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

Abstract approved:
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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:

1) to study the needs and benefits of a log production forecasting model.
2) to study the assumptions and requirements for the application of a model.
3) 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
2) optimization of the monetary returns from different grades of logs in the different manufacturing processes
3) 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
9) 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
3) 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 non-existent 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.

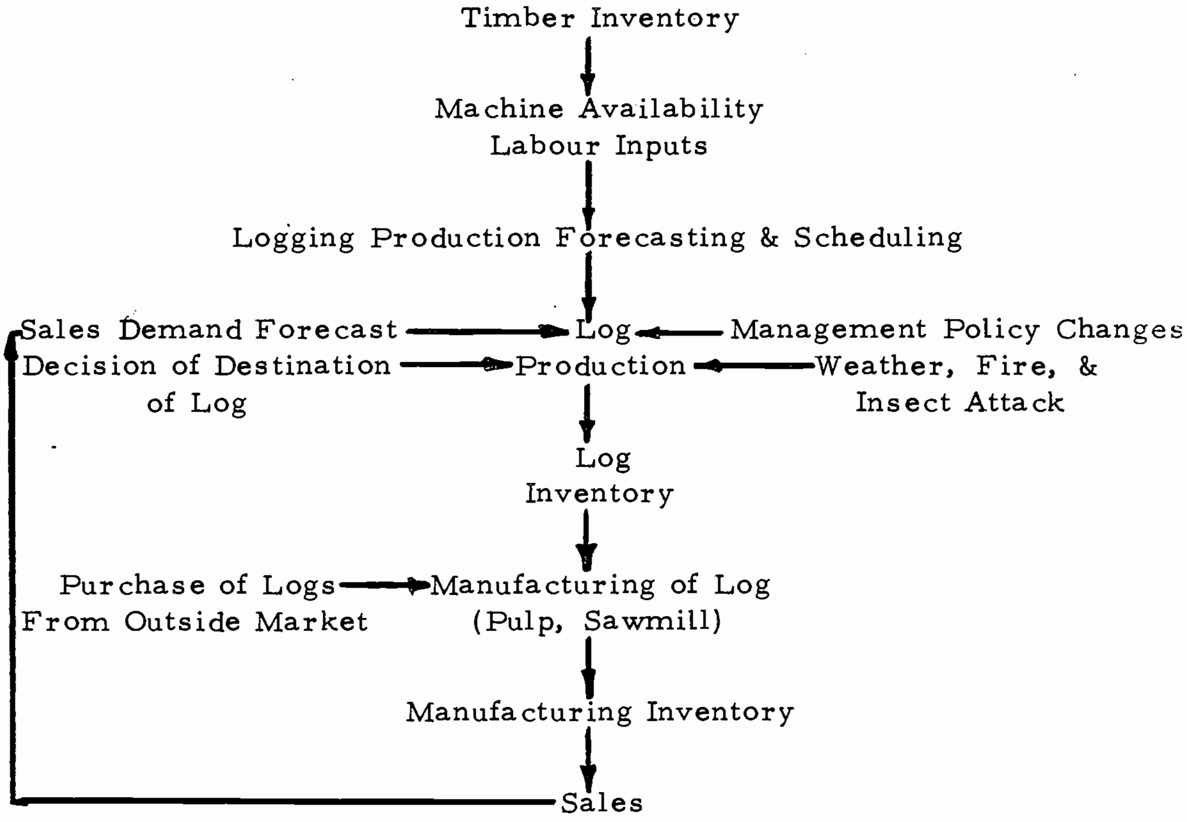


Figure 1. The Present Production System Flow Chart.

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

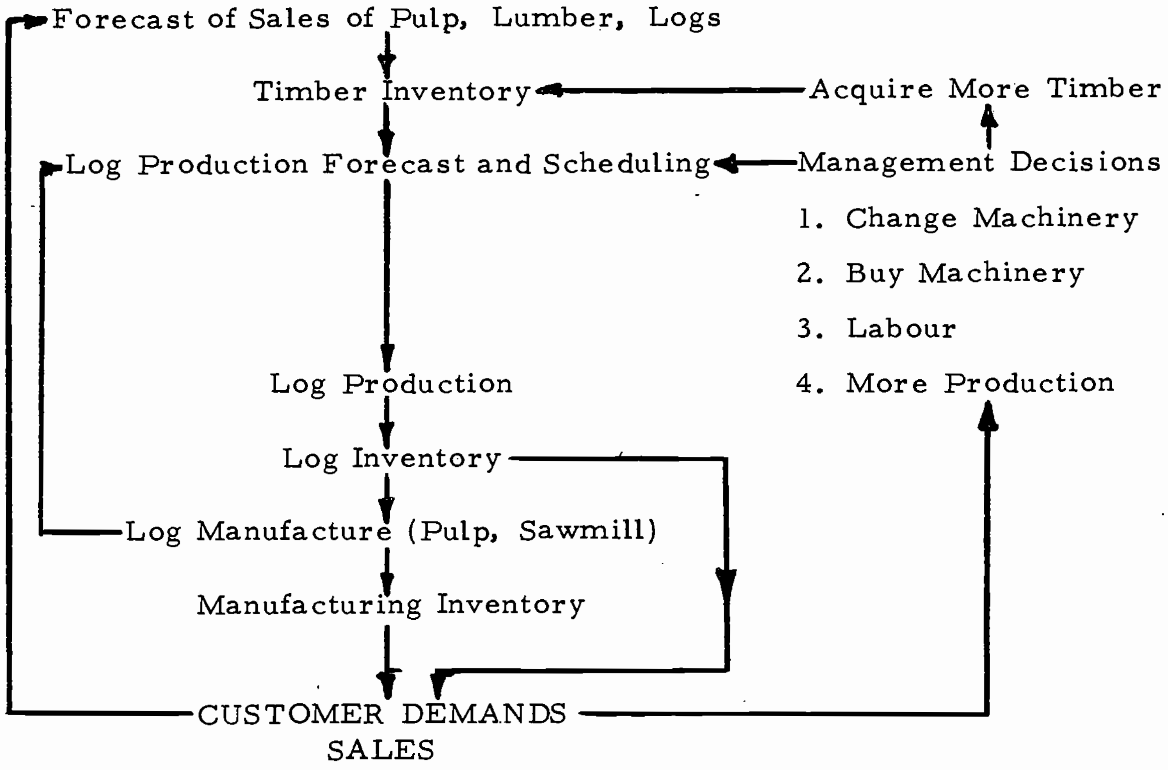


Figure 2. The Proposed Production System Flow Chart.

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 - F1 H4 C5 - 9 - 3 - 100 - 160 - 100 - Sa2 - S14 - PU4 - A1 B2 C5 D2

Setting V
5W - F2 H5 C3 - 9 - 3 - 90 - 100 - 60 - Sa2 - S15 - PU3 - A0 B2 C5 D3

Setting W
6W - F1 H5 C4 - 9 - 2 - 80 - 130 - 60 - Sa3 - S15 - PU2 - A0 B0 C6 D4

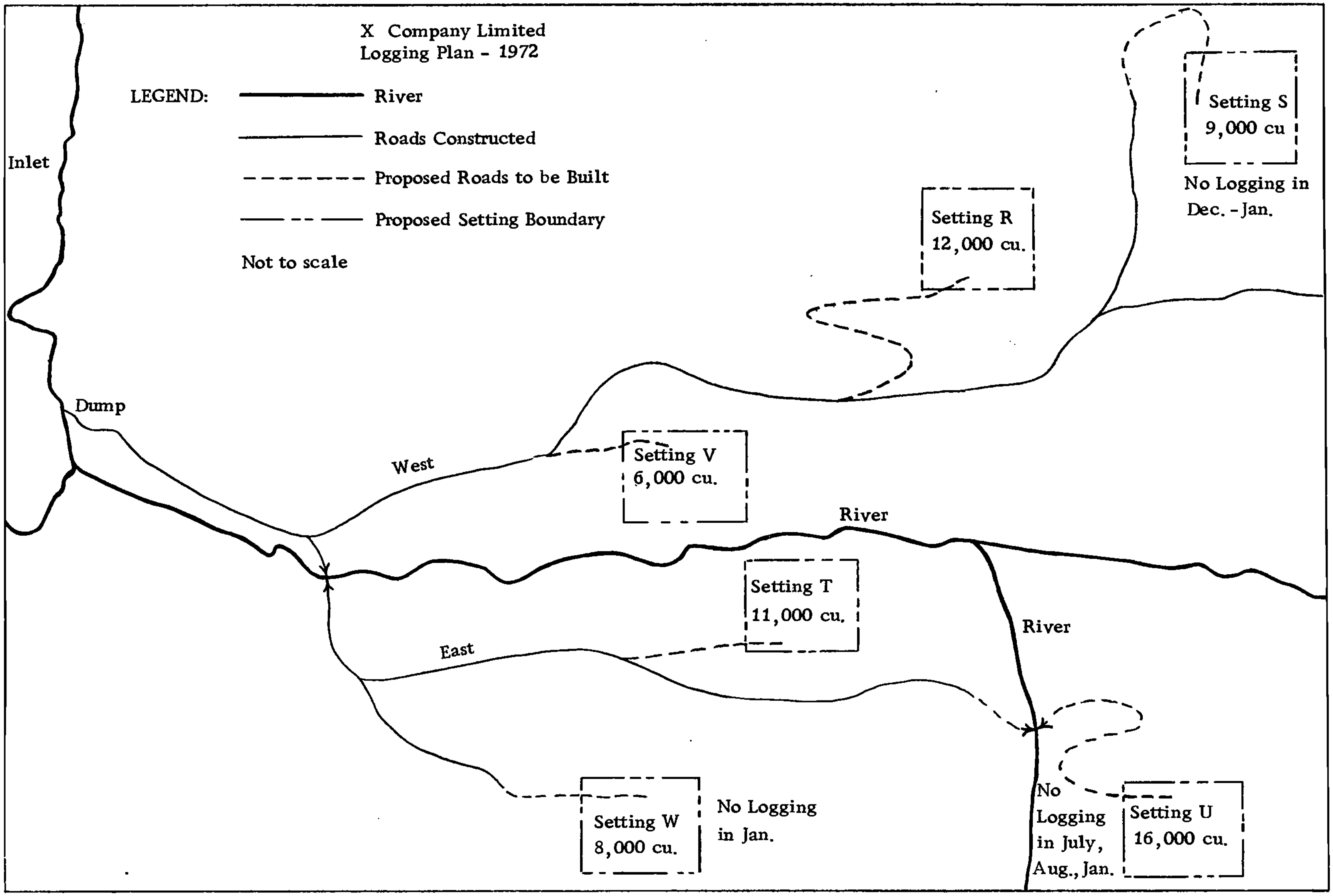


Figure 12. Planimetric Sketch of Areas to be Yarded.

TABLE II. TOPOGRAPHIC DATA

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

TABLE III. SETTING VOLUMES

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

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.

TABLE V. PRODUCTION RATES

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

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.

TABLE VI. SETTING REVENUES

Setting	Revenue per Cunit
R	$30.00
S	$32.00
T	$37.00
U	$27.00
V	$31.00
W	$29.00

TABLE VII. ACTIVITY TIMES

Activity		Time		
		Most Likely	Minimum	Maximum
Engineer Road to Setting	R	5	4	7
	S	12	10	16
	T	8	5	12
	U	15	12	17
	V	4	3	8
	W	8	6	12
Engineer Setting	R	8	7	10
	S	12	10	14
	T	6	5	7
	U	12	9	20
	V	7	5	10
	W	13	12	15
Road Construction to Setting	R	35	30	39
	S	55	50	58
	T	10	9	12
	U	68	55	74
	V	8	8	9
	W	15	13	18
Falling & Bucking Setting	R	40	32	50
	S	45	37	60
	T	38	30	45
	U	65	50	80
	V	14	12	16
	W	28	24	34

(Continued on next page)

TABLE VII. (Continued)

Activity		Time		
		Most Likely	Minimum	Maximum
Slack Time Setting	R	21	21	21
	S	21	21	21
	T	21	21	21
	U	21	21	21
	V	21	21	21
	W	21	21	21

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:

1) $80\ AR + 90\ BR + 10\ CR = 12{,}000$

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) $AR + AS + AT + AU + AV + AW \geq 0$

8) $BR + BS + BT + BU + BV + BW \geq 0$

9) $CR + CS + CT + CU + CV + CW \geq 0$

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 I 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) $W \leq 8{,}000$

13) $AR + AS + AT + AU + AV + AW \leq 250$

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:

$$
\begin{aligned}
&(30\ R - 360\ AR - 400\ BR - 115\ CR) + \\
&(32\ S - 360\ AS - 400\ BS - 115\ CS) + \\
&(37\ T - 360\ AT - 400\ BT - 115\ CT) + \\
&(27\ U - 360\ AU - 400\ BU - 115\ CU) + \\
&(31\ V - 360\ AV - 400\ BV - 115\ CV) + \\
&(29\ W - 360\ AW - 400\ BW - 115\ CW) + \\
&\quad - 250\ AI - 275\ BI - 80\ CI
\end{aligned}
$$

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

TABLE VIII. LINEAR PROGRAM MATRIX

Setting	R	S	T	U	V	W	AR	BR	CR	AS	BS	CS	AT	BT	CT	AU	BU	CU	AV	BV	CV	AW	BW	CW	AI	BI	CI
Objective Maximize	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
0 =	-1						80	90	10																		
0 =		-1								70	75	20															
0 =			-1										110	120	70												
0 =				-1												60	70	1									
0 =					-1														75	80	40						
0 =						-1																80	85	20			
12000 ≥	1																										
9000 ≥		1																									
11000 ≥			1																								
16000 ≥				1																							
6000 ≥					1																						
8000 ≥						1																					
250 =							1			1			1			1			1			1			1		
250 =								1			1			1			1			1			1			1	
250 =									1			1			1			1			1			1			1

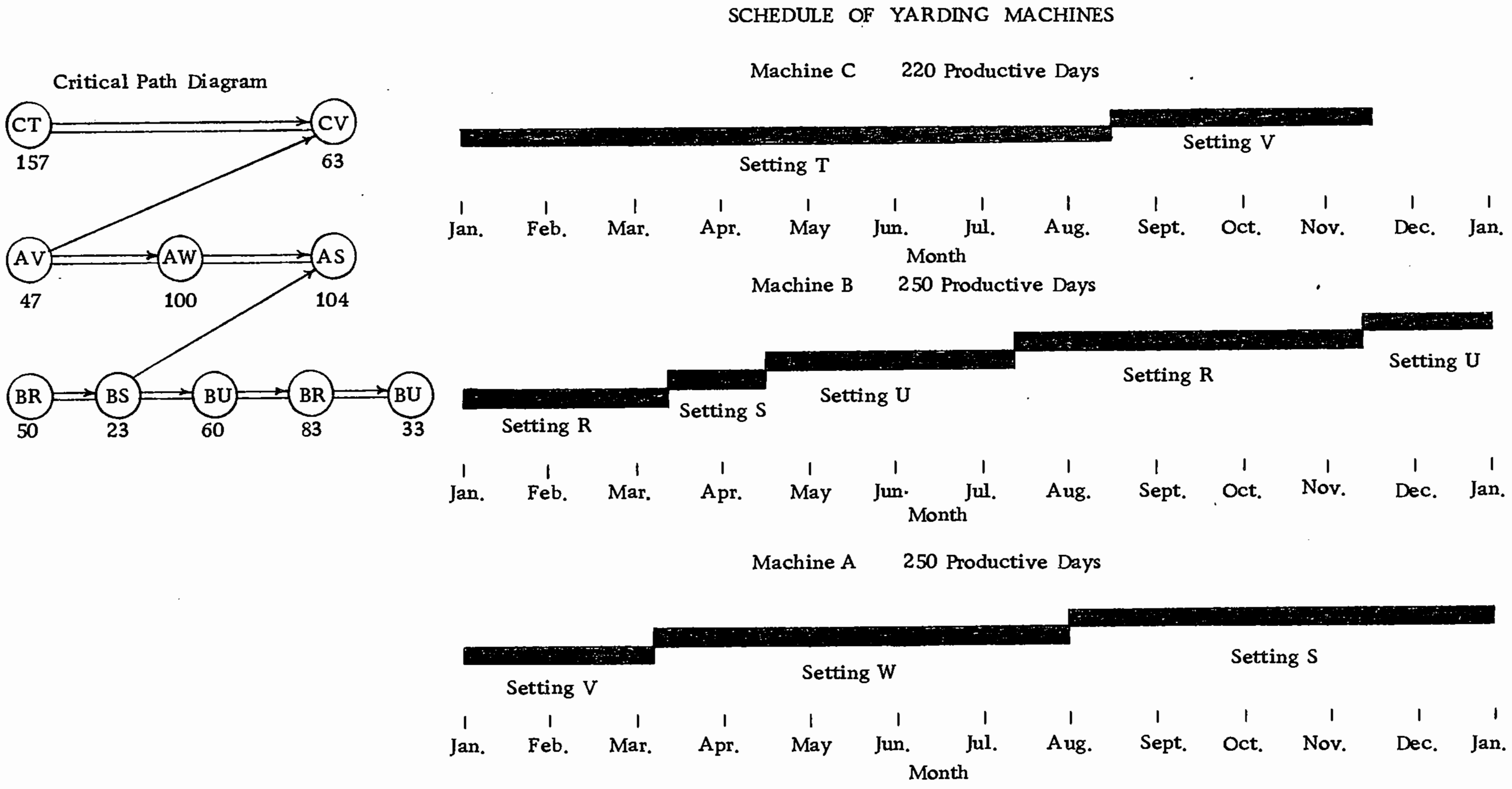
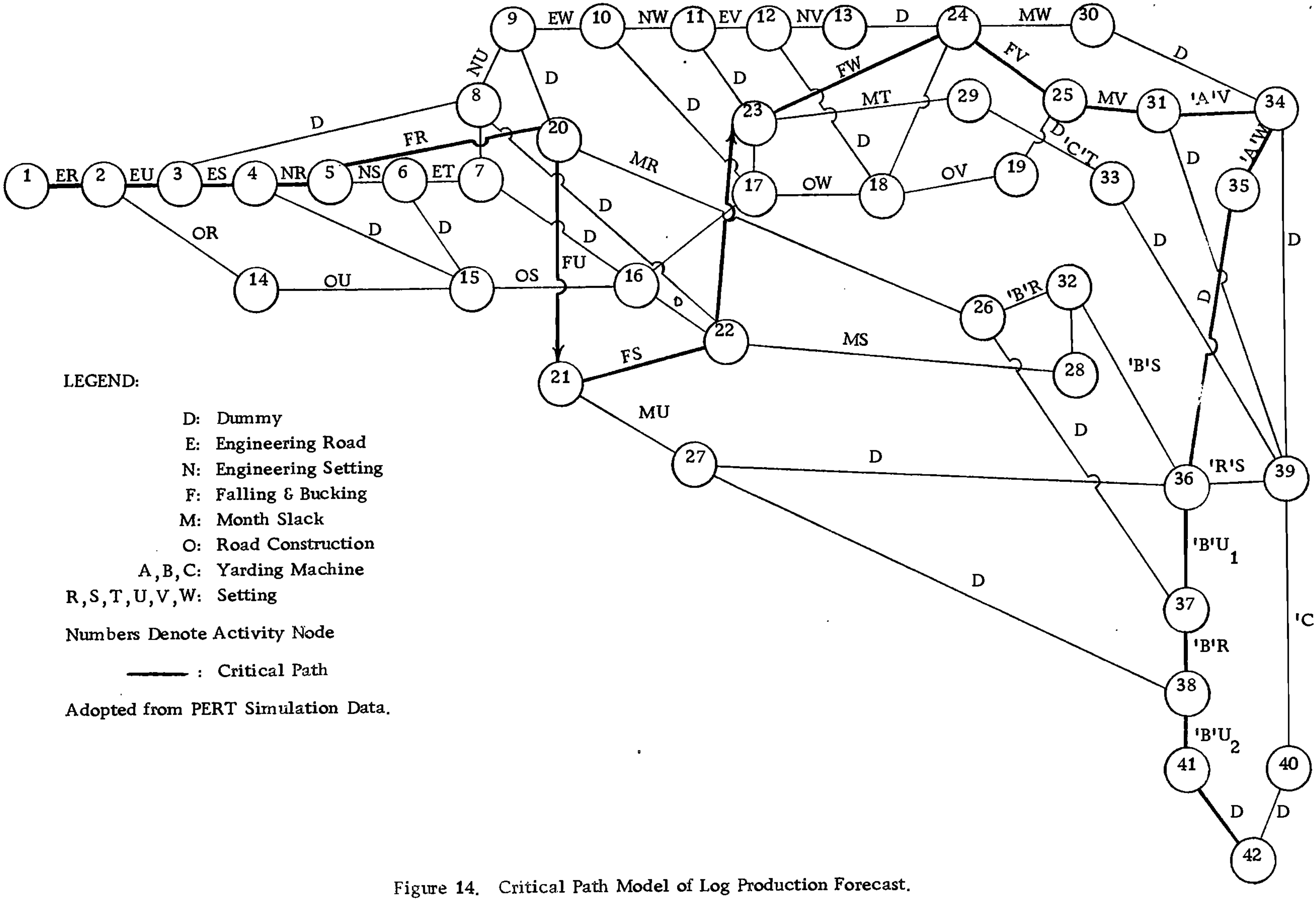


Figure 13. Schedule of Yarding Machinery on Critical Path Diagram and Graph. Adopted from Model II. Assume 21 Productive Days Per Month.



LEGEND:

D: Dummy
E: Engineering Road
N: Engineering Setting
F: Falling & Bucking
M: Month Slack
O: Road Construction
A, B, C: Yarding Machine
R, S, T, U, V, W: Setting

Numbers Denote Activity Node

——— : Critical Path

Adopted from PERT Simulation Data.

Figure 14. Critical Path Model of Log Production Forecast.

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.

TABLE IX. PERT SIMULATION DATA

Events	Activity	Time		
		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

(Continued on next page)

TABLE IX. (Continued)

Events	Activity	Time		
		Most Likely	Minimum	Maximum
22-28	Slack Time Setting S	21	21	21
23-24	Falling & Bucking Setting W	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 V1	47	40	52
31-39	Dummy	0	0	0
32-36	Machine B Yard Setting S	23	20	26
33-39	Dummy	0	0	0
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 U1	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

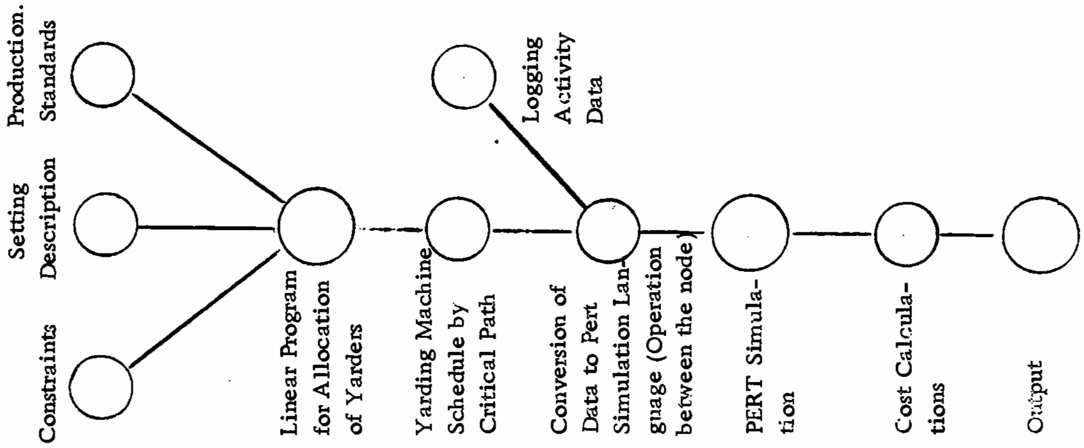


Figure 15. Operational Steps Involved in Making a Log Production Forecast.

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 co-operation 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

2) Species:

Douglas Fir	F
Western Red Cedar	C
Yellow Cedar	Y
True Fir	B
Spruce	S
Hemlock	H
Other	O

Limited to three dominant species in coding

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

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
3-10 years	2
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	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"	A
6.1"-12.0"	B
12.1"-20.0"	C
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	B
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	M
Clear	C

APPENDIX III

Linear Program Computer Output

MODEL I

0497

SAVE FOR BOB CRAIG

```
ROWS
SOBJ RW1 RW2 RW3 RW4 RW5 RW6 >RW7 >RW8 >RW9
COLUMNS
AR OBJ -360 RW1 80 RW7 1
BR OBJ -400 RW1 90 RW8 1
CR OBJ -115 RW1 10 RW9 1
AS OBJ -360 RW2 70 RW7 1
BS OBJ -400 RW2 75 RW8 1
CS OBJ -115 RW2 20 RW9 1
AT OBJ -360 RW3 110 RW7 1
BT OBJ -400 RW3 120 RW8 1
CT OBJ -115 RW3 70 RW9 1
AU OBJ -360 RW4 60 RW7 1
BU OBJ -400 RW4 70 RW8 1
CU OBJ -115 RW4 1 RW9 1
AV OBJ -360 RW5 75 RW7 1
BV OBJ -400 RW5 80 RW8 1
CV OBJ -115 RW5 40 RW9 1
AW OBJ -360 RW6 80 RW7 1
BW OBJ -400 RW6 85 RW8 1
CW OBJ -115 RW6 20 RW9 1
R *BOUND* 12000 OBJ 30 RW1 -1
S *BOUND* 9000 OBJ 32 RW2 -1
T *BOUND* 11000 OBJ 37 RW3 -1
U *BOUND* 16000 OBJ 27 RW4 -1
V *BOUND* 6000 OBJ 31 RW5 -1
w *BOUND* 8000 OBJ 29 RW6 -1
RHS
RESTR RW1 0 RW2 0 RW3 0 RW4 0 RW5 0 RW6 0 RW7 0
RESTR RW8 0 RW9 0
EOF
```

MODEL I

```
11/22/68           000000000000000000000000000000000000000000000000000000000000000000000000000000                  13:15:37

OBJ = OBJ                                      RHS = RESTR                                          MAXIMUM = 1542630.952362

                                    **   C O L U M N S   S E C T I O N   R E P O R T   **

  COLUMN       IND           AMOUNT             OBJECTIVE           LOWER LIMIT          UPPER LIMIT          REDUCED COST

  AR            L                  0           -360.000000                    0             PINF                4.444444
  BR            B         133.333333           -400.000000                    0             PINF                       0
  CR            L                  0           -115.000000                    0             PINF               70.555556
  AS            B         128.571429           -360.000000                    0             PINF                       0
  BS            L                  0           -400.000000                    0             PINF               14.285714
  CS            L                  0           -115.000000                    0             PINF               12.142857
  AT            L                  0           -360.000000                    0             PINF              179.285714
  BT            L                  0           -400.000000                    0             PINF              202.857143
  CT            B         157.142857           -115.000000                    0             PINF                       0
  AU            L                  0           -360.000000                    0             PINF               17.142857
  BU            B         228.571429           -400.000000                    0             PINF                       0
  CU            L                  0           -115.000000                    0             PINF              109.285714
  AV            L                  0           -360.000000                    0             PINF              144.375000
  BV            L                  0           -400.000000                    0             PINF              170.000000
  CV            B         150.000000           -115.000000                    0             PINF                       0
  AW            B         100.000000           -360.000000                    0             PINF                       0
  BW            L                  0           -400.000000                    0             PINF               17.500000
  CW            L                  0           -115.000000                    0             PINF               25.000000
  R             U       12000.000000             30.000000                    0     12000.000000              -25.555556
  S             U        9000.000000             32.000000                    0      9000.000000              -26.857143
  T             U       11000.000000             37.000000                    0     11000.000000              -35.357143
  U             U       16000.000000             27.000000                    0     16000.000000              -21.285714
  V             U        6000.000000             31.000000                    0      6000.000000              -28.125000
  W             U        8000.000000             29.000000                    0      8000.000000              -24.500000
```

MODEL II

0500

SAVE FOR BOB CRAIG

```
ROWS
$OBJ RW1 RW2 RW3 RW4 RW5 RW6 <RW7 <RW8 <RW9
COLUMNS
AR OBJ -360 RW1 80 RW7 1
BR OBJ -400 RW1 90 RW8 1
CR OBJ -115 RW1 10 RW9 1
AS OBJ -360 RW2 70 RW7 1
BS OBJ -400 RW2 75 RW8 1
CS OBJ -115 RW2 20 RW9 1
AT OBJ -360 RW3 110 RW7 1
BT OBJ -400 RW3 120 RW8 1
CT OBJ -115 RW3 70 RW9 1
AU OBJ -360 RW4 60 RW7 1
BU OBJ -400 RW4 70 RW8 1
CU OBJ -115 RW4 1 RW9 1
AV OBJ -360 RW5 75 RW7 1
BV OBJ -400 RW5 80 RW8 1
CV OBJ -115 RW5 40 RW9 1
AW OBJ -360 RW6 80 RW7 1
BW OBJ -400 RW6 85 RW8 1
CW OBJ -115 RW6 20 RW9 1
P *BOUND* 12000 OBJ 30 RW1 -1
S *BOUND* 9000 OBJ 32 RW2 -1
T *BOUND* 11000 OBJ 37 RW3 -1
U *BOUND* 16000 OBJ 27 RW4 -1
V *BOUND* 6000 OBJ 31 RW5 -1
W *BOUND* 8000 OBJ 29 RW6 -1
RHS
RESTR RW1 0 RW2 0 RW3 0 RW4 0 RW5 0 RW6 0 RW7 250
RESTR RW8 250 RW9 220
EOF
```

MODEL II

```
11/22/68          000000000000000000000000000000000000000000000000000000000000000000000000000          13:15:37

OBJ = OBJ                              RHS = RESTR                                     MAXIMUM = 1434015.999969

                              **   C O L U M N S   S E C T I O N   R E P O R T   **

 COLUMN      IND         AMOUNT           OBJECTIVE          LOWER LIMIT        UPPER LIMIT        REDUCED COST

 AR           L                0         -360.000000                   0            PINF             84.000000
 BR           B       133.333333         -400.000000                   0            PINF                     0
 CR           L                0         -115.000000                   0            PINF            730.800000
 AS           B       103.523810         -360.000000                   0            PINF                     0
 BS           B        23.377778         -400.000000                   0            PINF                     0
 CS           L                0         -115.000000                   0            PINF            436.800000
 AT           L                0         -360.000000                   0            PINF            285.600000
 BT           L                0         -400.000000                   0            PINF            277.200000
 CT           B       157.142857         -115.000000                   0            PINF               .000000
 AU           L                0         -360.000000                   0            PINF            144.000000
 BU           B        93.288889         -400.000000                   0            PINF                     0
 CU           L                0         -115.000000                   0            PINF            913.800000
 AV           B        46.476190         -360.000000                   0            PINF                     0
 BV           L                0         -400.000000                   0            PINF              8.400000
 CV           B        62.857143         -115.000000                   0            PINF             -0.000000
 AW           B       100.000000         -360.000000                   0            PINF                     0
 BW           L                0         -400.000000                   0            PINF             15.750000
 CW           L                0         -115.000000                   0            PINF            499.800000
 R            U     12000.000000           30.000000                   0     12000.000000             -9.000000
 S            U      9000.000000           32.000000                   0      9000.000000             -6.800000
 T            U     11000.000000           37.000000                   0     11000.000000            -23.560000
 U            B      6530.222222           27.000000                   0     16000.000000                     0
 V            U      6000.000000           31.000000                   0      6000.000000             -7.480000
 W            U      8000.000000           29.000000                   0      8000.000000             -6.950000
```

MODEL III

SAVE FOR BOB CRAIG

```
ROWS
$OBJ RW1 RW2 RW3 RW4 RW5 RW6 RW7 RW8 RW9
COLUMNS
R *BOUND* 12000 OBJ 30 RW1 -1
S *BOUND* 9000 OBJ 32 RW2 -1
T *BOUND* 11000 OBJ 37 RW3 -1
U *BOUND* 16000 OBJ 27 RW4 -1
V *BOUND* 6000 OBJ 31 RW5 -1
W *BOUND* 8000 OBJ 29 RW6 -1
AR OBJ -360 RW1 80 RW7 1
BR OBJ -400 RW1 90 RW8 1
CR OBJ -115 RW1 10 RW9 1
AS OBJ -360 RW2 70 RW7 1
BS OBJ -400 RW2 75 RW8 1
CS OBJ -115 RW2 20 RW9 1
AT OBJ -360 RW3 110 RW7 1
BT OBJ -400 RW3 120 RW8 1
CT OBJ -115 RW3 70 RW9 1
AU OBJ -360 RW4 60 RW7 1
BU OBJ -400 RW4 70 RW8 1
CU OBJ -115 RW4 1 RW9 1
AV OBJ -360 RW5 75 RW7 1
BV OBJ -400 RW5 80 RW8 1
CV OBJ -115 RW5 40 RW9 1
AW OBJ -360 RW6 80 RW7 1
BW OBJ -400 RW6 85 RW8 1
CW OBJ -115 RW6 20 RW9 1
AI OBJ -250 RW7 1
BI OBJ -275 RW8 1
CI OBJ -80 RW9 1
RHS
RESTR RW7 250 RW8 250 RW9 220
EOF
```

MODEL III

```
11/22/68          000000000000000000000000000000000000000000000000000000000000000000000000000          13:15:37

OBJ = OBJ                              RHS = RESTR                                  MAXIMUM = 1434015.999969

                              **  C O L U M N S   S E C T I O N   R E P O R T  **

  COLUMN     IND          AMOUNT            OBJECTIVE        LOWER LIMIT         UPPER LIMIT       * REDUCED COST

  R           U        12000.000000         30.000000                  0      12000.000000         -9.000000
  S           U         9000.000000         32.000000                  0       9000.000000         -6.800000
  T           U        11000.000000         37.000000                  0      11000.000000        -23.560000
  U           B         6530.222223         27.000000                  0      16000.000000                 0
  V           U         6000.000000         31.000000                  0       6000.000000         -7.490000
  W           U         8000.000000         29.000000                  0       8000.000000         -6.950000
  AR          L                   0       -360.000000                  0          PINF             84.000000
  BR          B          133.333333       -400.000000                  0          PINF                     0
  CR          L                   0       -115.000000                  0          PINF            730.800000
  AS          B          103.523810       -360.000000                  0          PINF                     0
  BS          B           23.377778       -400.000000                  0          PINF                     0
  CS          L                   0       -115.000000                  0          PINF            436.800000
  AT          L                   0       -360.000000                  0          PINF            285.600000
  BT          L                   0       -400.000000                  0          PINF            277.200000
  CT          B          157.142857       -115.000000                  0          PINF               .000000
  AU          L                   0       -360.000000                  0          PINF            144.000000
  BU          B           93.288889       -400.000000                  0          PINF                     0
  CU          L                   0       -115.000000                  0          PINF            913.800000
  AV          B           46.476190       -360.000000                  0          PINF               .000000
  BV          L                   0       -400.000000                  0          PINF              8.400000
  CV          B           62.857143       -115.000000                  0          PINF                     0
  AW          B          100.000000       -360.000000                  0          PINF                     0
  BW          L                   0       -400.000000                  0          PINF             15.750000
  CW          L                   0       -115.000000                  0          PINF            499.800000
  AI          L                   0       -250.000000                  0          PINF           1654.000000
  BI          L                   0       -275.000000                  0          PINF           1765.000000
  CI          L                   0        -80.000000                  0          PINF            905.800000
```

APPENDIX IV

PERT Simulation Computer Output

```
                                                                                              0307
JOB,90026      BOB CRAIG
APRIL 3, 1970  5:14 PM TERMINAL 177
TIME=400
MFBLKS=200
LABEL,62/CRAIG
90,10,11,12,22
FORTRAN,R

 NO ERRORS FOR CRSIMBAR

 NO ERRORS FOR DATAFORM

 NO ERRORS FOR FIXMAX

 NO ERRORS FOR SIMDU

 NO ERRORS FOR PATHANAL

 NO ERRORS FOR CUMULATE

 NO ERRORS FOR BARCHART
RUN
```

```
PERT SIM FOR LOGGING PRODUCTION FORECASTING   ROB CRAIG

        LOGGING PRODUCTION SCHEDULING

         NCODE= 3,     20 CYCLES PER SET PROGRAM VARIANCE SCALE FACTOR =1.00

PROGRAM PARAMETERS...NCODE=3 V=1.00 KSSWTCH=1 NSIM=  20 NSETSIM=  10 NPX=5894721 KBARCHRT =1


     INPUT DATA LIST

  NO.       I   J     DUR     MIN     MAX  NXCOOF   COMMENTS

   1        1   2       5       4       7     1      ENGINEERING ROAD SETTING R
   2        2   3      15      12      17     1      ENGINEERING ROAD SETTING U
   3        2  14      35      30      39     1      ROAD CONSTRUCTION SETTING R
   4        3   4      12      10      16     1      ENGINEERING ROAD SETTING S
   5        3   8       0       0       0     1      DUMMY
   6        3  14       0       0       0     1      DUMMY
   7        4   5       8       7      10     1      ENGINEERING SETTING R
   8        4  15       0       0       0     1      DUMMY
   9        5   6      12      10      14     1      ENGINEERING SETTING S
  10        5  20      40      32      50     1      FALLING AND BUCKING SETTING R
  11        6   7       8       5      12     1      ENGINEERING ROAD SETTING T
  12        6  15       0       0       0     1      DUMMY
  13        7   8       6       5       7     1      ENGINEERING SETTING T
  14        7  16       0       0       0     1      DUMMY
  15        8   9      12       9      20     1      ENGINEERING SETTING U
  16        8  22       0       0       0     1      DUMMY
  17        9  10       8       6      12     1      ENGINEERING ROAD SETTING W
  18        9  20       0       0       0     1      DUMMY
  19       10  11      13      12      15     1      ENGINEERING SETTING W
  20       10  17       0       0       0     1      DUMMY
  21       11  12       4       3       8     1      ENGINEERING ROAD SETTING V
  22       11  23       0       0       0     1      DUMMY
  23       12  13       7       5      10     1      ENGINEERING SETTING V
  24       12  18       0       0       0     1      DUMMY
  25       13  24       0       0       0     1      DUMMY
  26       14  15      68      55      74     1      ROAD CONSTRUCTION SETTING U
  27       14  20       0       0       0     1      DUMMY
  28       15  16      55      50      58     1      ROAD CONSTRUCTION SETTING S
  29       15  21       0       0       0     1      DUMMY
  30       16  17      10       9      12     1      ROAD CONSTRUCTION SETTING T
  31       16  22       0       0       0     1      DUMMY
  32       17  18      15      13      18     1      ROAD CONSTRUCTION SETTING W
  33       17  23       0       0       0     1      DUMMY
  34       18  19       8       8       9     1      ROAD CONSTRUCTION SETTING V
  35       18  24       0       0       0     1      DUMMY
  36       19  25       0       0       0     1      DUMMY
  37       20  21      65      50      80     1      FALLING AND BUCKING SETTING U
  38       20  26      21      21      21     1      SLACK TIME SETTING R
  39       21  22      45      37      60     1      FALLING AND BUCKING SETTING S
  40       21  27      21      21      21     1      SLACK TIME SETTING U
  41       22  23      38      30      45     1      FALLING AND BUCKING SETTING T
  42       22  28      21      21      21     1      SLACK TIME SETTING S
  43       23  24      29      24      34     1      FALLING AND BUCKING SETTING W
```

```
45       24  25    14     12     16     1       FALLING AND BUCKING SETTING V
46       24  30    21     21     21     1       SLACK TIME SETTING W
47       25  31    21     21     21     1       SLACK TIME SETTING V
48       26  32    50     49     51     1       MACHINE B YARD SETTING R
49       26  37     0      0      0     1       DUMMY
50       27  36     0      0      0     1       DUMMY
51       27  38     0      0      0     1       DUMMY
52       28  32     0      0      0     1       DUMMY
53       29  36     0      0      0     1       DUMMY
54       29  33   157    135    170     1       MACHINE C YARD SETTING T
55       30  34     0      0      0     1       DUMMY
56       31  34    47     40     52     1       MACHINE A YARD SETTING V2
57       31  39     0      0      0     1       DUMMY
58       32  36    23     20     26     1       MACHINE B YARD SETTING S
59       33  39     0      0      0     1       DUMMY
60       34  35   100     85    108     1       MACHINE A YARD SETTING W
61       34  39     0      0      0     1       DUMMY
62       35  36     0      0      0     1       DUMMY
63       36  37    60     59     61     1       MACHINE B YARD SETTINGU1
64       36  39   104     95    110     1       MACHINE A YARD SETTING S
65       37  34    83     75     90     1       MACHINE B YARD SETTINGR
66       38  41    33     25     38     1       MACHINE B YARD SETTING U2
67       39  40    63     53     69     1       MACHINE C YARD SETTING V2
68       40  42     0      0      0     1       ENDING ACTIVITY COMMON DUMMY
69      -41  42     0      0      0     1       ENDING ACTIVITY COMMON DUMMY
```

```
I. STANDARD CPM ANALYSIS OUTPUT DATA USING JOB TIME ESTIMATE W/O VARIANCE
     I      J    DUR    EST    LST    EFT    LFT     TF

     1      2      5      1      0      5      5      0      0  CRITICAL
     2      3     15      6      5     20     20      0      0  CRITICAL
     2     14     35      6     32     40     67     27      0
     3      4     12     21     20     32     32      0      0  CRITICAL
     3      8      0     21     69     20     68     48     46
     3     14      0     21     67     20     67     47     20
     4      5      8     33     32     40     40      0      0  CRITICAL
     4.    15      0     33    135     32    135    103     76
     5      6     12     41     42     52     54      2      0
     5     20     40     41     40     80     80      0      0  CRITICAL
     6      7      8     53     54     60     62      2      0
     6     15      0     53    135     52    135     83     56
     7      8      6     61     62     66     68      2      0
     7     16      0     61    190     60    190    130    103
     8      9     12     67     68     78     80      2      0
     8     22      0     67    190     66    190    124    124
     9     10      8     79    207     86    215    129      0
     9     20      0     79     80     78     80      2      2
    10     11     13     87    215     99    228    129      0
    10     17      0     87    228     86    228    142     87
    11     12      4    100    245    103    249    146      0
    11     23      0    100    228     99    228    129    129
    12     13      7    104    249    110    256    146      0
    12     18      0    104    256    103    256    153     85
    13     24      0    111    256    110    256    146    146
    14     15     68     41     67    108    135     27      0
    14     20      0     41     80     40     80     40     40
    15     16     55    109    135    163    190     27      0
    15     21      0    109    145    108    145     37     37
    16     17     10    164    218    173    228     55      0
    16     22      0    164    190    163    190     27     27
    17     18     15    174    241    188    256     68      0
    17     23      0    174    228    173    228     55     55
    18     19      8    189    262    196    270     74      0
    18     24      0    189    256    188    256     68     68
    19     25      0    197    270    196    270     74     74
    20     21     65     81     80    145    145      0      0  CRITICAL
    20     26     21     81    344    101    365    264      0
    21     22     45    146    145    190    190      0      0  CRITICAL
    21     27     21    146    417    166    438    272      0
    22     23     38    191    190    228    228      0      0  CRITICAL
    22     28     21    191    304    211    415    204      0
    23     24     28    229    229    256    256      0      0  CRITICAL
    23     29     21    229    373    249    394    145      0
    24     25     14    257    256    270    270      0      0  CRITICAL
    24     30     21    257    317    277    338     61      0
    25     31     21    271    270    291    291      0      0  CRITICAL
    26     32     50    102    365    151    415    264     60
    26     37      0    102    498    101    498    397    397
    27     36      0    167    438    166    438    272    272
    27     38      0    167    581    166    581    415    415
    28.    32      0    212    415    211    415    204      0
    28     36      0    212    438    211    438    227    227
    29     33    157    250    394    406    551    145      0
    30     34      0    278    338    277    338     61     61
    31     34     47    292    291    338    338      0      0  CRITICAL
    31     39      0    292    551    291    551    260    251
    32     36     23    212    415    234    438    204    204
    33     39      0    407    551    406    551    145    136
```

```
 34   35  100  339  339  438  438    0    0 CRITICAL
 34   39    0  339  551  339  551  213  204
 35   36    0  439  438  438  438    0    0 CRITICAL
 36   37   60  439  438  498  498    0    0 CRITICAL
 36   39  104  439  447  542  551    9    0
 37   38   83  499  498  581  581    0    0 CRITICAL
 38   41   33  582  581  614  614    0    0 CRITICAL
 39   40   63  543  551  605  614    9    0
 40   42    0  606  614  605  614    9    9
 41   42    0  615  614  614  614    0    0 CRITICAL

CRITICAL PATH I.D. NO. =(223357.944). TOTAL PROJECT TIME ON CRITICAL PATH =  614
```

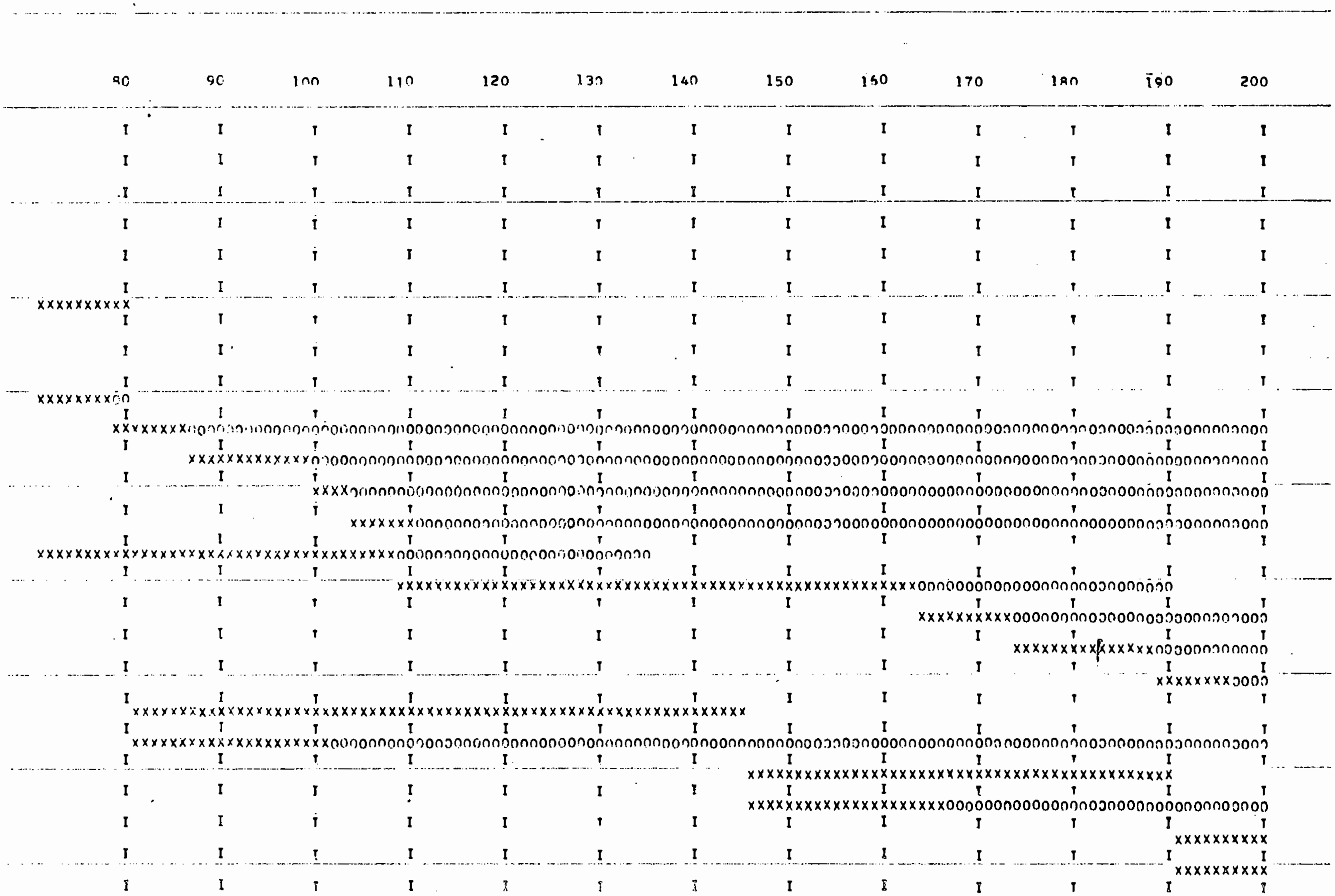
```
               PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG

                        ... SYMBOL LEGEND ...
X=JOB DAY WHEN WORK IS BEING DONE ON JOB

*=ACTIVITY FREE SLACK=MAXIMUM TIME BY WHICH ACTUAL COMPLETION CAN BE GREATER THAN EARLIEST EXPECTED TIME
  OF AN ACTIVITY WITHOUT ANY EFFECT ON OTHER ACTIVITIES OR EVENTS
O=TOTAL ACTIVITY SLACK=MAXIMUM TIME BY WHICH ACTUAL COMPLETION CAN BE GREATER THAN EARLIEST EXPECTED TIME
  OF AN ACTIVITY WITHOUT HAVING AN EFFECT ON THE OVERALL PROJECT DURATION
```

```
                  PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG
                       PROJECT JOB TIME SCHEDULE
 I   J  DUR        JOB DESCRIPTION                   DAYS 1234567890        20        30        40        50        60        70
  1   2    5    ENGINEERING ROAD SETTING R                XXXXX
                                                         I         I         I         I         I         I         I         I
  2   3   15    ENGINEERING ROAD SETTING U                     XXXXXXXXXXXXXXX
                                                         I         I         I         I         I         I         I         I
  2  14   35    ROAD CONSTRUCTION SETTING R                    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX000000000000000000000000000
                                                         I         I         I         I         I         I         I         I
  3   4   12    ENGINEERING ROAD SETTING S                                    XXXXXXXXXXXX
                                                         I         I         I         I         I         I         I         I
  4   5    8    ENGINEERING SETTING R                                                     XXXXXXXX
                                                         I         I         I         I         I         I         I         I
  5   6   12    ENGINEERING SETTING S                                                             XXXXXXXXXXXX00
                                                         I         I         I         I         I         I         I         I
  5  20   40    FALLING AND BUCKING SETTING R                                                     XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                                         I         I         I         I         I         I         I         I
  6   7    8    ENGINEERING ROAD SETTING T                                                                    XXXXXXXX00
                                                         I         I         I         I         I         I         I         I
  7   8    6    ENGINEERING SETTING T                                                                                 XXXXXX00
                                                         I         I         I         I         I         I         I         I
  8   9   12    ENGINEERING SETTING U                                                                                       XXXX
                                                         I         I         I         I         I         I         I         I
  9  10    8    ENGINEERING ROAD SETTING W
                                                         I         I         I         I         I         I         I         I
 10  11   13    ENGINEERING SETTING W
                                                         I         I         I         I         I         I         I         I
 11  12    4    ENGINEERING ROAD SETTING V
                                                         I         I         I         I         I         I         I         I
 12  13    7    ENGINEERING SETTING V
                                                         I         I         I         I         I         I         I         I
 14  15   68    ROAD CONSTRUCTION SETTING U                                                       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                                         I         I         I         I         I         I         I         I
 15  16   55    ROAD CONSTRUCTION SETTING S
                                                         I         I         I         I         I         I         I         I
 16  17   10    ROAD CONSTRUCTION SETTING T
                                                         I         I         I         I         I         I         I         I
 17  18   15    ROAD CONSTRUCTION SETTING W
                                                         I         I         I         I         I         I         I         I
 18  19    8    ROAD CONSTRUCTION SETTING V
                                                         I         I         I         I         I         I         I         I
 20  21   65    FALLING AND BUCKING SETTING U
                                                         I         I         I         I         I         I         I         I
 20  26   21    SLACK TIME SETTING R
                                                         I         I         I         I         I         I         I         I
 21  22   45    FALLING AND BUCKING SETTING S
                                                         I         I         I         I         I         I         I         I
 21  27   21    SLACK TIME SETTING U
                                                         I         I         I         I         I         I         I         I
 22  23   39    FALLING AND BUCKING SETTING T
                                                         I         I         I         I         I         I         I         I
 22  28   21    SLACK TIME SETTING S
                                                         I         I         I         I         I         I         I         I

       PAGE  1.0
```



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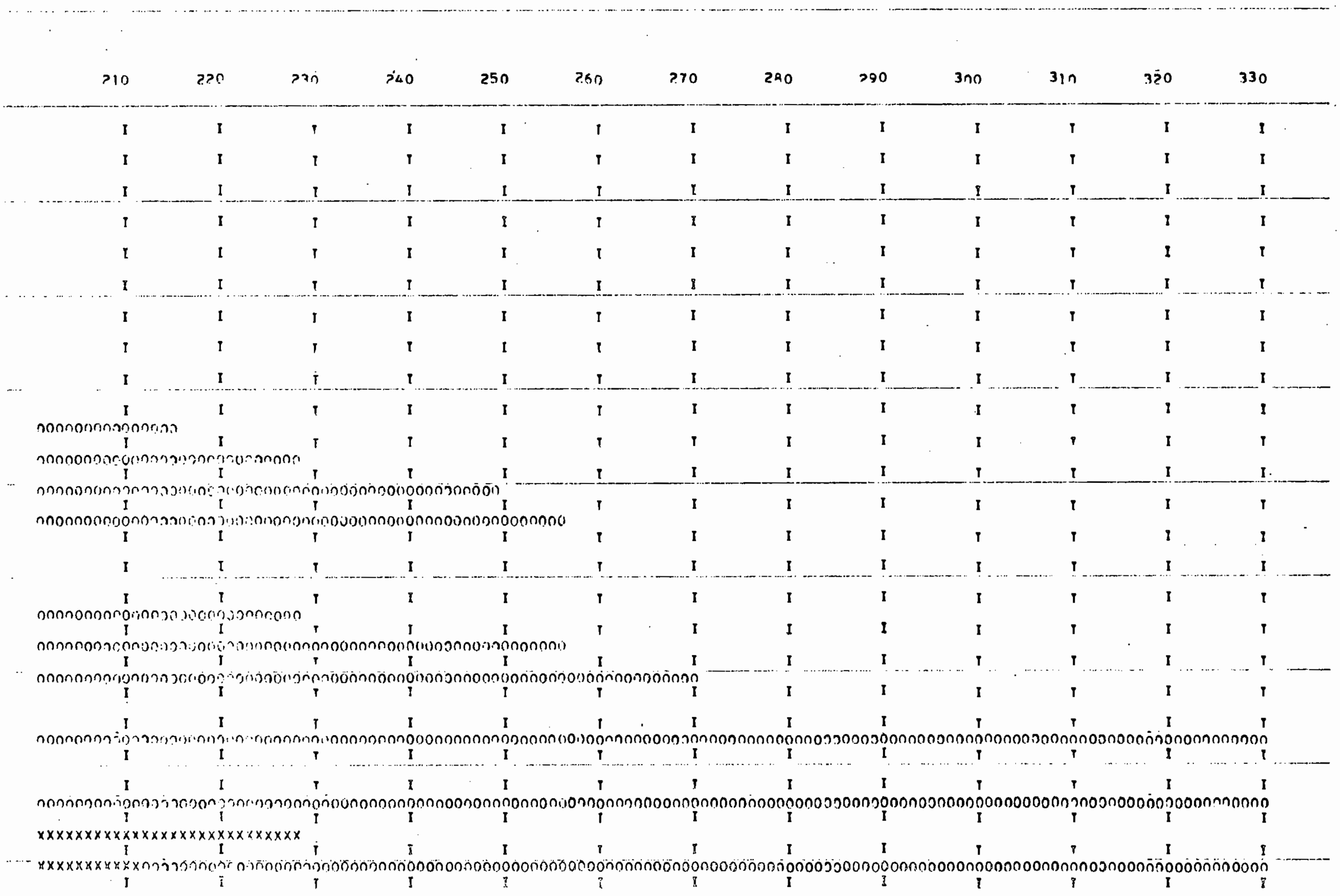
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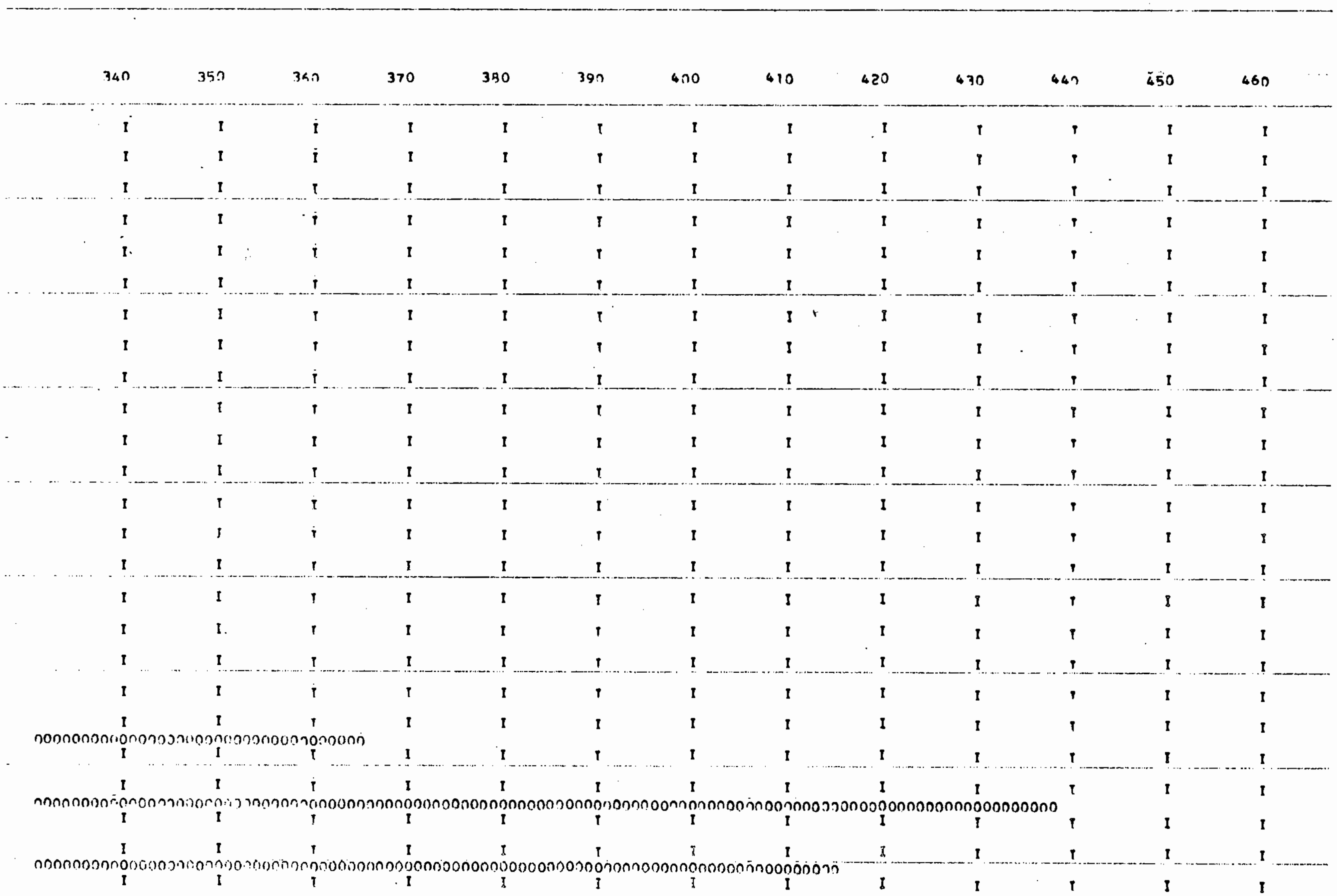
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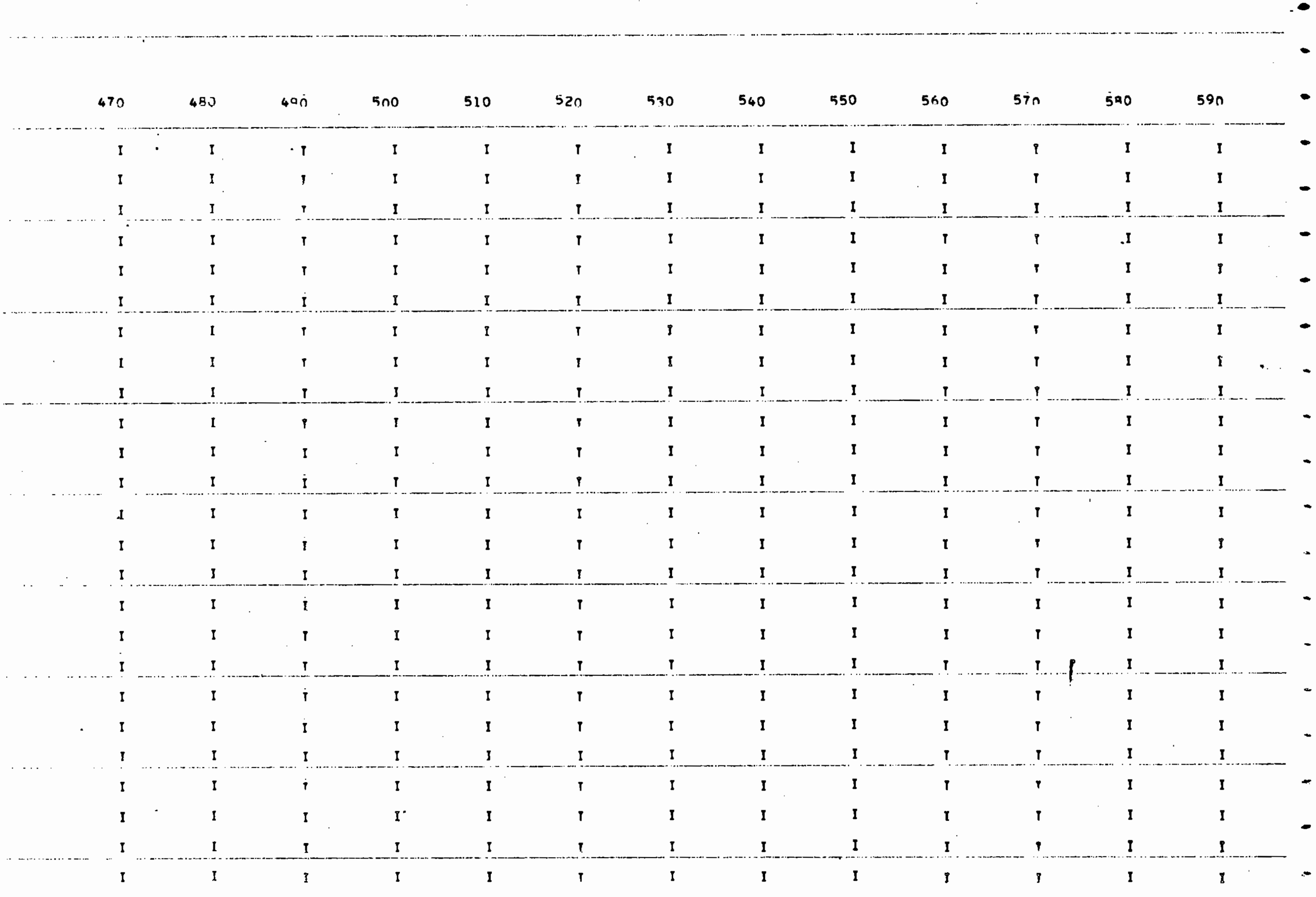

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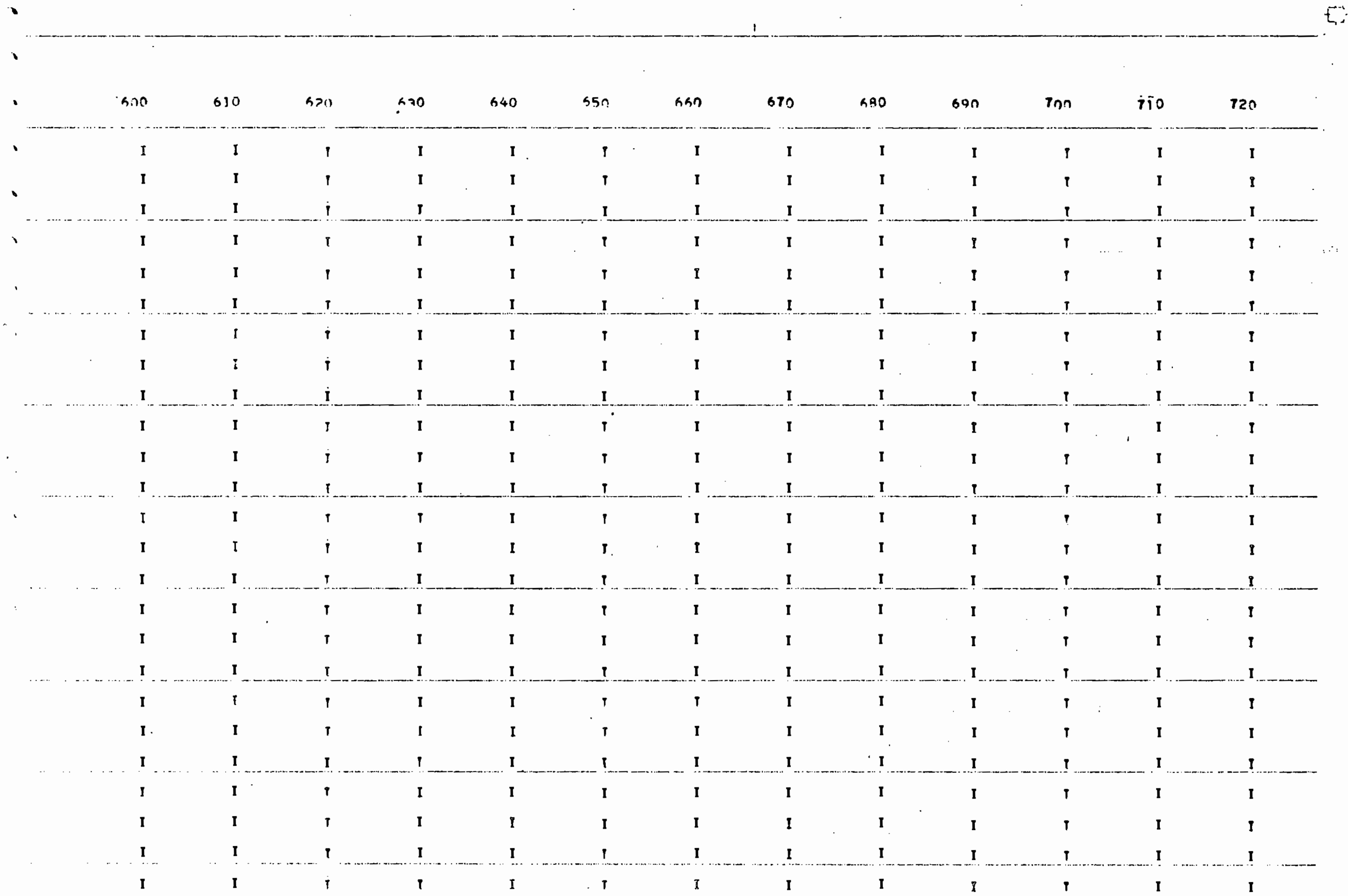
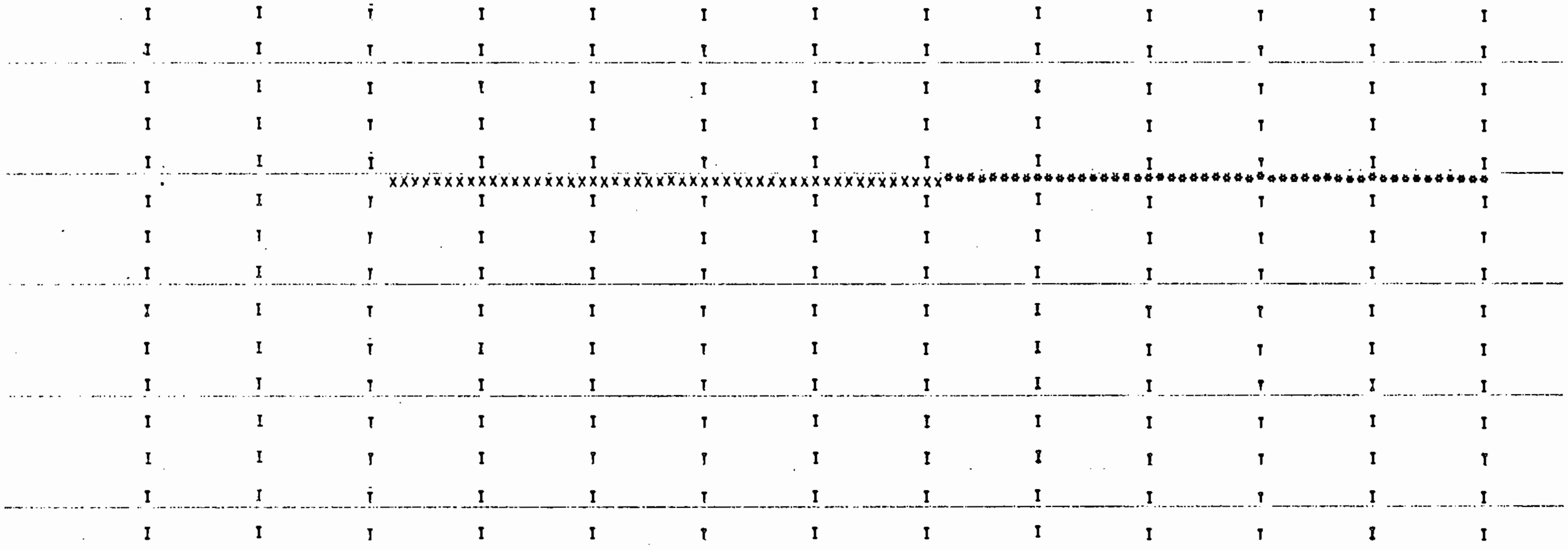


PAGE 1. 1

```
23  24   28    FALLING AND BUCKING SETTING W
                                                        I         I         I         I         I         I         I         I
23  29   21    SLACK TIME SETTING T
                                                        I         I         I         I         I         I         I         I
24  25   14    FALLING AND BUCKING SETTING V
                                                        I         I         I         I         I         I         I         I
24  30   21    SLACK TIME SETTING W
                                                        I         I         I         I         I         I         I         I
25  31   21    SLACK TIME SETTING V
                                                        I         I         I         I         I         I         I         I
26  32   50    MACHINE B YARD SETTING R
                                                        I         I         I         I         I         I         I         I
29  33  157    MACHINE C YARD SETTING T
                                                        I         I         I         I         I         I         I         I
31  34   47    MACHINE A YARD SETTING V2
                                                        I         I         I         I         I         I         I         I
32  36   23    MACHINE B YARD SETTING S
                                                        I         I         I         I         I         I         I         I
34  35  100    MACHINE A YARD SETTING W
                                                        I         I         I         I         I         I         I         I
36  37   60    MACHINE B YARD SETTINGU1
                                                        I         I         I         I         I         I         I         I
36  39  104    MACHINE A YARD SETTING S
                                                        I         I         I         I         I         I         I         I
37  38   33    MACHINE B YARD SETTINGP
                                                        I         I         I         I         I         I         I         I
38  41   33    MACHINE B YARD SETTING U2
                                                        I         I         I         I         I         I         I         I
39  40   63    MACHINE C YARD SETTING V2
                                                        I         I         I         I         I         I         I         I

       PAGE  2. 0
```



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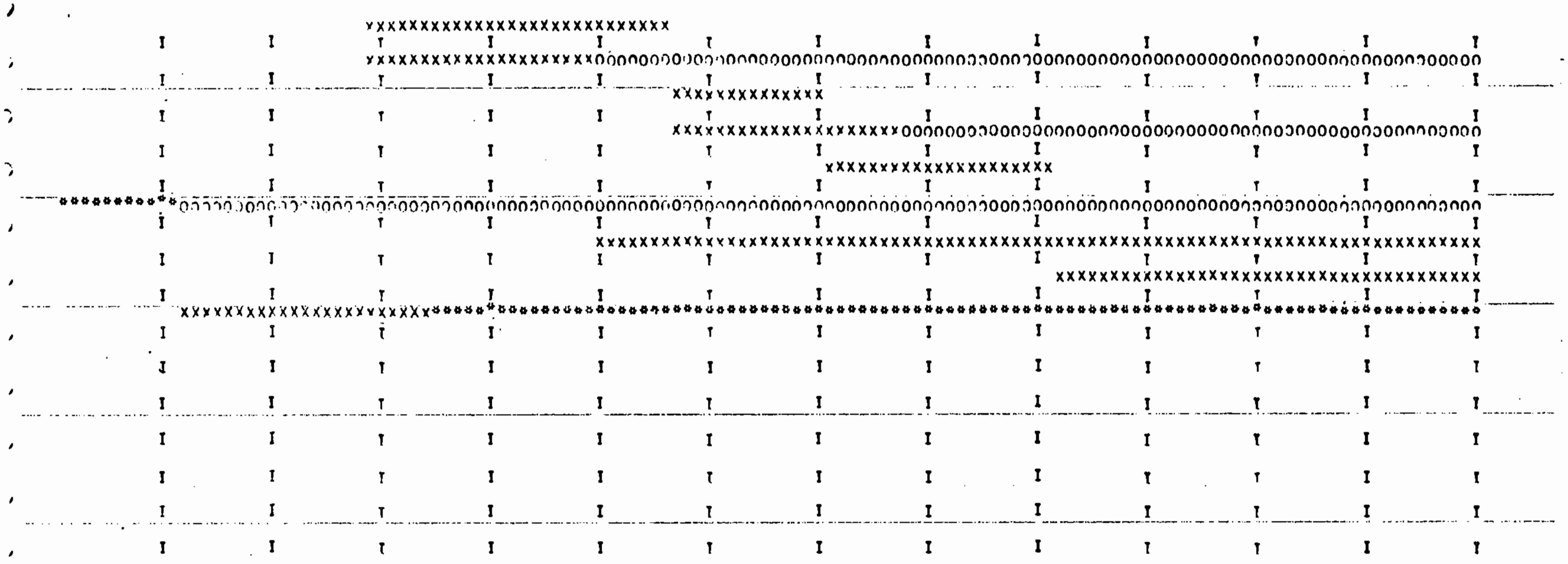

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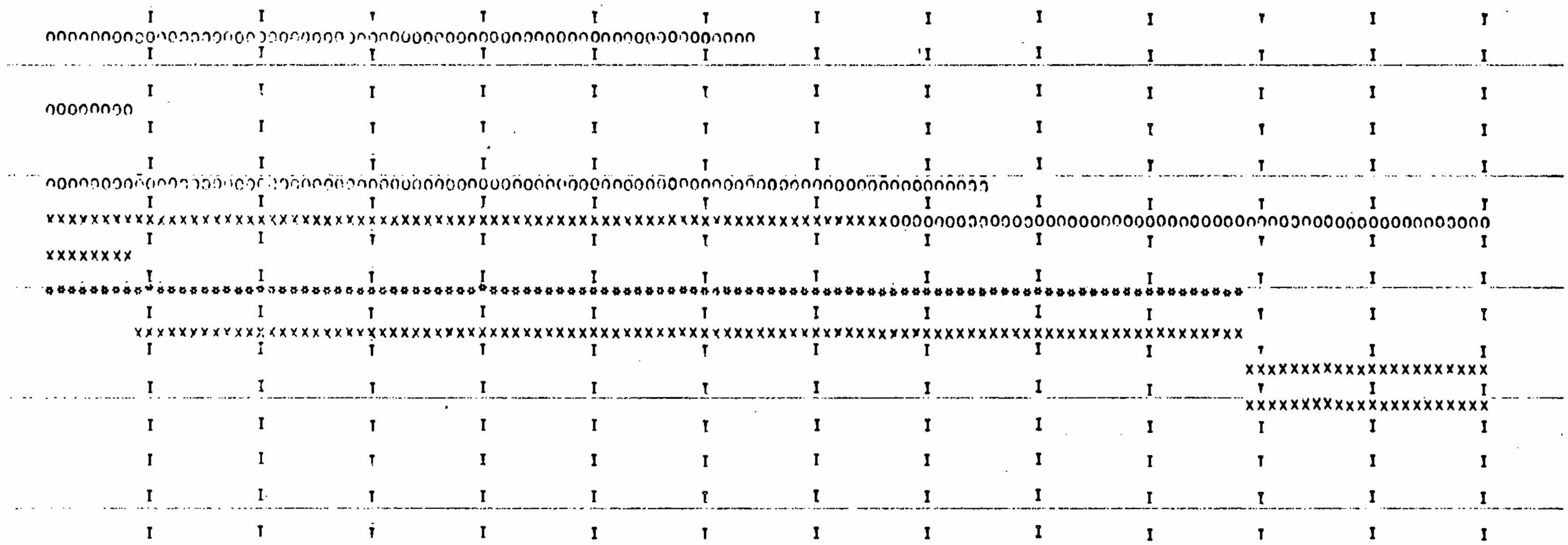

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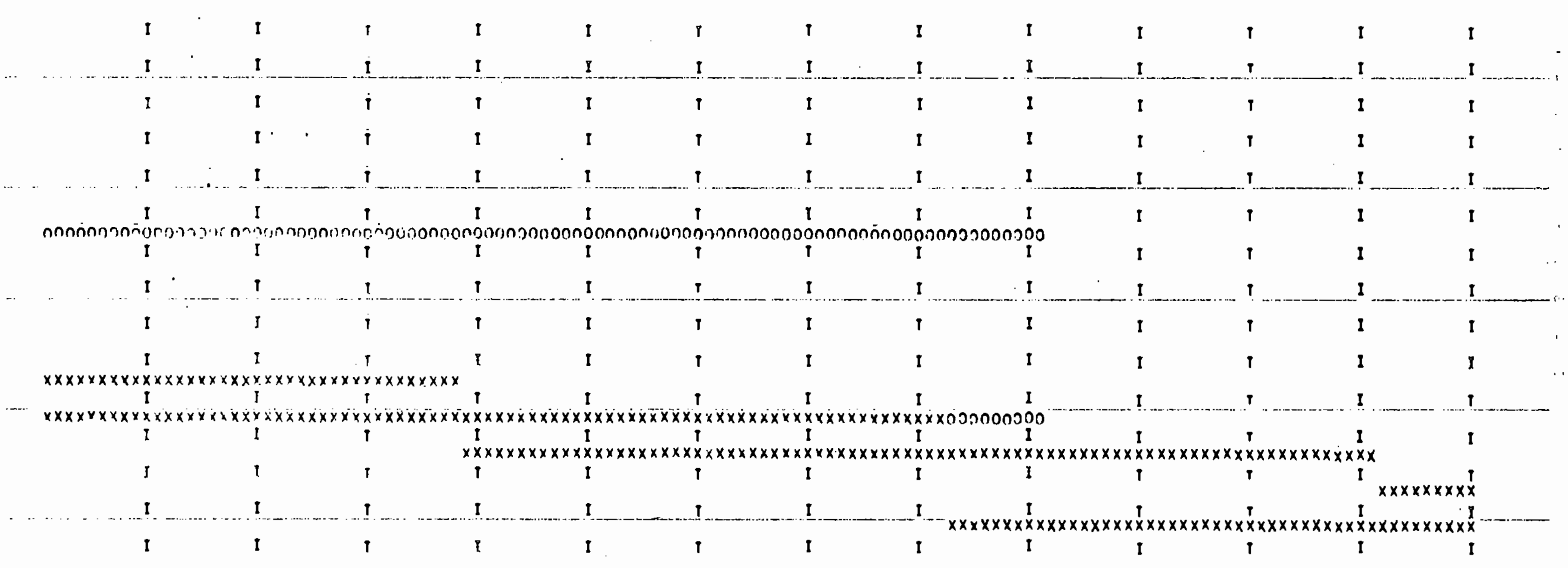
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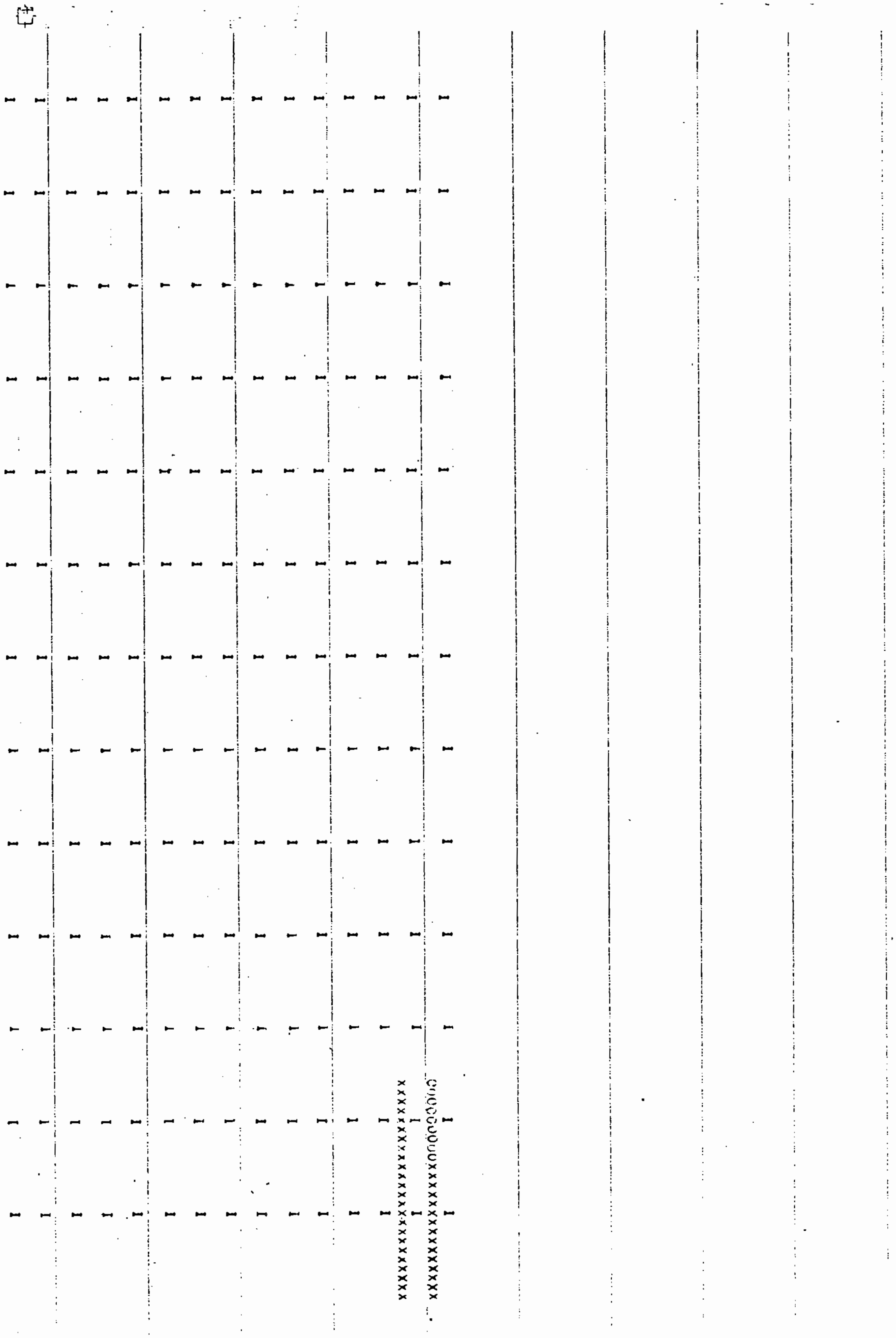

```
PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG

     LOGGING PRODUCTION SCHEDULING

II. SIMULATION ANALYSIS OUTPUT DATA .

   LIST OF CRITICAL PATHS..I.D. NO. (UNIQUE SERIAL NO.)
     CRITICAL JOBS ON PATH...I.J NO. (ESTIMATED JOB TIME GIVEN)

CRITICAL PATH I.D. NO.  1  (196385.136)
   10002 (   5),  20003 (  15),  30004 (  12),  40005 (   8),  50006 (  12),  60007 (   8),  70008 (   6),
   80009 (  12),  90020 (   0), 200021 (  65), 210022 (  45), 220023 (  38), 230024 (  28), 240025 (  14),
  250031 (  21), 310034 (  47), 340035 ( 100), 350036 (   0), 360037 (  60), 370038 (  83), 380041 (  33),
  410042 (   0),

CRITICAL PATH I.D. NO.  2  (223357.944)
   10002 (   5),  20003 (  15),  30004 (  12),  40005 (   8),  50020 (  40), 200021 (  65), 210022 (  45),
  220023 (  38), 230024 (  28), 240025 (  14), 250031 (  21), 310034 (  47), 340035 ( 100), 350036 (   0),
  360037 (  60), 370038 (  83), 380041 (  33), 410042 (   0),

CRITICAL PATH I.D. NO.  3  (214729.765)
   10002 (   5),  20003 (  15),  30004 (  12),  40005 (   8),  50020 (  40), 200021 (  65), 210022 (  45),
  220023 (  38), 230024 (  28), 240025 (  14), 250031 (  21), 310034 (  47), 340035 ( 100), 350036 (   0),
  360039 ( 104), 390040 (  63), 400042 (   0),

CRITICAL PATH I.D. NO.  4  (188116.000)
   10002 (   5),  20003 (  15),  30004 (  12),  40005 (   8),  50006 (  12),  60007 (   8),  70008 (   6),
   80009 (  12),  90020 (   0), 200021 (  65), 210022 (  45), 220023 (  38), 230024 (  28), 240025 (  14),
  250031 (  21), 310034 (  47), 340035 ( 100), 350036 (   0), 360039 ( 104), 390040 (  63), 400042 (   0),
```

```
PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG
        LOGGING PRODUCTION SCHEDULING


ANALYSIS OF CRITICAL PATHS FROM SIMULATION

NUMBER OF CRITICAL PATHS RESULTING =  4
   CRITICAL PATH I.D.NO.   NO. OF ACTIVITIES   NO. TIMES CRITICAL   PROBABILITY   AVERAGE TOTAL TIME
                 1                 22                   95             .475               613.4
                 2                 18                   98             .490               617.6
                 3                 17                    5             .025               618.0
                 4                 21                    2             .010               625.5
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PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG
        LOGGING PRODUCTION SCHEDULING



SUMMARY ANALYSIS OF  10 SETS OF  20 SIMULATIONS

    X-BAR-BAR....MEAN OF SET MEANS FOR PROJECT COMPLETION TIME =   615.7
    STANDARD ERROR OF THE ARITHMETIC MEAN FOR PROJECT COMPLETION TIME =   1.8
    RANGE OF MEANS =    5. MAX. =    618. MIN. =    613
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PERT SIM FOR LOGGING PRODUCTION FORECASTING   BOB CRAIG

         LOGGING PRODUCTION SCHEDULING


ANALYSIS OF PROJECT NETWORK ICH ACTIVITIES

ACTIVITY   PROBABILITY        AVERAGE VALUES FOR ACTIVITY TIMES
 I    J     CRITICAL      DUR      ES      LS      EF      LF    FLOAT

     10002    1.000        5.2       0       0     5.2     5.2       0
     20003    1.000       14.6     5.2     5.2    19.9    19.9       0
     20014        0       34.9     5.2    39.1    40.2    74.0    33.8
     30004    1.000       12.7    19.9    19.9    32.6    32.6       0
     30008        0          0    19.9    69.6    19.9    69.6    49.7
     30014        0          0    19.9    74.0    19.9    74.0    54.1
     40005    1.000        8.4    32.6    32.6    41.0    41.0       0
     40015        0          0    32.6   141.1    32.6   141.1   108.5
     50006     .485       12.0    41.0    43.1    52.9    55.0     2.1
     50022     .515       40.7    41.0    42.5    81.6    83.2     1.5
     60007     .485        8.5    52.9    55.0    61.4    63.5     2.1
     60015        0          0    52.9   141.1    52.9   141.1    88.2
     70008     .485        6.0    61.4    63.5    67.5    69.6     2.1
     70016        0          0    61.4   195.6    61.4   195.6   134.2
     80009     .485       13.6    67.5    69.6    81.0    83.2     2.1
     80022        0          0    67.5   195.6    67.5   195.6   128.1
     90010        0        8.7    81.0   211.1    89.8   219.9   130.1
     90020     .485          0    81.0    83.2    81.0    83.2     2.1
    100011        0       13.3    89.8   219.9   103.1   233.2   130.1
    100017        0          0    89.8   233.2    89.8   233.2   143.4
    110012        0        5.1   103.1   249.2   108.1   254.3   146.1
    110023        0          0   103.1   233.2   103.1   233.2   130.1
    120013        0        7.3   108.1   254.3   115.5   261.6   146.1
    120018        0          0   108.1   261.6   108.1   261.6   153.5
    130024        0          0   115.5   261.6   115.5   261.6   146.1
    140015        0       66.3    40.2    74.8   106.4   141.1    34.7
    140020        0          0    40.2    83.2    40.2    83.2    43.0
    150016        0       54.3   106.4   141.3   160.7   195.6    34.9
    150021        0          0   106.4   148.5   106.4   148.5    42.1
    160017        0       10.3   160.7   222.9   171.0   233.2    62.2
    160022        0          0   160.7   195.6   160.7   195.6    34.9
    170018        0       15.4   171.0   246.2   186.4   261.6    75.2
    170023        0          0   171.0   233.2   171.0   233.2    62.2
    180019        0        8.0   186.4   267.6   194.4   275.6    81.2
    180024        0          0   186.4   261.6   186.4   261.6    75.2
    190025        0          0   194.4   275.6   194.4   275.6    81.2
    200021    1.000       65.3    83.2    83.2   148.5   148.5       0
    200026        0       21.0    83.2   346.6   104.2   367.6   263.5
    210022    1.000       47.1   148.5   148.5   195.6   195.6       0
    210027        0       21.0   148.5   419.5   169.5   440.5   271.0
    220023    1.000       37.6   195.6   195.6   233.2   233.2       0
    220028        0       21.0   195.6   396.6   216.6   417.6   201.0
    230024    1.000       28.4   233.2   233.2   261.6   261.6       0
    230029        0       21.0   233.2   378.9   254.2   399.9   145.7
    240025    1.000       14.0   261.6   261.6   275.6   275.6       0
    240030        0       21.0   261.6   321.7   282.6   342.7    60.1
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260032       0        50.0   104.2   367.6   154.1   417.6   263.5
260037       0           0   104.2   500.6   104.2   500.6   306.4
270036       0           0   169.5   440.5   169.5   440.5   271.0
270038       0           0   169.5   583.3   169.5   583.3   413.9
280032       0           0   216.6   417.6   216.6   417.6   201.0
280036       0           0   216.6   440.5   216.6   440.5   223.9
290033       0       154.1   254.2   399.9   408.3   554.0   145.7
300034       0           0   282.6   342.7   282.6   342.7    60.1
310034   1.000        46.1   296.6   296.6   342.7   342.7       0
310039       0           0   296.6   554.0   296.6   554.0   257.4
320036       0        22.9   216.6   417.6   239.5   440.5   201.0
330039       0           0   408.3   554.0   408.3   554.0   145.7
340035   1.000        97.8   342.7   342.7   440.5   440.5       0
340039       0           0   342.7   554.0   342.7   554.0   211.3
350036   1.000           0   440.5   440.5   440.5   440.5       0
360037    .965        60.0   440.5   440.6   500.5   500.6      .1
360039    .035       102.9   440.5   451.1   543.4   554.0    10.6
370038    .965        82.8   500.5   500.6   583.3   583.3      .1
380041    .965        32.4   583.3   583.3   615.6   615.7      .1
390040    .035        61.7   543.4   554.0   605.1   615.7    10.6
400042    .035           0   605.1   615.7   605.1   615.7    10.6
410042    .965           0   615.6   615.7   615.6   615.7      .1
```