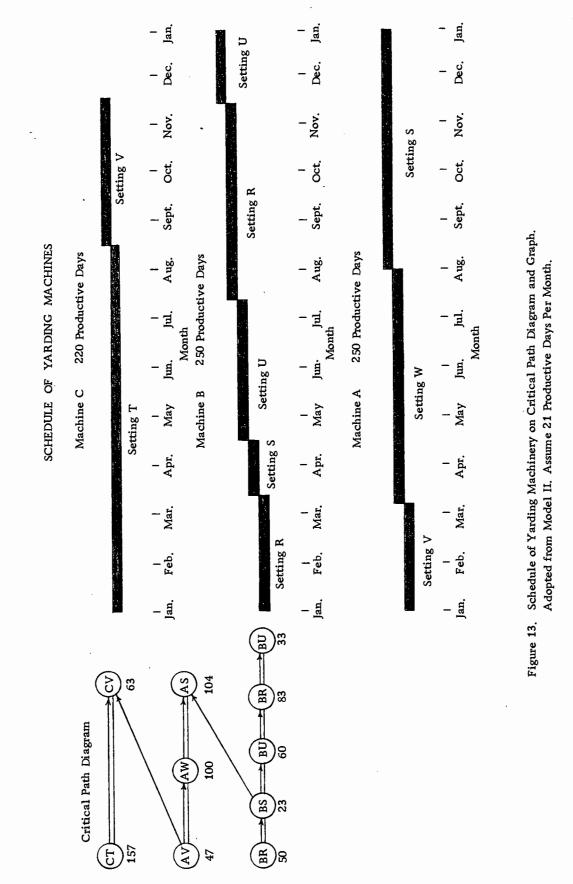
Once the allocation of the machinery is done by utilizing the linear program (Model I, II, or III), the machinery should be scheduled according to any scheduling constraints. This scheduling is best done by a simple critical path diagram shown in Figure 13. The purpose of this CPM is to simplify the scheduling in the PERT Sim system.

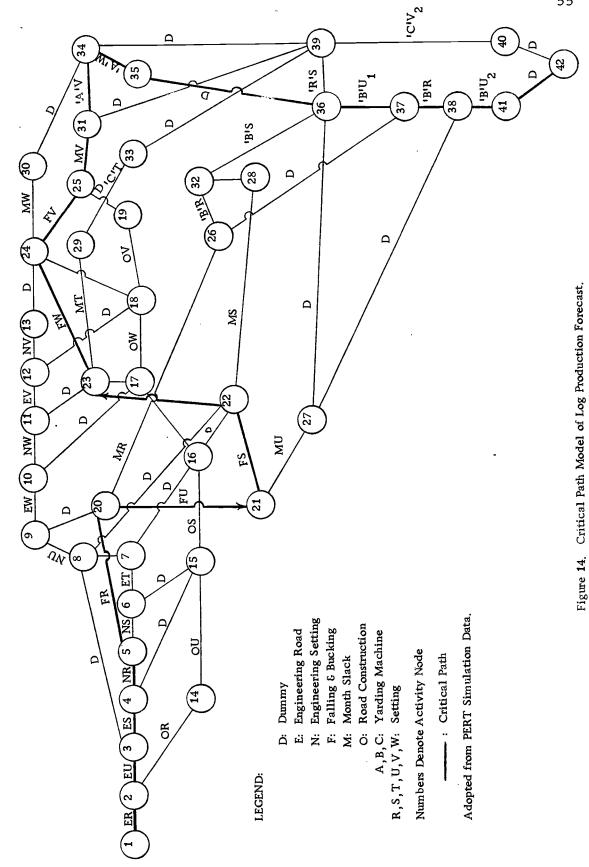
5. PERT Simulation

The schedule of machinery derived in the critical path can then be used in the formulation of a PERT Simulation network. The purpose of the PERT Simulation is to plan, schedule, and control the total logging operation.

The initial step is to convert and combine the activity times shown in Table VII with the yarding machine schedule (Figure 13) to produce an activity list of operations between the nodes in rising numerical sequence. One method is to list the "operations on the nodes" and the operations that each one of the activities must precede. Simple critical path computer software can then be used to convert to "operation between the node" listing. Another method, although very tedious, is to draw the network and manually list the operations between the nodes in numerical order. Figure 14 shows the complexity

IJ 30 32 37 27 31 29 - 360 - 400 - 115 - 360 - 400 - 115 - 360 - 400 - 115 - 360 - 400 - 115 - 360 - 400 - 115 - 360 - 400 - 115 - 250 - 275 - 80 AT BT CT AU BU CU AV BV CV AW BW CW AI BI 20 85 80 4 80 75 20 TABLE VIII. LINEAR PROGRAM MATRIX 60 110 120 70 S 20 75 BS 70 CR AS 9 8 R S T U V W AR BR 80 7 ۲ ٦ 7 7 ۲ Objective Maximize ~ 0008 12000 _ ₹ 0009 ". 0 ~ 0006 11000 2 16000 2 250 = 250 = 250 = ။ 0 п 0 || 0 = 0 || 0 Setting





of the critical path for the simple problem described in this paper. Table IX illustrates the PERT Simulation Data that is required for computer imput.

The next step in the PERT Sim model is to run the PERT Sim program on the computer. The computer output is shown in Appendix IV. The program defines the critical path, a graphical representation by days for each activity complete with slack times, a criticality index for each different path, and a criticality index for each activity.

From this information, the harvesting system can be scheduled and effectively controlled by knowing which activities are crucial in the PERT paths and altering these. From this PERT Simulation schedule, costs can be derived for each operation and the total cost calculated.

Figure 15 illustrates a simplified sequence of operations involved in making the logging production forecast.

IX. SUMMARY

A suitable model of logging production forecasting can be developed that will incorporate all the major variables of the logging process into a minimum total wood cost function. Other models should be developed to maximize the monetary returns of a log by integrating the sales forecast, inventories, logging, and manufacturing.

	A		Time	
Events	Activity	Most Likely	Minimum	Maximum
1-2	Engineering Road Setting R	5	4	7
2-3	Engineering Road Setting U	15	12	17
2-14	Road Construction Setting R	. 35	30	39
3-4	Engineering Road Setting S	12	10	16
3-8	Dummy	. 0	0	0
3-14	Dummy	0	0	0
4-5	Engineering Setting R	8	7	10
4-15	Dummy	0	0	0
5-6	Engineering Setting S	12	10	14
5-20	Falling & Bucking Setting R	40	32	50
6- 7	Engineering Road Setting T	8	5	12
6-15	Dummy	0	0	0
7-8	Engineering Setting T	6	5	7
7-16	Dummy	0	0	0
8-9	Engineering Setting U	12	9	20
8-22	Dummy	0	0	0
9-10	Engineering Road Setting W	8	6	12
9-20	Dummy	0	0	0
10-11	Engineering Setting W	13	12	15
10-17	Dummy	0	0	0
11-12	Engineering Road Setting V	4	3	8
11-23	Dummy	0	0	0
12-13	Engineering Setting V	7	5	10
12-18	Dummy	0	0	0
13-24	Dummy	0	0	0
14-15	Road Construction Setting U	68	55	74
14-20	Dummy	0	0	0
15-16	Road Construction Setting S	55	50	58
15-21	Dummy	0	0	0
16-17	Road Construction Setting T	10	9	12
16-22	Dummy	0	0	0
17-18	Road Construction Setting W	15	13	18
17-23	Dummy	0	0	0
18-19 ·	Road Construction Setting V	8	8	9
18-24	Dummy	0	0	0
19-25	Dummy	0	0	0
20-21	Falling & Bucking Setting U	65	50	80
20-26	Slack Time Setting R	21	21	21
21-22	Falling & Bucking Setting S	45	37	60
21-27	Slack Time Setting U	21 .	21	21
22-23	Falling & Bucking Setting T	38	30	45

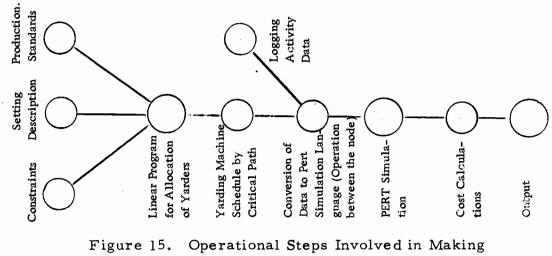
TABLE IX. PERT SIMULATION DATA

(Continued on next page)

TABLE	IX. (Continued)
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e.

			Time	
Events	Activity	Most Likely	Minimum	Maximum
22-28	Slack Time Setting S	21	21	21
23-24	Falling & Bucking Setting W	7 28	24	34
23-29	Slack Time Setting T	21	21	21
24-25	Falling & Bucking Setting V	14	12	16
24-30	Slack Time Setting W	21	21	21
25-31	Slack Time Setting V	21	21	21
26-32	Machine B Yard Setting R	50	49	51
26-37	Dummy	0	0	0
27-36	Dummy	0	0	0
27-38	Dummy	0	0	0
28-32	Dummy	0	0	0
28-36	Dummy	0	0	0
29-33	Machine C Yard Setting T	157	135	170
30-34	Dummy	0	0	0
31-34	Machine A Yard Setting Vl	47	40	52
31-39	Dummy	0	0	0
32-36	Machine B Yard Setting S	23	20	26
33-39	Dummy	0	0	Ο.
34 - 35	Machine A Yard Setting W	100	85	108
34-39	Dummy	0	0	0
35 - 36	Dummy	0	0	0
36-37	Machine B Yard Setting Ul	60	59	61
36-39	Machine A Yard Setting S	104	95	110
37-38	Machine B Yard Setting R	83	75	90
38-41	Machine B Yard Setting U2	33	25	38
39-40	Machine C Yard Setting V2	63	53	69



a Log Production Forecast.

What has been demonstrated in this preliminary paper on the formulation of logging production forecasts is only the initial methodology required to establish a budget model. The report illustrates that much work needs to be done with data collection and in establishing production standards prior to any reasonable production planning. Once the standards have been derived, production planning can be done by numerous operation research techniques. Some of the simple methods were incorporated in the illustrated model.

Implementation of this forecasting program will require cooperation from the labour and line supervisors in collecting the data. Some of the data is presently being recorded on daily time sheets. It must be remembered that the total model is only as good as the minimal quality of the input data.

Forecasting must change within the forest industry from "guesstimates" to a more efficient production forecasting model. Potentially large savings can be realized within the forest industry by improved machine scheduling, labour scheduling, machine investment, inventory costs, and the maximization of wood value. In the near future, without improved production forecasting, increasing demands of labour, the government, public pressures, financiers, and world markets, forest companies that do not improve their production forecasting, planning, and scheduling, could be faced with adverse economic status.

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APPENDICES

APPENDIX I

Cruising Classification

1) Setting unit identification number eg. 75 W

Species:	Douglas Fir	F	
	Western Red Cedar	С	1
	Yellow Cedar	Y	Limited to three dominant species
	True Fir	в	in coding
	Spruce .	s	
	Hemlock	H	
	Other	0)

The percentage of each species volume in the unit can be given by 10 percent classes after the species symbol.

3) Average age of stand

2)

Decadent old growth 9 100-150 years 8 80-100 years 7 60-80 years 6 40-60 years 5 20-40 years 4 10-20 years 3 2 3-10 years 0-3 years 1

4) Height class of dominant trees

- 1. 200 feet
- 2. 170 feet
- 3. 140 feet
- 4. 110 feet
- 5. 80 feet
- 6. 60 feet

5) Percent stocking in the setting unit

6) Average total gross volume per acre in cunits

7) Acreage of setting unit

8) Grades of wood by percentage volume to the nearest 10 percent

Peeler	\mathbf{PE}
#1 Sawlog	SA
#2 Sawlog	SL
Pulp	PU

9) Number of tree stems by D. B. H. classes to the nearest 10 percent

0"-6.0"	Α
6.1"-12.0"	в
12.1"-20.0"	С
20.1" +	D

APPENDIX II

Topographic Classification

1) Setting unit identification number

2) Average slope of unit in percent from landing

3) General topography

Rock Bluffs	R
Broken Ground	В
Flat	F
Rolling	S

4) Number of available landings per setting unit

- 5) Average number of months that snow prevents logging to nearest one-half month
- 6) Elevation in feet above sea level
- 7) Aspect

8) Soil conditions defined by the Unified Soil Classification System

9) Brush conditions

Dense		D
Medium		М
Clear	•	С

APPENDIX III

Linear Program Computer Output

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APPENDIX IV

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