ANALYSIS OF METHODS OF STUDYING OPERATIONAL EFFICIENCY IN FORESTRY

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Dipl. For. Eng., Swiss Federal
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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF FORESTRY

in the Department
of
Forestry

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1967

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Date May 5, 1967

ABSTRACT

Increasing effectiveness of use of the agents of production (efficiency) is needed to compensate for steadily rising costs of labor and equipment. Efficiency can be measured in various ways, depending on the type and scope of an operation. The methods available and the circumstances under which they can, and should, be used are the major concern of this thesis.

Due to some peculiarities of primary forest production such as highly variable work conditions and irregular stand characteristics, many well known techniques of industrial engineering have not been used widely in forestry. Although progress to date has been limited, time study and several other work measurement techniques can be applied successfully.

Time measurements have to be supplemented by costs and other data, to allow for comparison of alternatives. The production methods themselves should be analysed more carefully to find means for technological improvements. The role of the woods worker also deserves more attention because of his heavy and often dangerous work and his outdoor working conditions.

In recent years the various activities of forest management, logging and mill supply have been viewed as part of a system which should

be optimized for overall efficiency. Operations research has greatly increased the possibilities of studying the influence of variables which govern the system, although the systems approach has not yet been applied fully to an existing forest enterprise. Parts of the system or sub-systems may be complex enough to warrant the application of operations research, and its success should encourage increased research in this field.

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ACKNOWLEDGEMENT

Financial assistance for this study was provided in the form of a research assistantship by the National Research Council of Canada, and is gratefully acknowledged.

I would like to thank Dr. J. H. G. Smith for his encouragement and direction, without which the early completion of this thesis would have been impossible. Also, Mr. J. R. Mills and Mr. L. Adamovich contributed helpful ideas and criticism.

The use of logging data supplied by the Logging Research Section of MacMillan, Bloedel Ltd., directed by Mr. C. Rasmussen, was greatly appreciated.

INTRODUCTION

1. Definitions

To make sure that the terms used in this thesis are properly understood, some expressions will be defined to clarify their meaning. Work Study is a term of British origin meaning "the systematic, objective and critical examination of all the factors governing the operational efficiency of any specific activity in order to effect improvement " B. C. Work Study School (B. C. W. S.) Commonly, work study is split into the two interrelated fields of method study and work measurement. Method Study is "the systematic recording, analysis and critical examination of existing and proposed ways of doing work and the development and application of easier and more effective methods" International Labour Office (I. L. O., 1964). It should be noticed that in some American textbooks the expression motion study is used with the same meaning as method study; however in this thesis Motion Study has a more specific meaning, namely, "the analysis of the manual and the eye movements occurring in an operation or work cycle for the purpose of eliminating wasted movements and establishing a better sequence or coordination of movements" American Society of Mechanical Engineers (ASME), Maynard (1963).

Work Measurement is "the application of techniques designed to establish the work content of a specific task by determining the time required for carrying it out at a defined standard performance by a qualified worker" (I. L. O., 1964). These techniques are defined as follows: Time Study is a "technique for determining as accurately as possible from a limited number of observations the time necessary to carry out a given activity" (I. L. O., 1964). Work Sampling is a "statistical sampling technique employed to determine the proportion of delays or other classifications of activity present in a total work cycle" (Maynard, 1963). Group Timing Technique (GTT) is a "work measuring procedure for multiple activities that enables one observer using a stop watch to make a detailed elemental time study on from two to fifteen men and/or machines at the same time" (Maynard, 1963). Multi Moment Technique (MMT) can be defined as a procedure to make a detailed elemental time study of one operator using very short but constant observation intervals. Predetermined Motion Time Systems (PMTS) are "procedures in which (a) all manual motions are analytically subdivided into the basic elements required for their performance and (b) predetermined time values are assigned to the basic elements" (Maynard, 1963). Analytical Estimating is a "technique of estimating elements that it is desirable to measure when the means to do so by other techniques are not available or appropriate" (B.C.W.S.).

Operations Research (OR) has been defined by Kaufmann (1964) as a "scientific approach to decisions". A preferable and more precise definition was given by Lussier (1961) who defined OR as a "group of techniques whose objective is to optimize the combination of production agents that make up an industrial organization." These techniques may also be applied to problems below the managerial level if an operation or a number of operations are more or less independent within a system. In this thesis Systems Analysis is considered a part of OR and is defined as "the study of the behaviour of existing systems to achieve better understanding of the particular entities and relationships underlying that behaviour" (Machol, 1965). To solve the problems defined in system analysis we use one of the following techniques which are defined at the same time: "Linear Programming (LP) is a method of allocating some kind of limited resources to competing demands in the most efficient way" (Buffa, 1963). "Dynamic Programming is a method of solving multi stage programming problems in which the decisions at one stage become the conditions governing the succeeding stage" (Lindsay, 1963). Simulation can be defined as a systematic trial and error procedure for solving complex problems." Critical Path Method (CPM) is a network analysis technique which is based upon the time/cost relationship" (Woodgate, 1964). Decision Theory involves a mathematical or statistical approach to decision making in the face of uncertainty.

The term Operational Efficiency has been used mainly as a summary term for university courses dealing with planning and control of logging operations, cost analysis (engineering economics), work study, work physiology (ergonomics) and psychology, safety and operations research. More generally, operational efficiency can be defined as the effectiveness with which human potential and capital are utilized in a production system.

2. Improvements of Operational Efficiency

Maximization of profits is a generally accepted goal of business. To arrive at this goal, a constant effort has to be made to increase the efficiency and therefore productivity of all operations of an enterprise. However, the opposite does not necessarily hold as it is possible to increase productivity without improving the efficiency. Increased efficiency may be achieved by a) changing methods of operation, b) using different materials and tools, c) training of manpower, d) improving environmental conditions or working climate, f) standardizing methods, g) combining several operations, and h) optimization of a whole system of operations rather than a single operation.

Industrial engineers aid management in increasing the efficiency of an enterprise. Until recently industrial engineering was mainly concerned with improving single operations on a shop or plant level. This will be dealt with in the chapter about work study. It seems likely that in the future more emphasis will be on the management level.

Operations research is expected to become an indispensable tool in management decision making.

The primary forest industry (logging and timber production) as distinct from other industries including sawmilling and pulp and paper production, has scarcely begun to apply industrial engineering techniques.

3. Uniqueness of Forestry

Certain peculiarities of forest operations do create difficulties in the application of work study. Foresters seldom have a standard place of working conditions and this very often results in changes in the working method. Expressed in other words, environmental and stand conditions have an important influence on the work. Short cycle and highly repetitive work seldom occurs and therefore performance rating of laborer is difficult. Also, several activities in the forest necessitate team work which is not as easy to measure as the work of an independent worker.

In Europe, where many work studies have been applied, most forest work is paid for on piece rates which have to be adjusted to working conditions and particularly to stand characteristics. Stand characteristics never varied greatly within a region in America's old growth stands. According to Rapraeger et al. (1931) most piece work was paid on a straight volume basis because incentive payments for work above a so-called standard performance have not been applied in forestry mainly because this performance is difficult to establish. Crosse (1962) mentioned two other points with respect to British Columbia and the forest industry as a whole. If profits are high, as they were for decades on the west coast, there is little incentive to increase efficiency. Secondly, industrial engineering flourishes best in industries with a highly scientific outlook like aerodynamics, electronics and chemistry.

Operations research still is little used in primary forest production even though its application is not basically different from that of other industries. Lack of basic data and trained personnel as well as only recent recognition of the importance of overall optimization are some of the pertinent reasons for this slow utilization.

4. Accounting Basis for Process Evaluation

Very often the present accounting procedure is not suited to cost analysis and feasibility studies. This can be improved with little effort but it is up to the engineer to advise the accountant about the type of data required for his production study. It cannot be stressed enough that accurate physical input and output data are of little value if we are not able to associate the relevant costs with them. Due to rapid mechanization the costs of capital expenditures are becoming increasingly important and are creating serious problems in determining applicable interest rate and length of write-off period. In his article "Pitfalls in logging cost analysis," Lussier (1966) stated that he found a high number of errors in these analyses. They can be summarized under the headings a) including irrelevant costs and omitting relevant costs, b) failing to optimize the controlable variables, c) using a bad economic model or improperly applying a good one, d) failure to consider uncertainty, e) adding interdependent costs, and f) failure to consider different economic lives of alternatives.

5. Future Trends

There is no doubt that operations research will be increasingly applied in forest operations but more and better data are required and these must be obtained by proper work study techniques and suitable accounting procedures. The universities will have to promote more research into the field of operational efficiency, specifically into the possibilities of applying operations research techniques to forestry.

Increased mechanization will necessitate better training of forest labor. In the long run unskilled labor will have few opportunities in forest work. Finally it can be expected that the psychological aspects of forest work will gain in importance as it will become more and more difficult to recruit manpower for forestry in remote areas.

II WORK STUDY

1. Purpose

The objective of work study is to make optimum use of human and material resources to accomplish the work upon which they are applied. Currie (1959) saw three fundamental aspects:

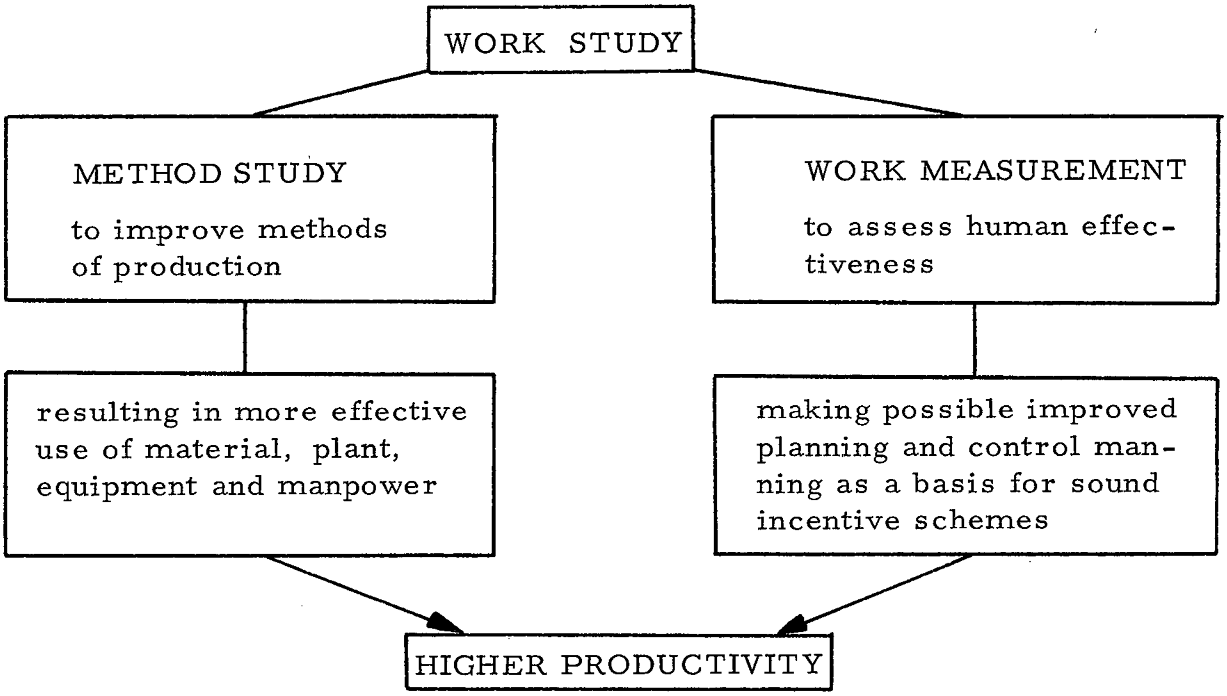
- The most effective use of plant and equipment,
- The most effective use of human effort,
- The evaluation of human work.

Recently work study has been increasingly applied to the design of more effective plants or machinery. In our world of fast technological changes it is very easy to make people believe that every method of production or operation can be improved. But we need an objective procedure to determine the facts about existing operations. Work study will provide us with the means to improve methods of production and achieve higher productive efficiency.

2. Procedure

Work study is basically an integral combination of two techniques, namely method study and work measurement. Method study in which a job is broken down into its procedural elements and critically examined, must be supplemented by quantitative data to given an objective picture of the operation.

Currie (1959) proposed the explanatory chart below:



Quantitative data are not only times or efficiencies obtained from work measurement techniques but also may include analyses of variables such as costs, speeds, distances and weights. Normally a work study project starts with a method study which is then supplemented with the necessary quantitative data from work measurement and other sources. Improved methods and new time standards have to be ascertained by new measurements.

III METHOD STUDY

(Method Analysis)

I. Introduction

Method study originated from the term motion study, a technique which was developed by Frank and Lillian Gilbreth (1953). Originally confined to short, highly repetitive work, method study is applied in virtually every field to-day.

Before considering a method study investigation it is important to make some economic evaluations. Is the proposed study related to an expected improvement? Have technical problems and the human reaction to changes been considered?

2. Types of Method Studies

Mainly economic considerations dictate the scope of a method study. The "Industrial Engineering Handbook" (Maynard, 1964) gives several analytical techniques which have to be employed according to the characteristics of the operation under study. Criteria are:

- The repetitiveness of the activity,
- The hourly labor rate paid for the activity,
- Its labor content;
- Anticipated life of the activity.

The resulting techniques are not basically different and differ mainly in intensity. This author prefers the British system which is simpler but has to be adjusted in its extent to the importance of the study object. The six key words (steps) are: select, record, examine, develop, install and maintain. (Currie, 1959).

Select the work to be studied and its scope. We often may study a relatively small part of an operation because of "Pareto's law"; in any series of elements to be controlled, a selected small fraction, in terms of numbers of elements, always accounts for a large fraction, in terms of effects.

Record all the relevant facts. To simplify the recording and to make the result easily understood, several aids have been developed. These shall be dealt with later.

Examine by analysis and synthesis. Critical examination is one of the most difficult parts in a method study. In addition to the technical knowledge required, some creative thinking is needed. Essentially we try to find alternatives or to eliminate certain parts of a process.

Develop a new method of change the current method. The design should take into account not only the technical factors but also the human factors. For this reason knowledge about basic human movements should be applied to make the work easier.

In the last two stages appropriate data have to be obtained to support the feasibility of the improvement. Then a report will be submitted to management that should contain: 1) recommendations, 2) reasons for recommendations, 3) results expected from recommendations (Currie, 1959). Economic proof of the benefits to be obtained by a new procedure is of utmost importance to management, but possible fringe benefits should also be mentioned. Technical presentations should be made clearer by charts, photographs and diagrams.

Install and Maintain. After the improved method has been accepted, it can be put into production. Some changes may be necessary which could not have been foreseen. After final installation we have to make sure that the new method is actually applied. Then frequent checks for further improvements should be made.

3. Motion Study

Method study originates from motion study, a technique developed by the Gilbreths to analyse and improve highly repetitive work of short duration. Therefore its application is more or less limited to manufacturing industries. In principle, motion study breaks down the work elements into elementary movements and determines if they are necessary or how they could be improved. Direct observation and recording of the motions is very seldom applied. They usually are evaluated from a motion picture film of the operation. The latter technique is known as micromotion study if a timing device is built into the camera.

4. Recording Procedures

A multitude of charts and diagrams have been developed to simplify method studies. Charts like outline process charts, flow process charts, simultaneous motion cycle charts and multiple activity charts facilitate the description of processes and motions and may relate them to time. Diagrams and models are mainly used in plant or operations layout to show the movement of men and materials.

IV WORK MEASUREMENT

1. Introduction

Measuring the time it takes to produce a certain amount of goods is so common that it needs no further explanations. According to B. C. W. S. the objective of work measurement is to establish standards for effecting economic control of manpower by determining the time required for the work which has to be carried out. We can develop standards for a certain job and thereupon set up wage incentive schemes. Standard times are also useful for the weighing of alternative procedures. Work measurement can be used to evaluate the effect of physical variables like distance, size, weight and environmental conditions on production time.

2. Time Study

a) Procedure

Time study is the technique used most commonly to measure work. To ease the timing procedure an operation is broken down into elements. Clear definition of the start and finish of the elements is very important. Hand in hand with timing goes the rating of the work performed. Rating depends on the judgment of the observer, the "normal" being taken as 100 per cent. Normal pace can be defined as "the rate of working which the operator could sustain over long periods of time without resulting in a build-up of cumulative fatigue" (B.C.W.S.) The effective time multiplied by the rating as a fraction results in the "normal time". To obtain a standard time, this normal time is supplemented by certain allowances which will be discussed later.

b) Variation in techniques

The differences are only of degree and not of principle. In a continuous time study the operation either may be broken down into elements of several seconds duration or studied by time for a complete cycle. The gross data time study technique is relatively new. The period of observation includes many cycles and is most commonly a day. Single elements or cycles are not timed but the number of cycles is recorded. Such studies can only be performed if the environmental or operating conditions are fairly constant within the chosen period. Costs for gross data studies are considerably lower than for the ordinary technique. Alternatively, the study can be spread out over a long period of time at the same cost. Use of daily production records differs from the latter technique insofar as they simply involve the total production per day; there may be no reference as to effective working time, number of workcycles or the influence of physical factors. The same limitations may hold for monthly and yearly production records which are the compiled data from the daily reports.

c) Application of time study

Originally time study was applied to short, highly repetitive operations. Technically there are no limitations to this technique but there are economic limits. Non-repetitive work very seldom justifies a time study.

In the manufacturing industry time studies are generally applied to elements of a duration between 8 and 50 centiminutes. (cm). Shorter elements may be measured separately from the cycle but more likely a motion picture camera would be used.

Gross data time study is not necessarily less accurate than the continuous time study method. If the elements of a cycle are not truly independent we do not make a mistake as easily as it might occur in an analysis of the elemental times.

d) Processing of results

We do not necessarily need a computer for processing the results of a time study. If the working method and conditions are constant (standardized), the normal time and the standard time for the elements of an activity can be easily computed by hand or with help of a desk calculator. However, if it is desired to calculate the accuracy of the result or the relationship between variables and time, only an electronic computer can handle a large amount of data in reasonable time. Generally the influence of various variables on time is expressed as a regression equation with time as the dependent variable (Y axis). Assuming that the time study is a sample from a normal distribution we can determine the standard error of the mean ($s_{\bar{x}}$).

$$s_{\bar{x}} = \frac{s}{\sqrt{N}}$$

s = standard deviation $= \sqrt{\frac{(x_i - \bar{x})^2}{N-1}}$

$\bar{x}$ = mean

x_i = single measurement

N = number of observations

Generally a probability of 0.95, which equals two standard deviations, is applied to determine the accuracy;

$$\text{accuracy in \%} = \frac{2 \; s_{\bar{x}}}{\bar{x}} \; 100 .$$

Determination of sample size; taking the common 0.95 probability we can set equal $a \; \bar{x} = 2 \; s_{\bar{x}}$ a = required accuracy as decimal

or $a \; \bar{x} = 2 \frac{s}{\sqrt{N}}$

and $N = \left(\frac{2 \; s}{a \; \bar{x}} \right)^2$

Unfortunately the standard deviation is very seldom known. It has to be estimated from a preliminary study or during the time study.

3. Work Sampling (Activity sampling, Ratio delay)

Originally the technique was applied to measure delay time but soon it was found that it could be applied much more widely to estimate element times of most activities. In many cases the work sampling procedure is cheaper than the common time study approach. This, however, depends on the objectives of the study.

a) Statistical Theory of Sampling

With a sample we can estimate the population proportion of a specific activity. Because at a certain instant an activity occurs, or does not occur, a random draw leads to a binomial distribution. If the sample size is fairly large the binomial distribution can be substituted by the normal distribution. Thus we assume that one standard deviation of the population proportion is equal to 0.68 probability, two standard deviations = 0.95 probability and three standard deviations = 0.997 probability. (Mayer, 1962).

The binomial distribution holds:

$$\mu = p^1$$

$$\sigma_p = \sqrt{\frac{p'(1-p')}{N}}$$

μ = average of population

p^1 = population proportion

σ_p = standard error of the proportion

N = sample size

confidence limit for probability 68% : $p^1 \pm 1\sigma_p$

confidence limit for probability 95% : $p^1 \pm 2\sigma_p$

If we require 5% relative accuracy (A) at the 95% confidence level we can set equal $0.05\ p^1 = 2\ \sigma_p = 2\sqrt{\frac{p'(1-p')}{N}}$

or $A\ p^1 = 2\sqrt{\frac{p'(1-p')}{N}}$

The required number of observations (N) is:

$$N = \left(\frac{2}{A\ p^1}\right)^2 \left(p'(1-p')\right) \quad \text{or} \quad N = \left(\frac{2}{A}\right)^2 \frac{(1-p')}{p'}$$

The absolute accuracy (a) equals: $a = A\ p^{1}$

Examples of required number of observations for given accuracy:

Confidence level 95%	Population proportion	Accuracy relative	Accuracy absolute	Number of observations
	p^{1}	A	a	N
	0.5	0.05	0.025	1600
	0.1	0.05	0.005	14400
	0.1	0.25	0.025	576

b) Techniques of work sampling

The steps in making a work sampling study are as follows:

1. Define the objective of the study
2. Determine the desired accuracy of the final result.
3. Estimate or determine with a preliminary study the percentage of occurrence of the activity to be measured.
4. Prepare the study, using random numbers.
5. Make the observations and prepare the data for processing.
6. Analyse the data and check for accuracy.
7. Draw conclusions and make recommendations.

c) Application of work sampling

If we do not require a very detailed study, work sampling is generally cheaper than a continuous time study. This holds especially where we are only interested in the proportion and cause of delay time.

Work sampling can be easily interrupted and spread out over a long time period. The accuracy can be predetermined. Work sampling does not disturb the operator or make him change his normal pace. The observer does not have to be trained for a long time.

Work sampling is especially suited to:

- Team work because a single analyst can observe several operators.
- Heterogenous or non-repetitive work as in warehouses, repair shops and offices.
- Production control.

Some major disadvantages of work sampling are:

- If activity or delay to be measured is only a small fraction of total time, the number of observations for high accuracy becomes very large.
- Sometimes it is difficult to identify delay time.
- If work conditions are continuously changing work sampling may be inadequate.

4. Other Techniques

a) Group-timing technique (GTT)

As opposed to work sampling the observations are made at predetermined fixed intervals. For each man and/or machine the job is broken down into elements which are tallied at the time of observation.

The time interval depends on the number of men to be observed and varies from one half to three minutes. GTT should be used primarily as an indication of time expenditure for a certain activity because no statistical error calculation is carried out.

b) Multi-moment technique

A single operator is observed at constant but short time intervals, for example one tenth of a minute. Due to a relative high percentage of observation time such as 10%, the statistical error can be kept within small limits depending on average time of activity and coefficient of variation (Häberle, 1961). The procedure allows for a detailed analysis which we generally do not require in forestry.

c) Predetermined motion-time systems (PMTS)

By the PMTS approach standard times can be determined without making a time study. If the motion pattern of an operation is known in advance, the time required to perform a job can be estimated by adding the respective predetermined motion times. This may be useful in comparing alternatives. Today there exist many systems such as methods-time measurement (MTM), work-factor and basic motion time study (Maynard, 1963), differing only in time unit, number and kind of basic motions. For example, MTM consists of tables of eight basic hand and arm motions and thirteen body, leg and eye motions which are further refined according to variables such as distance and angle. The time unit is one TMU or 0.00001 hour. MTM was developed originally from an analysis of motion-picture films. In American industry PMTS are used extensively in setting standard times and are replacing to a great extent conventional time study.

d) Physiological work measurement

Time standards can be established with physiological methods but they are mainly used to evaluate the energy consumption of a certain job. The two most commonly applied methods are the measurement of oxygen consumption and heart beat, the latter being simpler and less disturbing for the person under study. Consumption of oxygen and pulse rate are linearly correlated to physical work performed which includes also the recovery period after the work has been finished. One serious disadvantage inherent in these methods is the great individual difference of people to withstand physical stress. Because energy expenditure is proportional to body weight, the generally assumed maximum value of five calories per minute or 2400 calories per working day for a physically fit worker has to be used carefully.

Physiological work measurement can be applied to answer the following two questions: how many, and how long, rest periods are needed during performance of heavy work? Can one person perform the task or does it lead to undue fatigue? We may also determine the optimum speed or weight of a handling job and set a standard thereupon. Such comparisons have to be carried out with the same person to avoid errors due to individual variation.

e) Analytical Estimating

For non-repetitive work such as maintenance, warehouse work and some construction jobs, we may not be able to get enough results from time study or predetermined motion-time standards, therefore, we have to apply analytical estimating. The only difference between ordinary estimating and analytical estimating is that we normally make an estimate of a job as a whole and not of its elements. We can increase the accuracy by measuring some job parts and estimating the remaining elements.

f) Job Evaluation

Job evaluation is not a work measurement technique in the common meaning of the word because it measures values rather than time. Since there is no precise method of measurement, it is more a judgment or rating system. One tries to determine the value of a job in relation to other jobs. The purpose is to establish a basis of sound wage administration. Many different kinds of job evaluation systems are in existence.

1	Non-quantitative:	a) Rating system
		b) Grade description system
2	Quantitative:	a) Point system
		b) Factor comparison system

The general principles of job evaluation are widely accepted. Difficulties do not arise from jobs on subordinate positions but with jobs having approximately the same level. A quantitative analysis should be favored because it allows to a certain extent for comparison with other firms.

5. Development and Testing of Work Standards

The ultimate aim of most work measurement studies is to establish standard times. However, such a standard can only be applied to a defined method and prescribed working place. This includes the case where we have a variation in production time due to size or quality of the product. There are two principle ways to arrive at time standards. First the work involved in a job is measured by time study, by work sampling or by a motion picture camera with a time measuring device. The resultant standard times are applicable to the particular job but may be used for the same job at another place under similar conditions. Secondly, the motions for a certain job are known or the job content corresponds to a standard method whose standard times are available. In these cases we arrive at a standard by adding up all predetermined standard times.

Normal time has been defined earlier. It will be arrived at by multiplying the actual element time with the rating factor. To arrive at the standard time, we have to add certain allowances to the normal time. They can be classified broadly as:

- Process allowances
- Rest and personal allowances
- Special allowances
- Policy allowances

The actual performance of a particular job cannot be predicted but the frequency distribution of a group of workers can be found. Standard time corresponds to 100% performance but it is unlikely that without an incentive system the average laborer will work at this performance level. Performance changes if we introduce a wage incentive scheme. The average incentive performance has been found to be 125% to 130% of normal performance. (Barnes, 1963).

Standard times are widely used in industry, especially in repetitive work. Standards can be applied in comparing various alternative methods. The efficiency of laborer can be compared and the production can be controlled by standards. Costing and accounting use standard times to calculate the direct labor costs. Piece work and incentive plans are based on standard data which is probably their most important application.

V EXAMPLES OF WORK MEASUREMENT APPLICATION TO FORESTRY

The first two examples show the application of time study to certain elements of a simple operation and to continuous timing of an entire operation. In a third example time study results are compared with results from work sampling, group-timing technique and gross data analyses. A summary only of the original studies is given.

1. Time Study of Tree Diameter Measuring Devices

The objective of the study was to determine a relationship between precision (repeatability), accuracy (approach to "true" value) and time required to use various tree measuring devices in order to find the least expensive one for a desired accuracy. The performance of several individuals shall also be investigated on a plantation between Lower Mall and Fraser River parking lot on the U.B. C. campus. The diameters of five trees, four Douglas firs and one cedar, were measured at heights of 4. 5, 17, 33, 49 and 65 feet above ground, using different instruments and repeating measurements with different teams. Measurements were carried out in January and February 1967.

Instruments tested for dbh measurement included a metal caliper, an Industrial Forestry Service (I.F. S.) caliper (Kondor, 1964) and a diameter tape. All bole diameters were measured with a Penta Prism (Altman, 1962), a wedge prism (Dilworth and Bell, 1963), a Barr and Stroud dendrometer (Mesavage, 1964), a Bitterlich relascope (Bitterlich, 1958) and a wide angle Bitterlich relascope (Bitterlich, 1962). Control measurements were carried out by climbing the trees and measuring them with a metal caliper to one tenth of an inch. The control value for dbh measurements was obtained from a special set of measurements with the metal caliper subsequent to the time study.

A stop watch was used and times were recorded to the nearest second. No performance rating was carried out. The element times were as follows:

For the two calipers and the diameter tape: from stop walking (approximately one to two feet from tree) to walk away from tree.

For the other instruments: a) layout of tape, if required, b) take position and first measurement, c) consecutive measurement without moving, d) removing of tape, if necessary.

Moving time between trees was not recorded.

In order to evaluate the results, times were averaged. Accuracy was calculated as the difference between the estimate mean and the control value. This can also be called bias of the measurements. Relative precision, relative because it depends on the accuracy, was calculated according to formula:

$$\text{Std. Dev.} = \sqrt{\frac{\sum (\bar{c} - x_i)^2}{n - 1}}$$

$\bar{c}$ = control value

x_i = individual observation

n = no. of observations

For a limited number of single diameters the absolute precision, independent of accuracy, was calculated replacing the control value $\bar{c}$ with the estimated mean $\bar{x}$ in the above formula. Some of the results are shown in graphical form. (Figures 1, 2, 3 and 4).

If it can be assumed that the instrument is used for some hundred hours a year, the capital costs are neglectable, for all instruments but the Barr and Stroud dendrometer. The time for moving from one tree to another is assumed constant for all instruments, thus the costs vary directly with the measuring time. For dbh measurements the metal caliper is best suited because it has the best accuracy and requires the least time. (Figure 1.). However, the I.F.S. caliper lags only a little behind. The diameter tape yields the highest absolute precision but it is slightly biased and requires some more time. For measuring different diameters, the Penta Prism required by far the lowest time and gave the best overall accuracy. (Figure 2). On the other hand its precision is low and the individual bias is remarkable. Highest precision and lowest individual bias were obtained by using the Barr and Stroud dendrometer (Figure 3). This however was only after some obviously wrong results had been removed. The source of these errors is not yet exactly known and deserves some studies. The time requirement of the Barr and Stroud is almost three times that for the Penta Prism. Both relascopes require about the same times as the dendrometer but are less accurate and precise. It seems that accuracy of the relascope is correlated with measuring time rather than to precision. The prism is not suited for diameters other than at lower heights. The time for higher measurements increases rapidly whereas accuracy decreases. If high accuracy in a single measurement is required, use of the Barr and Stroud dendrometer is recommended. For lower accuracy requirements one should use the Penta Prism, or make two measurements of the same diameter which still requires less time than the dendrometer, to increase the accuracy of the Penta Prism (Figure 4.).

2. High Lead Yarding Study - U.B.C. Research Forest

The objective was to determine the influence of yarding distance and turn volume on element times and yarding cycle time.

A continuous stop watch time study was made on a whole setting during the summer of 1965. The yarding cycle was broken down into the elements: choke, yard, chase and haulback. Excluded from the

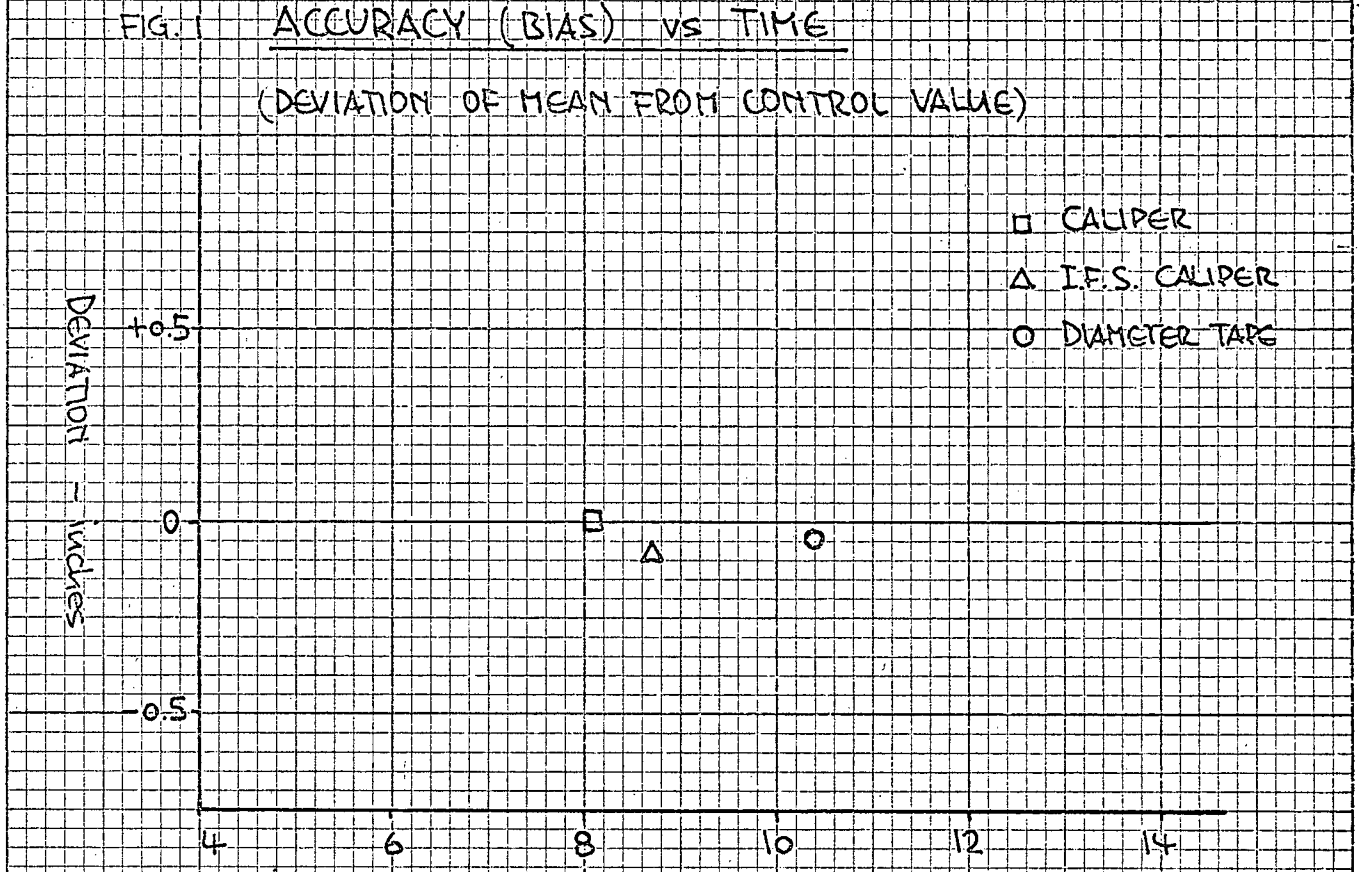


FIG. 1 ACCURACY (BIAS) vs TIME
(DEVIATION OF MEAN FROM CONTROL VALUE)
CALIPER
I.F.S. CALIPER
DIAMETER TAPE
DEVIATION - inches
+0.5
0
-0.5
4
6
8
10
12
14

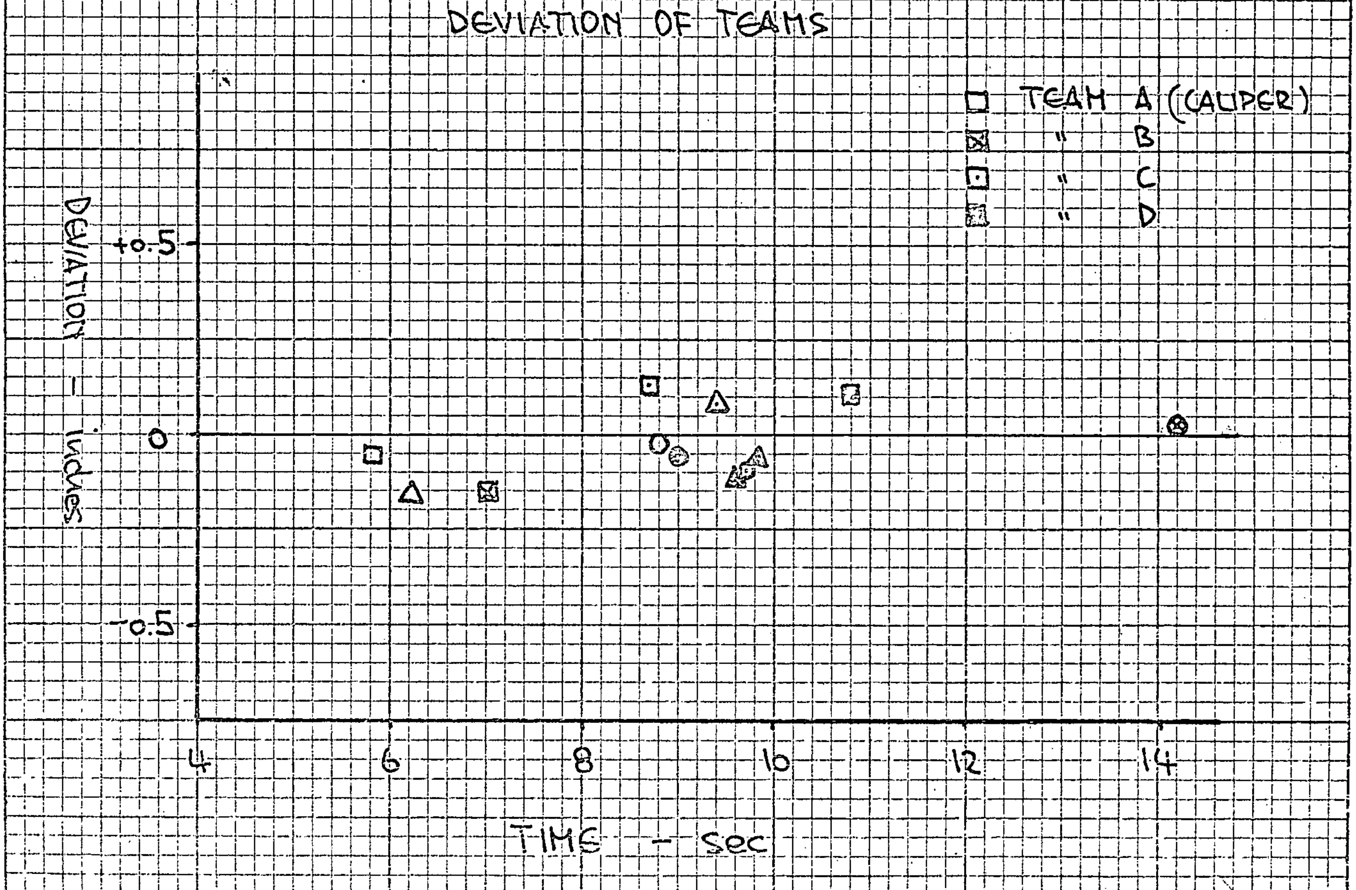

DEVIATION OF TEAMS
TEAM A (CALIPER)
" B
" C
" D
DEVIATION - inches
+0.5
0
-0.5
4
6
8
10
12
14
TIME - sec

FIG. 2 ACCURACY (BIAS) vs TIME

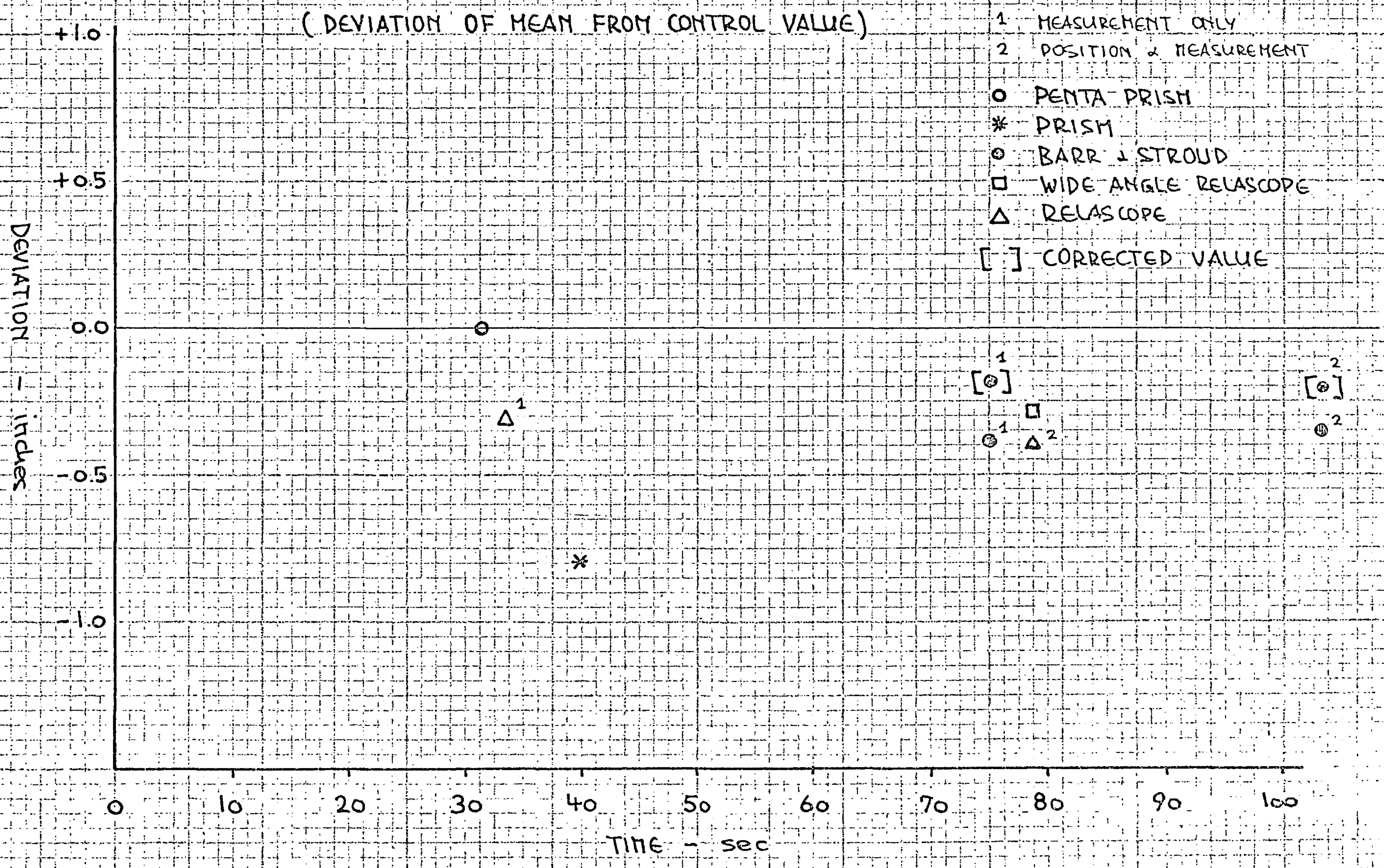


FIG. 3 ACCURACY OF SINGLE MEASUREMENTS vs TIME

(AVERAGE DEVIATION OF SINGLE MEASUREMENT FROM CONTROL VALUE)

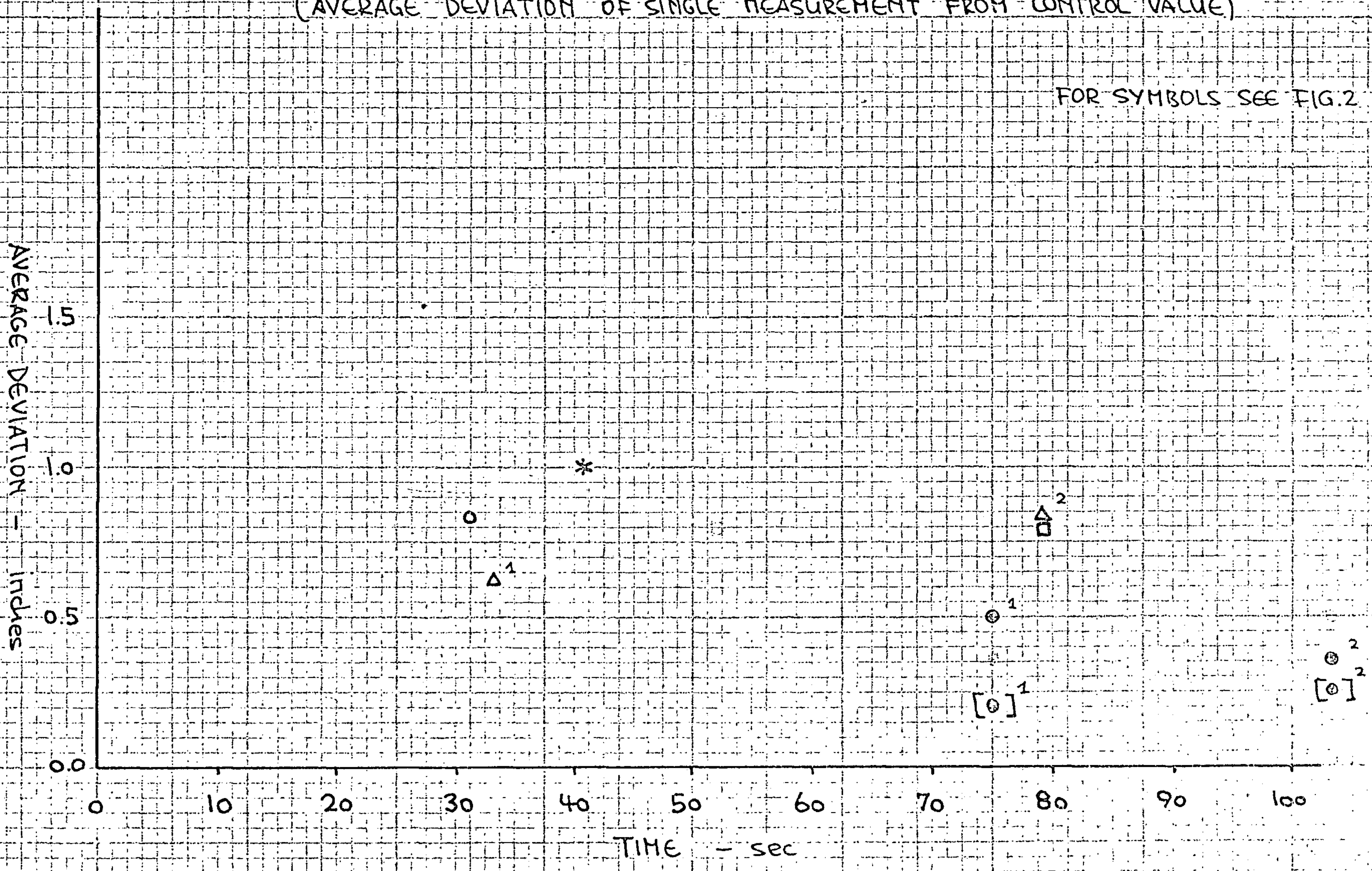
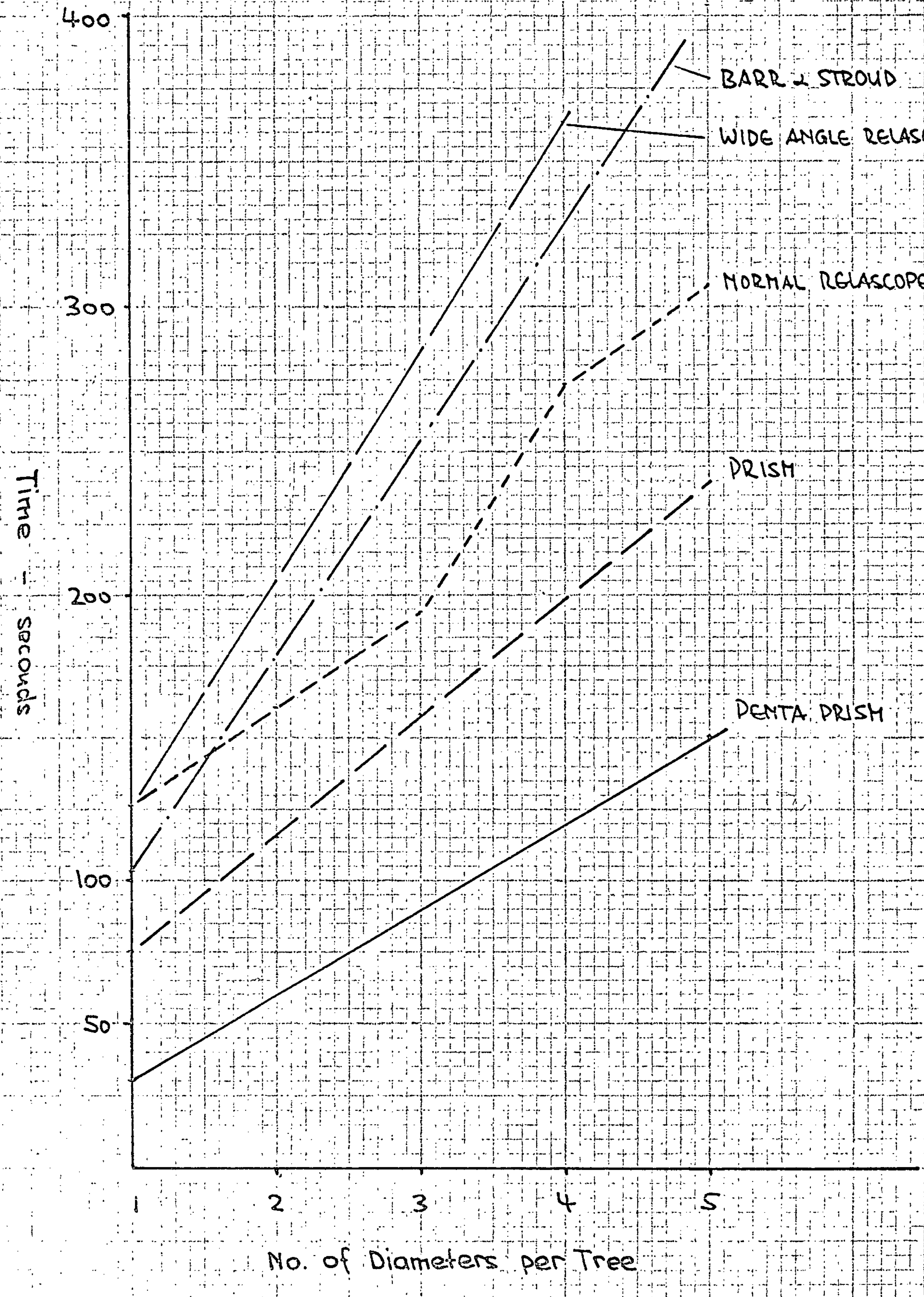


FIG. 4 TIME vs No. OF DIAMETERS MEASURED PER TREE



cycle were yarding road changes and other delays not related to the yarding cycle. 1) the variance of element times at distances 100, 200, 300 to 800 feet was calculated to check for homogeneity of variance. 2) two-variable linear regressions of all times, except choking, on yarding distance and turn volume were calculated. 3) the less important independent variable was omitted and a simple linear regression analysis of the remaining variable was carried out.

The variance of all element times and yarding cycle time at yarding distances 100 to 700 feet was homogeneous. Due to a small number of observation (n=6) and a resulting large variation, the data at yarding distance 800 feet have been excluded from the regression analysis.

The contribution of turn volume in the two-variable regression was statistically significant at the 95% level for choke, yard and cycle times, however the practical importance was very small. Turn volume accounted for a maximum of 1% of the total variation. The important independent variable was yarding distance which yielded a coefficient of determination (r2) of 0.31 for the yarding cycle time. The variation accounted for is relatively small but is similar to that found by McIntosh (1963) and Rasmussen (1965).

There are two possible explanations, first, the inherent variation of the high-lead yarding operation is very large and/or second, some of the important variables have not been identified. It seems that the crew performance and the micro-topography are two of these variables.

Regression equations and confidence intervals for yarding time and yarding cycle time are given in two graphs (Figures 5 and 6). It should be mentioned that the regression lines in Figures 6 and 7 do not represent the same yarding cycle time. In Figure 6 cycle time does not include any delays other than hang-ups.

3. Comparison of Four Different Work Measurement Techniques - High-lead Yarding Study II, Kelsey Bay, B.C.

The objective was to determine the feasibility of various work measurement techniques for the evaluation of a high-lead yarding operation.

A work sampling study, a group-timing study and a gross data analysis were superimposed on the original record sheets of a continuous time study. The results obtained by these different techniques were compared with the original time study results.

The original time study was a continuous time study of a high-lead yarding operation carried out in 1965 at the Kelsey Bay Division of MacMillan Bloedel. The main objective was to study the influence of yarding distance, involving two settings with long yarding roads, on yarding production and costs. Among other objectives the distribution of element times and effective (active) working times of the crew

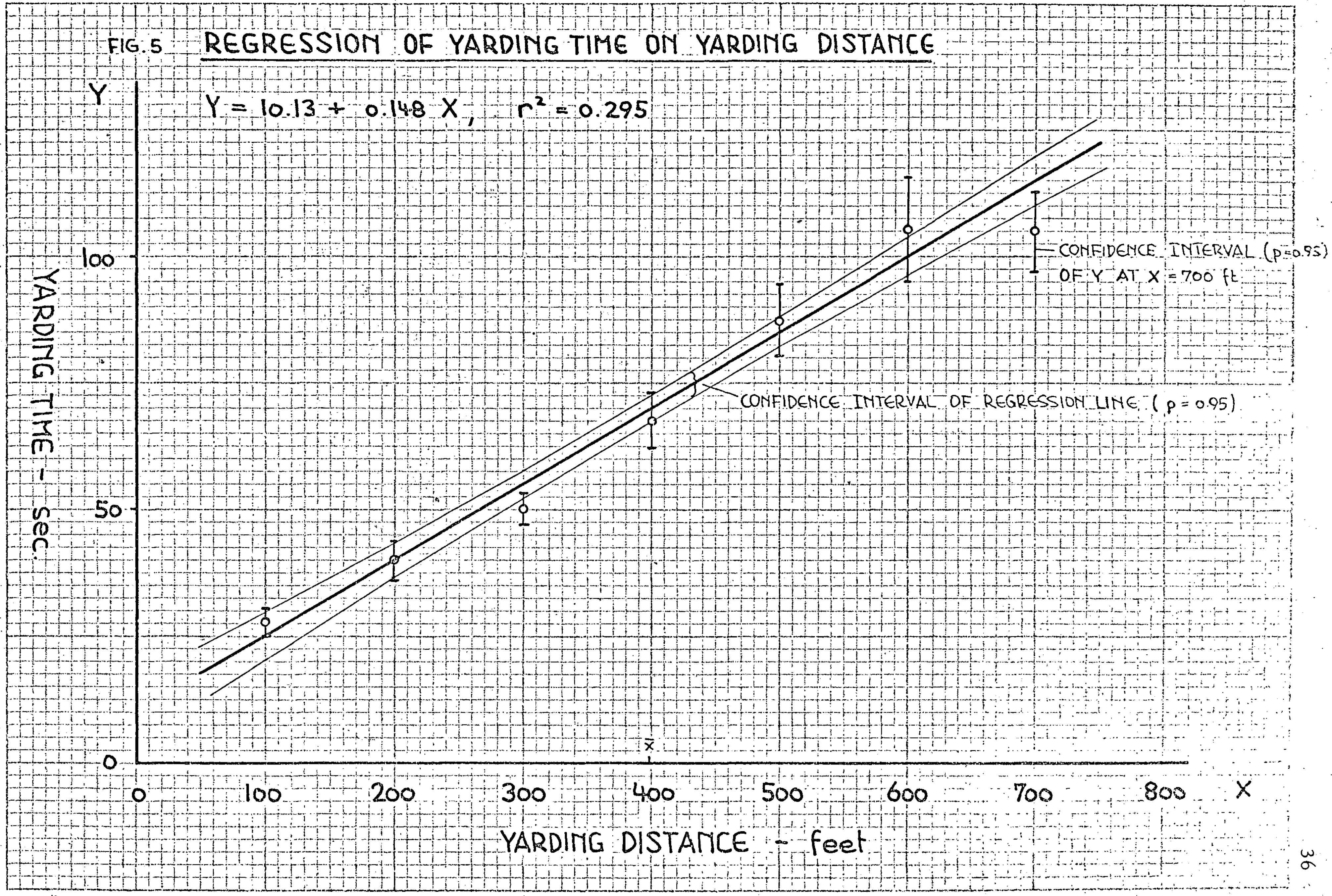
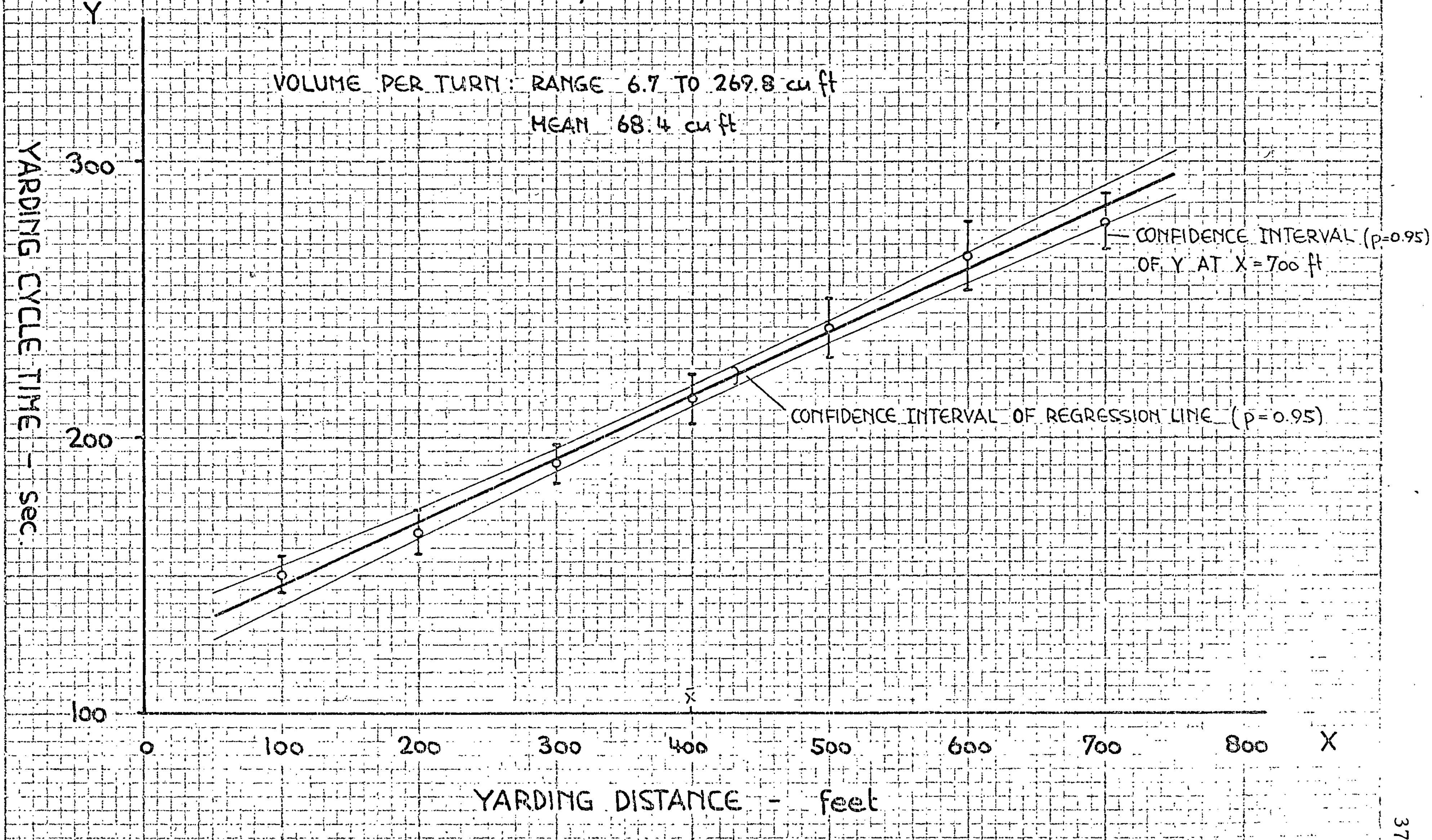


FIG. 5
REGRESSION OF YARDING TIME ON YARDING DISTANCE
Y = 10.13 + 0.148 X , r² = 0.295
Y
100
50
0
YARDING TIME - sec.
CONFIDENCE INTERVAL (p=0.95)
OF Y AT X = 700 ft
CONFIDENCE INTERVAL OF REGRESSION LINE (p = 0.95)
x̄
0
100
200
300
400
500
600
700
800
X
YARDING DISTANCE - feet

FIG. 6 REGRESSION OF YARDING CYCLE TIME ON YARDING DISTANCE

$Y = 123.77 + 0.23\,X, \quad r^2 = 0.31$



members was also investigated. The analysis of the data was done during summer 1966 by this author under the guidance of Carl Rasmussen, head of the Logging Research Section, at Kelsey Bay. Some results of the study are shown in Figures 7, 8 and 9.

The work sampling approach (see Table I) used seven days out of the original twelve day study which were selected at random for a work sampling study. Ninety random times, falling into the official working period from 8:00 a.m. to 12:00 a.m. and 0:30 p.m. to 4:30 p.m. were obtained from a random number table. Due to frequent element times up to four minutes these ninety observations must be considered at the upper limit of permissible observations to maintain their independence. Because the original records state the element times of the operation only, and not the single operators involved in them, work sampling had to be done on the same basis. It must be admitted that the whole procedure of superimposing the observation times may include some errors as it was not always possible to find out exactly between which elements the indicated delay occurred.

The results are summarized in Table I. It can be seen that the distribution of element times could be found accurately by work sampling requiring only about one quarter of the time spent on the continuous study. (The time study required two observers for this type of operation.). On the other hand we could not establish any relationship between yarding cycle time and yarding distance or other variables because work sampling did not furnish the necessary data. The separation of

TABLE 1. WORK SAMPLING AS COMPARED TO TIME STUDY

ACTIVITY	TIME STUDY: Time per Turn sec	TIME STUDY: % of total time	WORK SAMPLING[1]: % of total time	WORK SAMPLING[1]: 95% Confidence level, absolute accuracy %	WORK SAMPLING[1]: 95% Confidence level, relative accuracy %	WORK SAMPLING[1]: % of net yarding cycle time, turns 550ft	WORK SAMPLING[1]: % of net yarding cycle time, turns 550 ft +
Haulback	37.2	8.0	7.9	±2.1	27	9	11
Stop choker and hook-up	167.9	36.0	37.1	±3.1	8.3	49	44
Yarding and hang-up	87.8	18.8	20.5	±3.2	15.7	21	29
Position and unhook	68.3	14.6	14.6	±2.8	19.3	21	16
Road change	21.9	4.7	7.1[2]				
Miscellaneous Delays	83.4	17.9[2]	12.8				
Total Delays[3]	105.3	22.6	19.9	±3.2	16.0		

[1] Total numbers of observations = 630 (7 days @ 90 observations)

[2] Includes strawline extension

[3] Road change and miscellaneous delays

turns with short and long yarding distance reveals only that the distribution of the element times changes with yarding distance. As expected, haulback and yarding time account for a greater percentage of the cycle time for long distances.

The group-timing technique (GTT) (See table 2) involved one forenoon and one afternoon chosen at random. The observation interval was one minute which would have allowed for 240 observations. However, a major breakdown in one case and late start and early stop in the other case shortened the observation period in which it was possible to allocate the work performed to a particular operator. Work in this context also includes work during an operation delay. It should be noticed that in a "real" study hook tender, rigging slinger and chokermen can be recorded separately.

In spite of the short observation period the results give a good indication as to the active or idle time of the various jobs. The technique seems to be feasible to detect projects that are worth studying further.

The gross data time study (See table 3) represents a summary of the time study results which could be easily obtained also by the foreman or a crew member. "Time on job" is obtained by subtraction of times for late start, early stop and excess lunch time from the full eight hour day. Itis suspected that it would not be recorded truly in most cases. "Major delays" involved obvious delays of a duration of at least

TABLE 2. GROUP-TIMING TECHNIQUE (GTT) AS COMPARED TO TIME STUDY

	ACTIVE TIME AS % OF OPERATING OR TOTAL TIME		
	Yarder Engineer	Chaser	Chokerman Rigging Slinger
Excluding Delay Time			
1. (= Operating time)			
Time Study	41	16	46
GTT (forenoon)	41	20	43
GTT (afternoon)	46	19	41
2. Including Delay Time			
Time Study	37	16	40
GTT (forenoon)	34	17	38
* GTT (forenoon)	40	19	45
GTT (afternoon)	39	18	35
*GTT (afternoon)	45	21	40

* (Excludes delay time when men were idle)

three minutes, like yarder and rigging breakdowns, exchange of bull-hook and chokers, tightening guylines and hold-ups due to loading, just to name a few. The average time per turn has been calculated by dividing the effective operating time by the number of turns per day.

This type of gross data study does not seem satisfactory for a high-lead yarding operation. Even if extended over a longer period the average time per turn could hardly be related to one of the variables listed. This can be easily understood because the cycle time is strongly related only to the yarding distance for which the range is no effective measurement. The daily average cycle times vary greatly but only the shortest and largest values indicate a relationship with the range of the yarding distance.

A service recorder, attached to the main line drum of the yarder may be a means of refining the gross data technique. On the other hand it would be virtually impossible to distinguish between the records resulting from the regular yarding of turns and those of strawline extension or yarding of lost logs.

The choice of the work measurement technique to be applied to a particular operation depends on the objectives of the study and the characteristics of the operation. The original time study was the only procedure which could provide for detection of important factors which influence the yarding production. A very sophisticated gross data time study may furnish the same results but probably not at lower costs.

Work sampling and group-timing techniques, although applicable to the operation, could only provide for a small portion of the time study results.

TABLE 3. GROSS DATA TIME STUDY

Date		July/8	July/9	July/12	July/13	July/14	July/15	July/16	July/19	July/20	July/21	July/22	July/23	July/26	Average	Time Study (without delays)
Yarder		J-114	J-114	J-114	J-114	J-37	J-37	J-37	J-37	J-37	J-37	J-114	J-114	J-114		
Crew size		6	6	6	5	5	6	6	6	6	6	6	6	5		
Chokers "flown"		2	3	2	2	2	2	3	3	3/2	2	2	2	2		
Directions 1) 2)	?	down	down	down	down	down	down	down	down	down	down	up	up	up		
Range of yarding distance	ft	100 to 600	100 to 800	200 to 800	200 to 800	100 to 950	100 to 900	50 to 850	150 to 950	100 to 900	250 to 900	100 to 750	100 to 750	200 to 800	50 to 950	
Time on job	min	133	467	467	391	463	462	452	468	467	468	483	456	467		
Major delays	min	14	25	5	21	3	-	3	17	7	121	14	90	26		
Road changes	min	12	55	18	32	41	4	-	56	35	-	63	19	21		
Effective working time	min	107	387	444	338	419	458	449	395	425	347	406	347	420		
No. of turns/day		24	66	70	44	76	66	64	61	59	37	66	53	64		
Average time per turn	sec	267	352	380	461	331	416	421	389	432	563	369	393	394	395 3)	361
No. of logs/day		56	140	175	96	151	119	147	118	125	74	149	116	139		
No. of logs/turn		2.3	2.1	2.5	2.2	2.0	1.8	2.3	1.9	2.1	2.0	2.3	2.2	2.2	2.14	2.14

1) Downhill or uphill

2) Slope should be indicated

3) Includes minor delays

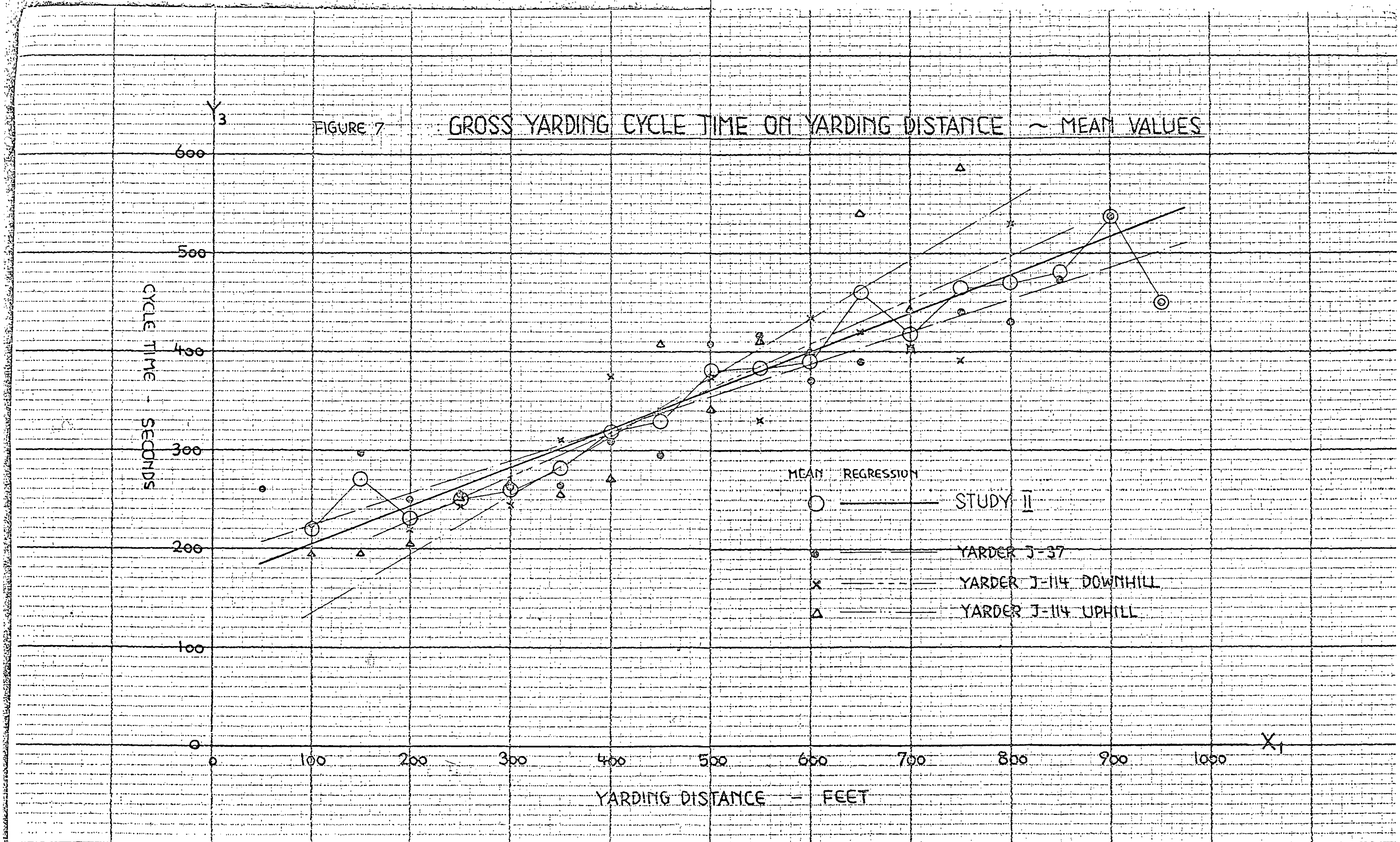


FIGURE 7
GROSS YARDING CYCLE TIME ON YARDING DISTANCE ~ MEAN VALUES
Y_3
CYCLE TIME - SECONDS
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
X_1
YARDING DISTANCE - FEET
MEAN REGRESSION
STUDY II
YARDER J-37
YARDER J-114 DOWNHILL
YARDER J-114 UPHILL

FIG. 8 MULTIPLE ACTIVITY CHART ~ YARDING (ALL COMBINATIONS)

AVERAGE NET YARDING CYCLE

FUNCTION / MEN & MACHINE	HAULBACK	STOP-CHOKER	HOOK-UP	YARDING	HANG UP	POSITION	UNHOOK	TOTAL ACTIVE TIME Secs	TOTAL ACTIVE TIME %	TOTAL IDLE TIME Secs	TOTAL IDLE TIME %
MOBILE SPAR								148.5	41.1	212.7	58.9
YARDER ENGINEER								148.5	41.1	212.7	58.9
CHASER						50%		56.5	15.6	304.7	84.4
RIGGING SLINGER								176.2	48.8	185.0	51.2
CHOKERMAN # 1								167.9	46.5	193.3	53.5
CHOKERMAN # 2								167.9	46.5	193.3	53.5
AVERAGE TIME (seconds)	37.2	24.2	143.7	79.5	8.3	23.5	44.8	361.2			
% of TOTAL YARDING CYCLE	10.3	6.7	39.8	22.0	2.3	6.5	12.4	100.0			

IDLE TIME [hatched box]

ACTIVE TIME [blank box]

AVERAGE YARDING DISTANCE = 549 ft

AVERAGE TURN SIZE { = 2.14 LOGS
= 165.3 cu ft or 991.8 FBM

FIG. 9 MULTIPLE ACTIVITY CHART ~ YARDING (ALL COMBINATIONS)

AVERAGE GROSS YARDING CYCLE (INCLUDING ALL DELAYS PRORATED TO THE CYCLE)

FUNCTION / MEN & MACHINE	HAULBACK	STOP CHOKERS	HOOK - UP	YARD DELAY	YARDING	HANG UP	LNDG. DELAY	POSITION	UNHOOK	MISC DELAYS	* L.S. E.Q. E.L.	CHANGE ROADS	TOTAL ACTIVE TIME secs	TOTAL ACTIVE TIME %	TOTAL IDLE TIME secs	TOTAL IDLE TIME %
MOBILE SPAR										5		20	165.7	35.6	300.3	64.4
YARDER ENGINEER										15%		20	170.4	36.6	295.6	63.4
CHASER						53 %		50%		10		80%	76.7	16.5	389.3	83.5
RIGGING SLINGER										5		80%	206.3	44.3	259.7	55.7
CHOKERMAN # 1										5		80%	187.7	40.3	278.3	59.7
CHOKERMAN # 2										5		80%	187.7	40.3	278.3	59.7
AVERAGE TIME (seconds)	37.2	24.2	143.7	10.7	79.5	8.3	12.6	23.5	44.8	47.1	13.0	21.9	466.5			
% of TOTAL YARDING CYCLE	8.0	5.2	30.8	2.3	17.1	1.7	2.7	5.0	9.6	10.1	2.8	4.7	100.0			

IDLE TIME [hatched box]

ACTIVE TIME [open box]

AVERAGE YARDING DISTANCE = 549 ft

AVERAGE TURN SIZE { = 2.14 LOGS
= 1.65.3 cu ft or 991.8 FBM

* LATE START
EARLY QUIT
EXCESS LUNCH

VI PAST APPLICATION OF WORK STUDY IN FORESTRY

1. Introduction

Although until recently work study was not considered very suitable in forestry there have been many applications, mainly time studies, in earlier days. Such studies were performed mainly by forest research stations. In Europe where piece rates were and still are dominant in primary forest production, standard times have been widely used to establish "fair" piece rates. In North America the piece rate often related to a standard volume like 1000 fbm or 100 cubic feet. In recent years unions have become very strong in North America and generally they do not favor piece rates. In Canada, time studies have been concentrated on the evaluation of physical factors of the environment. The continuous stop watch technique is by far the most widely used work measurement, but its high cost has recently led to the application of other techniques.

Method studies of simple operations and equipment for felling, bucking and planting to effect improvements have been made commonly in Europe, but seldom in North America. Here the emphasis has been on the comparison of alternative methods.

2. Review of Literature

Rapraeger and Spelman (1931) conducted a time study of falling and bucking in the northwestern States to investigate the influence of tree size. They recommended standard piece rates according to tree diameter and demonstrated the effect of an average piece rate on small and large timber.

One of the earliest comprehensive work studies in forestry was carried out by Brandstrom (1933) in the Douglas fir region. His data on yarding and loading costs were based on extensive time studies at different locations in an attempt to represent average conditions. All the important methods which were used in the forest at that time, are compared as to their costs and feasibility. After these early attempts to introduce work study in forestry there were very few applications during the following two decades. Matthews (1942) stressed the importance of accurate data in his book "Cost Control in the Logging Industry" but did not illustrate it by examples. The cost of thinning young Douglas fir was tackled by Worthington and Shaw (1952). The stock of original data is rather small however, and it is stated that one of the fallers worked above average efficiency. Since no rating was carried out this statement is rather weak and demonstrates one of the difficulties of work study in forestry. More recent time studies of falling and bucking to study the influence of tree size on those costs, have been reported by Nixon and Gunn (1957), Kurta (1961), Tessier and Smith (1961) and Valg (1962). A series of sophisticated yarding studies was initiated by Tennas et al.(1955) to evaluate the effect of several variables including distance, turn volume, number of logs per turn, and slope, on yarding production. Stand conditions, equipment, yarding method and time study procedure were described in detail, thus allowing for further application of the results. McIntosh (1963), Adams (1965) and Rasmussen (1965) used the same approach. The first two also compared pre-logging and re-logging methods of yarding.

In 1958, Gunn and Guernsey made a detailed comparison of skidding times at five different locations in the southern interior of British Columbia. Since the introduction of articulated wheel skidders there have been many time and cost analyses by individual companies and research groups. However, they are seldom published in forms other than production and cost data. Loading and hauling have been studied by Valg (1962) and Doyle and Calvert (1961). Times for pruning of trees with different diameters and up to different height have been reported by Smith and Walters (1961).

There is virtually no restriction in the application of work study. Two senior students at the University of British Columbia applied time studies to topographic mapping and the establishment of permanent sample plots. Sawby (1962) could improve mapping using his time study of a two man crew. Farenholtz (1959) arrived at a schedule for optimum crew size under varying work conditions.

As Marshall (1961) reported, the B.C. Forest Service has since 1955 made its own "time, production and cost studies" covering all operations from falling to trucking of lumber. It aims at forecasting production and cost of different logging chances without having to rely solely on data from industry.

Time studies to establish standard times or as a supplement to method study are more numerous in Europe than in North America. In Great Britain, the Work Study Section of the Forestry Commission has published standard data. Crowther (1962) dealt with cable skidding. Forrester (1962) described improved tools and techniques for manual forest work. In 1966 the Work Study Section consisted of eight crews which were mainly concerned with extraction, clear felling, debarkers, pruning, mechanical loading, hauling and development of standard data.

The Department of Operational Efficiency of the Royal Swedish Forestry College is a leading Institute in work study application. The director, U. Sundberg, published in 1963, a review of research carried out since 1949. Most studies were directed towards tool improvement or comparison of alternative working methods and even such specialized items as collection of cones from felled trees (Hagner and Callin, 1959). Germany also puts emphasis on improving forest working techniques. The Research Institute in Reinbek/Hamburg (Director H. H. Hilf) and the University of Freiburg (Director H. Steinlin) are taking the lead in this field. Mechanization seems to be the main concern in recent years.

A felling study carried out in Sweden, Austria and Germany by the FAO/ECE Joint Committee for Forest Working Techniques and Training of Forest Workers was reported by Sundberg (1963). This international body serves more to exchange information than to conduct its own research program.

Work measurement techniques other than time study have been little used in forestry. This is not true for the widely applied daily production record which does not give us information as to delay time, effective machine hours and various physical variables that may influence daily production. The gross time study technique is in a way a supplemented daily production record. Bennett *et al*. (1965) made extensive use of this technique in studying the environmental factors affecting skidding production in eastern Canada. Within a day the skidding cycles including number and volume of logs, distance travelled, delay time and several environmental factors could be established fairly accurately. A "Gross Job Time Study" was described by Worley *et al*. (1965) and examples of a juniper clearing and thinning operation were given. Records are kept by day, allocating the effective man and machine times to a certain job. Gross time studies seem to be fairly common in hauling operations (e.g. Clark, 1966) where there are few and relatively long element times.

Work sampling has been scarcely applied in forestry. King (1966) proposed a work sampling approach to planting, giving an element breakdown but no practical data. Lussier (1961) compared data from time study and work sampling of falling and skidding and reported a satisfactory result by the second technique.

3. Personal Information

Work study and systems analysis play an important role in the Engineering Service Division of the B. C. Forest Service. The purposes of work study are budgeting, weighing of alternatives, contracting and piece rates. Studies have been carried out and the results compiled over the years in three major groups, namely, site preparation, silviculture and road construction. In right-of-way clearing, work sampling has been applied where several groups of contractors worked scattered over a long distance. The results are shown mainly in graphical form with either cost, production, or time as the dependent variable. But good time and production data based on past performance are not sufficient for budgeting and planning. The Division also considers it essential to make a thorough survey of the conditions to be encountered in the field.

In the Pacific Northwest most logging studies have been done by the PNW Forest and Range Experiment Station in Oregon and some large companies. This author worked one summer with one of these companies and could observe a variety of work study applications to forestry. The level of accuracy was determined by economical considerations and consequently continuous time study was used only where a high amount of accuracy was required. Work sampling was applied to operations like hauling of gravel and maintenance shop work. In eastern Canada even small sized companies like Fraser Co. in New Brunswick, have their own work study group in logging. This has been strongly induced by the appearance of the wheeled skidder. Time and method studies are applied on experimental crews to find the skidding method best suited for a particular case.

4. Importance in Professional Forestry Curriculum

Canadian forestry schools do not provide for courses in industrial engineering or work study. But production and cost data are generally dealt with in logging courses or in cost analysis. Laval University and the University of British Columbia have recently started to give an introduction into operations research.

The Scandinavian schools put a much greater emphasis on courses in operational efficiency which include logging, soil, snow and ice mechanics, work physiology and psychology; occupational health and safety, and work study techniques. The practical part deals mainly with working techniques, work study analysis, maintenance and service of machines. (Sundberg, 1961).

In middle Europe there is less emphasis on operational efficiency but most schools offer courses which deal with work physiology and work study techniques.

VII ACCOUNTING BASIS FOR PROCESS EVALUATION

Work measurement techniques are means of providing time date for a work study, but other quantitative data must be used to arrive at the final input - output function. Management is not interested in higher production if the cost per unit is not reduced. Costs occurring in a work study project can be divided into three major groups; namely (1) cost of labor, (2) cost of equipment, temporary and permanent structures and (3) overhead costs.

1. Cost of Labor

Generally these costs are not a serious problem provided all additional costs, such as social benefits and travel time expenditures are added to the actual wages. Camp and cookhouse losses and public relation expenditures may be included in camp overhead instead of being listed as in-direct labor costs. Cost of supervisory personnel, not working with the crew, is also likely to be treated as overhead. Where wage incentive schemes are applied, the cost per unit of time is somewhat more difficult to calculate. Labor cost can be expressed as cost per unit of work time, or unit of time of effective work or per unit of production.

2. Cost of Equipment, Buildings and Roads

Preferably these costs are divided into the two major groups of operating costs and fixed costs, the latter being independent of the level of production.

a) Operating cost depend directly on the working hours and are often termed variable costs. They include:

- expenditures for power requirements.
- spare parts directly related to time in-use, like tires, filters, chains, cables and chokers.
- maintenance and repair.
- operator cost, as discussed in the previous section, may be included if we calculate the machine rate.

Maintenance and repairs are not truly variable costs because they occur to a reduced amount on both idle equipment and idle structures. Therefore these costs are often calculated as a percentage of the initial investment and distributed over the same period of time as the latter.

b) Fixed costs. The allocation of fixed costs is a difficult task and thus deserves some explanation. Fixed costs can be classified as 1) Depreciation, amortization and depletion, 2) Interest on invested capital and 3) Insurances, taxes and licences. These costs are usually calculated on a yearly basis with the unit of allocation differing for equipment, buildings, roads and timber.

Depreciation may be defined as the loss of invested capital due to use, wear, physical deterioration and obsolescence. These losses are recovered by annual depreciation charges but no special fund is established for this and the money is re-invested in the business. Some of the procedures used to calculate yearly depreciation are straight-line, declining-balance, and sinking fund methods. The best method of calculating hourly costs, or cost per unit of output is the straight-line depreciation method. For accounting and income tax purposes other methods may be applied.

Depletion is the write-off of exhaustable resources which in forestry is the timber, separated from the timber land. Timber is usually depleted on a volume basis.

Amortization provides for replacement of capital by putting annually an amount into a special fund which does not allow for re-investment of the money in the business. This somewhat conservative form of write-off which yields a relatively small interest is applied to roads by some forest companies.

Interest on invested capital is the cost of using borrowed money. The main elements determining the interest rate are: risk involved, length of investment, size of company and interest rates on long term government investments. In cost analysis we use the alternative rate of return of the firm, thus including interest, to evaluate the feasibility of an investment. In rare cases this rate can be determined directly; usually it is stated by the firm.

Income Tax is paid on gross profit therefore it does not enter our production costs. Most economy studies are made "before income tax" which means that alternatives are compared before deduction of income tax rather than after deduction. Other taxes, insurances and licences are dealt with as annual charges and are allocated to working time or units of production.

3. Overhead costs

Overhead may include costs like supervision, administration, technical staff, camp losses, warehouse and public relation expenditures. The allocation is never very accurate and several different methods can be applied. The one best suited for work study purposes is the direct-labor-hour method but it should only be applied if labor costs make up a substantial part of the total cost. This also applies to the direct-labor-cost method which allocates more overhead to highly paid work. In the case of logging costs, overhead expenses may be distributed on the basis of cost per unit of volume although we know that unit costs depend strongly on log size. Heavily mechanized operations, such as road construction, favor allocation of overhead according to machine rates.

4. Modifications for more than one shift per day

The more expensive the equipment becomes the higher are capital costs. Operation on a two or three-shift basis reduces these costs by one half or one third, respectively. On the other hand depreciation charges will be higher but not proportionate and so will be the labor cost for shift work to a certain extent. Overhead costs per unit of output, as well as costs for taxes and licenses will be reduced. For the highly mechanized forest company more than one shift is becoming increasingly desirable but the reaction of labor and unions has to be considered.

VI HUMAN FACTORS

1. Introduction

The basic relationship between man and work has not been dealt with intensively in application of work study. This deficiency is due more to the complexity of the problem than to consideration of its importance. It seems that woods labor deserves some special interest as it is considerably different from other industrial work.

In the early days of time study it was recognized that there is a large variation in times between operators carrying out the same job. Performance rating was introduced to eliminate this variation but the reason for variation is very difficult to assess. We may assume that a combination of emotional, economical and physical factors influence each worker and determine his individual performance; however, these factors cannot be measured quantitatively. In factory work, the influence of the environment was recognized early and great attention is paid to factors like working position, light, noise level, colors, temperature and cleanliness. For outdoor work, several of these conditions cannot be controlled easily but rapid mechanization will result in steady improvements.

A field widely neglected in forestry is the training of labor. Recently vocational training for woods workers has been made available, for example, at a school in Nanaimo, B.C. under the joint sponsorship of the Federal and Provincial Governments and the forest industry of British Columbia. This recognizes that even a simple job requires a certain amount of introductory time until full efficiency is reached. Unfortunately, it is much more difficult to evaluate the learning period under the varying conditions of the forest than in a plant under standard conditions.

2. Physiology of Woods Labor

Logging and mining are the jobs which require the heaviest physical work. It seems, however, that this may change in the future as fully mechanized logging systems will become reality. But for many years to come a large amount of work in the forest will be done by men subject to weather, topography and stand conditions. Most improvements in forestry have been aimed at reduction of physical effort of labor.

Measurement of physical effort by the respiration or heart beat method is not new but applications in forestry are few. Sweden took a lead in this field and most of today's literature originates from that country and from Germany. New methods are not only tested for their efficieincy but also for the work strain involved, e.g. Callin and Hansson (1958) studied planting of pine and spruce. In a comparison of two felling and bucking methods it was found that production per man/day was similar but the physical effort differed and led to the choice of one method over the other (Sundberg, 1963). The same author also determined the optimum weight and size of logs for manual handling, resulting in highest production without undue fatigue. Not only the magnitude of the work strain but also changes in amplitude and length of rest periods are important. Every athlete knows that a series of sprints is more tiring than a constant pace. The same holds for short and heavy work strains as compared to a leveled work load. From experience we know that forest work is composed of steadily changing effort, therefore non-working or idle time may not be completely eliminated as it serves as recovery time.

3. Psychology of Woods Labor

It will be appreciated that this is a very complex field and many foresters tend to neglect or discard it. One may ask, who is the "homo sapiens" who likes or is willing to work in the bush? For decades it was mainly the economical advantages which were responsible for the interest in woods work. In Europe the farmers found additional source of income in the forest. In America the high wages attracted the physically fit men for the logging jobs. However, it is suspected that there were some other motivations like more freedom in working rhythm, satisfaction by seeing the day's work and a certain pride of the profession or pioneer spirit. It seems that today the attractiveness of forest work is diminishing and labor often has to be recruited from groups having low educational levels. The answer lies not only in high wages but also in improved working conditions, better living and recreation facilities and improved social security. The assessments of these factors are, however, a difficult task and quantitative values will always be disputed.

Other problems are created by difficulty of supervision of many jobs, frequent need for team work and variable management-labor relationships. In many recent studies it has been concluded that crew performance is of prime importance in work like skidding and yarding (McIntosh, 1963; Rasmussen, 1965; Bennett et al.,1965). In all these studies the variation in productivity caused by physical factors of the environment and stand could not explain a large proportion of the total variation. An interesting study was carried out by the Battelle Memorial Institute (Hamilton, 1966) in the southeastern pine region of the U. S. Besides physical factors a factor, "crew aggressiveness" was introduced in the study, dividing the studied crews into 1) aggressive 2) average and 3) not aggressive. It may be of interest to define the aggressive crew which was:

- highly flexible, having good team work
- working according to production standards and well equipped
- watching for safety and welfare of each other
- recognizing the authority of the boss.

In the harvesting cost model which lists eight variables, crew aggressiveness was the most important single factor. Even under diverse environmental and stand conditions the aggressive crew produced as much as the not aggressive crew under optimum conditions. The crews were paid on piece rate and therefore the result may be different from work on hourly pay but a major influence on productivity in the latter case is also likely.

4. Safety

Safety has been given very much consideration in the forest industry mainly because the industry and particularly the logging part ranks very high or even on top in number of accidents and lost time. In British Columbia, for example, the logging industry pays a basic rate of 9.25% of the payroll for the Workmen's Compensation Board. A merit system allows lower rates for individual companies with low accident frequency, thus directly reducing the cost of labor. How can we prevent accidents? As mentioned earlier, safety considerations play an important role in method study, however the safe method has to be sought and encouraged continuously. It is common knowledge that carefully planned and supervised operations have lower accident frequencies, although data for comparison cannot easily be obtained. As evidence it may be mentioned that the generally better organized logging companies comprising the B.C. Loggers' Association show a significantly and constantly lower accident frequency than the entire

B. C. logging industry. A correlation between accidents and time of training on the job can be established from accident statistics, showing a much higher proportion of accidents in the first few months than after familiarization with the job.

Beside mechanical failure and carelessness, there are some other factors of combinations of them which cause accidents. They may be attributed to the individual and his environment. It seems that certain people are inherently more subject to accidents and that at least temporary accident proneness can be assumed. It is a fact that almost every victim of a fatal accident in the logging industry has had already a file indicating previous compensable accidents. Bad physical conditions but more often mental and emotional disturbances may be the original cause of unsafe behavior and consequent accidents.

IX OPERATIONS RESEARCH

1. Introduction

The foregoing chapters have dealt with single operations without consideration of their possible interdependency. In logging, for example, we are not just interested in optimizing a single operation. We want to minimize the cost of the whole sequence of operations from the standing tree to the mill. Quite some time ago the interrelationship between yarding cost and road construction cost was recognized and lead to development of the road spacing model by Matthews (1942). Modern management increasingly deals with models which include several operations. The following description of techniques for management decision making will be rather general because a detailed presentation is beyond the scope of this thesis. As will be seen, most techniques have not been widely applied in forestry.

2. Systems Analysis.

The purpose of systems analysis is the definition and analysis of entire systems. It is common practice to present a system in the form of a flow chart which contains all pertinent operations and their interrelationships. The examination of a system must be done according to a method for consistency. To improve and maintain the performance of the system, problem solving techniques are required. If the system is very complex it is taken apart for the analysis but due consideration has to be given to the interrelationship of sub-systems and they should contribute to optimization of the system as a whole.

3. Linear Programming (LP)

LP is basically used in solving allocation problems and as such it can become a major tool in production planning. LP has been successfully applied to transportation and scheduling problems, blending processes, warehousing and distribution problems and machine loading.

Simply expressed, a LP model consists of a number of linear equations or inequalities, containing several variables, which cannot take negative values. These equations are called constraints. In addition there is the objective function, a linear function of all variables that is to be maximized in the case of profit or minimized for cost. A problem with two variables only can be solved graphically but complex LP problems can be solved only by use of an electronic computer.

LP has been applied in the forest products industry for several years. A very suitable problem is to find the best allocation of logs to different final products. In forest management, LP has been applied to a typical problem by Curtis (1962). Various compartments are scheduled for cutting and subsequent planting, using current product values and costs. Significant changes of the latter will require a recalculation which is easily done by the electronic computer. Valg (1962) determined the economically marginal tree size for harvesting at the University of British Columbia Research Forest through linear programming. Donnelly (1963), who is one of the few operations research specialists in the forestry field, recommended an integration of forest management and logging as the latter provides for and determines the future crops. Lussier (1960) demonstrated the application of LP to logging layout as a substitute for the road spacing model of Matthews (1942).

4. Dynamic Programming

Dynamic programming is especially suited to problems where the decisions have to be made cumulatively and at different times (stages) in the future. If there are many possible alternatives at every stage and many stages, it would be virtually impossible to calculate all combinations. Decisions as to the best alternative may be based on probability distributions. Some fields of applications are a) long range capital budgeting, b) timing of equipment replacement, c) transportation scheduling to meet shifting demand and d) allocation of limited resources between current consumption and reinvestment to increase future output. Applications of dynamic programming in forestry are very few. Hool (1966) described a dynamic programming approach to forest management.

5. Simulation

If a problem is very complex and no mathematical procedure for optimization is known simulation is often used. Kaufmann (1964) distinguished between direct and indirect simulation and use of a simulation device. The most well known technique is the Monte Carlo Method or simulation on an artificial sample. This method can only be applied if we know something about the distribution of the data under study and we can describe the distribution, for example, a normal distribution with mean and standard deviation. From a random table we draw numbers and determine the corresponding values of the distribution to arrive at an artificial sample. If we cannot determine the kind of distribution of the data we may apply direct sampling. The cumulative frequency distribution is divided into arbitrary intervals which are continuously numbered. From a random number table a set of numbers is obtained and the corresponding values of the original data are reconstructed. This procedure only gives reliable results if the number of observation of the initial data is fairly large.

5. Simulations have not been used extensively in forestry. Lussier (1960) and Winer et al.(1963) discussed the application of simulation to a felling-skidding operation. Essentially, instead of using average times for falling and skidding, random times are used to provide a more realistic picture of the interrelationship between these two operations. As a result the optimum number of fallers and skidders was obtained. Newnham (1966) described the simulation of a modern tree harvester cutting a hypothetical stand. The effect of different boom reaches on different stand patterns was studied and the most efficient boom deter-

mined. Another application of this technique to management problems is the simulation of stand development for Douglas fir and lodgepole pine as carried out by Newnham and Smith (1964), Smith (1967).

6. Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT)

These two techniques are essentially scheduling procedures developed in the mid 1950's. In a short time they became standard tools in the construction industry, for example, EXPO 1967 in Montreal has been scheduled entirely on a three stage CPM program. CPM and PERT are applied where a high number of partially independent, partially interdependent activities occur with a predetermined sequence. The time to perform a certain activity and the costs involved have to be known fairly accurately, especially if we apply CPM. PERT differs from CPM in that it allows for a variation in activity duration time.

Until today forestry has made little use of CPM and PERT for two reasons mainly. First, there are few operations with several paths or planes of activities thus the critical path is usually obvious. Secondly, basic data, particularly that dependent on several physical variables, is seldom accurate. The Engineering Services Branch of the B.C. Forest Service made use of CPM in some of its road projects, location surveys and bridge construction. One point that deviates from the original purpose of CPM is that the critical path is known before drawing the diagram and is made up of the actual construction phase. However, it has been found that CPM is a useful planning and scheduling tool.

7. Decision Theory

As mentioned in the introduction, decision theory is based on statistics. Often management has to make decisions without knowing if the assumptions leading to these decisions will be met in reality. Some people distinguish between risk and uncertainty. In the case of risk we know something about the probability of different alternatives. Uncertainty means that we do not even know the outcome in probabilistic terms. We then have to estimate the chances associated with a number of possible outcomes. In sales and service requirements we deal mainly with uncertainty whereas risk is more frequent in engineering and production planning.

Dane (1965) gave an example of the application of decision theory to logging. Various methods such as tractor skidding and high-lead yarding are related to a known probability of rainfall which affects the two methods differently. In his model, Dane allowed also for differing attitudes towards risk of money.

X CONCLUSIONS REGARDING OPERATIONAL EFFICIENCY IN FORESTRY

Increased efficiency of forestry operations can result from the application of both work study and operations research. To avoid sub-optimization we have to become more system conscious in forestry and therefore carry out more systems analyses. Operations research will aid in solving the defined problems but the basic data has to be furnished by work study. It must be stressed that the whole field of operational efficiency, and particularly operations research, is subject to rapid changes currently and therefore few firm conclusions can be drawn. Possibly an entirely new approach to the forestry system may emerge.

Contrary to real life situations where the starting point is a problem to be solved, this thesis has evaluated the problem solving techniques and has tried to determine to what kind of problems they can be applied. This approach has been chosen because it would be virtually impossible to list all the problems and indicate the technique with which they could be solved.

It must be stressed again that technical or rational solutions are bound to fail without due considerations of the human aspects involved. We cannot neglect the reaction of the single employee, of teams of employees, of unions and their relationship to management, and the cooperation of different departments within a business firm. The latter also has a responsibility to society as a whole which influences decision making on the higher levels.

1. Method Study

There are two different viewpoints as to how new methods will be implemented. One may wait for a genius with a brilliant idea or try to improve the existing method gradually. Since the latter is much more common, method study is an important tool by which to effect improvement. However, in forestry this is not recognized widely. The work study analyst often faces stiff resistance upon trying to introduce an improved method. One solution could be experimental crews which are not required to produce higher efficiency from the first day on and which may even allow for an initial loss in production.

Method study may also furnish new ideas and entirely new methods because it analyses a process in detail and thus may pin-point some crucial basic relationships. It is here where creativity enters the picture and where mere knowledge no longer succeeds.

Motion study as a specialized form of method study will not be discussed any further because its application to forestry is very limited.

2. Work Measurement

Several work measurement techniques have been discussed and illustrated in chapter IV. From the nature of activities in forestry it can easily be seen that some techniques cannot be applied to forestry operations. They are the ones confined to short cycles and high repetitiveness, such as predetermined motion-time standards and timing with camera. Figure 10 shows to what purposes the other work measurement techniques can be applied. It is seen that continuous time study is the most versatile technique, this being the reason for its wide application. However, in many instances another technique could provide for similar results at much lower costs. Figure 11 illustrates the feasibility of different techniques according to various factors which are important for the choice of a particular technique. It should be possible to classify all activities in forestry into one of the final groups, thus a lengthy listing of activities can be omitted. The physical difference between high and low accuracy is arbitrary. It may be said that in the case of low accuracy we do not bother to calculate it.

a) Evaluation of various techniques

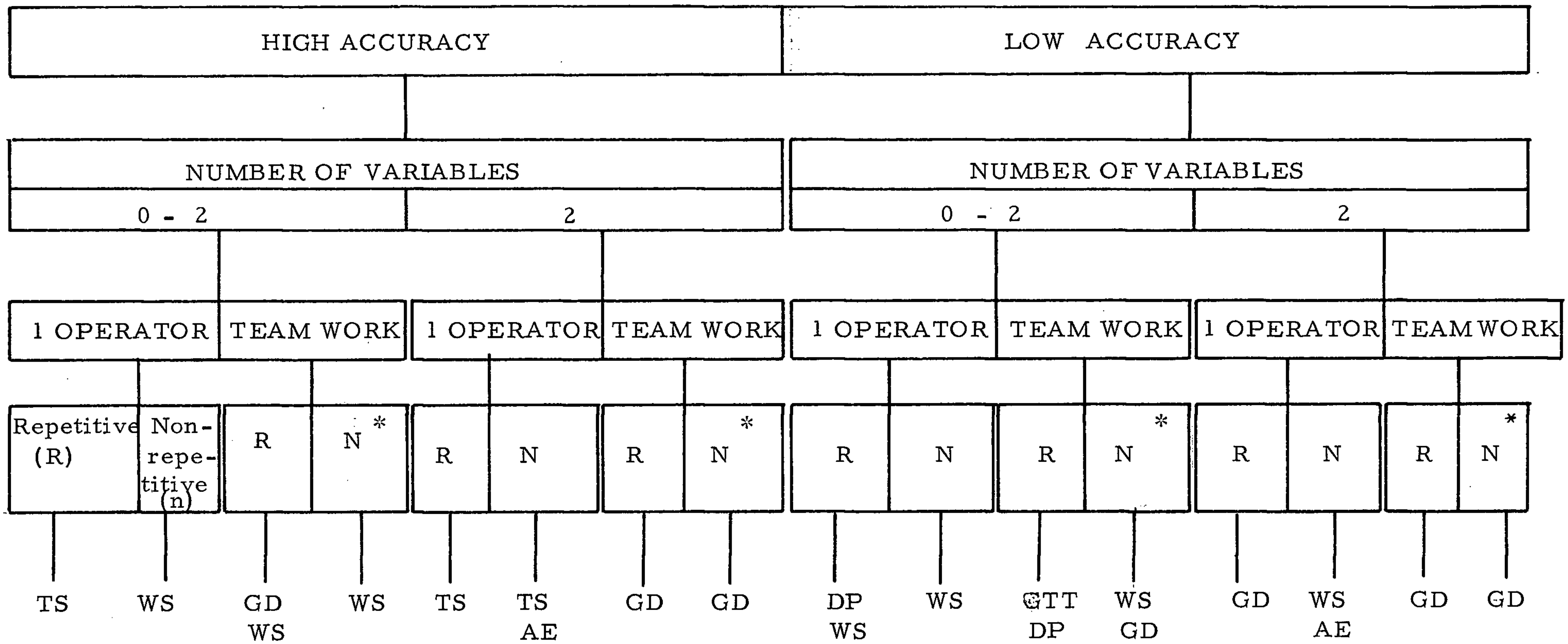
The multi-moment technique is not likely to be applied in forestry very often because it is too expensive and our long element times do not warrant such short observation periods. It may be used for the establishment of differentiated standard times.

FIGURE 10. POSSIBLE APPLICATION OF WORK MEASUREMENT TECHNIQUE TO FORESTRY

(x = possible)
(◯ = favorite)

WORK MEASUREMENT TECHNIQUE / OBJECTIVE OF STUDY	Daily production record	Gross data time study	Continuous time study	Work sampling	Group timing technique	Analytical estimating	Multimoment technique	Physiological work measurements
TIME STANDARDS for piece rates, incentive plans, cost analysis, production planning			(X)	X		X	X	X
INFLUENCE OF VARIABLES on production. For planning, models, operations research		(X)	(X)				X	X
COMPARISON OF ALTERNATIVES. Methods, Equipment	X	X	(X)	X			X	X
DISTRIBUTION OF PRODUCTIVE AND DELAY TIME Man, Machines		X	X	(X)	X		X	
PRODUCTION CONTROL	X	X	X	(X)	X		X	X
HUMAN PERFORMANCE			(X)					
HUMAN ENERGY CONSUMPTION								(X)

FIGURE 11. SUITABILITY OF WORK MEASUREMENT TECHNIQUES TO TYPE OF OPERATION AND ACCURACY REQUIRED



Symbols:
- TS Continuous time study
- GD Gross data time study
- WS Work sampling
- GTT Group-timing technique
- DP Daily production record
- AE Analytical estimating

Remarks: Team work means separate recording of operator within team

* Non-repetitive team work is very rare

For continuous time study the following rule should be followed: use time study only after checking if none of the other techniques could provide for the desired data. As can be seen from Figure 10 there are alternative methods available in every case but they may not be accurate enough. Presently time study is superior in the following fields. a) Evaluation of environmental and stand factors if these factors vary from cycle to cycle and cannot be averaged over a day. b) Assessment of differences in human performance. This may be done by performance rating in a simple operation or by introduction of variables like aggressiveness (Hamilton, 1966) in a complex operation. c) Comparison of different methods and new equipment which do not vary greatly therefore require high accuracy. For example with time study results it may be possible to justify the purchase of more expensive equipment in spite of equal specifications of the manufacturers. d) Establishment and control of time standards for operations of short duration. Besides high costs there are some other disadvantages to the continuous time study. It covers a short time period only and therefore it may not be representative of a wide range of conditions. The observer may influence the performance of the operator either positively or negatively It has been suggested that we replace the observer with a closed circuit television system but this is very expensive and can only be applied to a stationary operation. With one stop watch we can time only one operator or the operation itself as in the case of high-lead yarding studies. The evaluation and interpretation of results may be rather complicated if many variables are introduced into the study.

Gross data time study can replace the more costly time study in many cases and should be more often applied. Especially suited are mechanized operations where we can use service recorders for timing or counting the number of cycles, for example, skidding and hauling operations. Other advantages of gross data studies are: it can be spread out over a long time period and several operators can be included in one study. It was pointed out earlier that gross data means merely a detailed daily production record. Besides mechanical measuring devices the additional required data may have to be furnished by supervisors or the operator himself. For example a spacing operation may include such variables as weather, topography, number of trees cut per acre obtained from a sample, average diameter of cut, effective working time and of course the two figures which are recorded anyway, total working time and acres treated per day. All this data may be coded for computer processing, giving increasingly accurate results and indicating the pertinent variables. Reviewing our example we will detect some weaknesses of gross data studies. First, there is a greater possibility of errors than in a time study and also a chance for the operator to cheat. Second, we may not include pertinent variables and third, we may not be able to improve the operation because we do not know the time for elements like walking, cutting and power saw care.

The daily production record can be used for production control and planning of fairly simple operations which are independent of variables. It is well known that there are few activities of this kind in forestry. With increased use of computers in accounting daily production records could in many cases be adapted and converted to more valuable data for improvement of operational efficiency.

Undoubtedly work sampling deserves more attention by foresters. Generally its application is cheaper than continuous timing, especially if it is carried out by the foreman. Delays and element times exceeding 5% of total time can be determined accurately, as proven by Lussier (1961). From such an analysis we may find the key element, the element whose improvement will result in the greatest increase of efficiency. Work sampling is particularly suited to team work as one observer can time several operators. Furthermore, the observation period can be interrupted and spread out over a long time span, thus eliminating some short term variation. For non-repetitive work as in repair shops, warehouses, offices and for supervisory personnel, work sampling is superior to time study. Another application is production control although it is not yet widely used in forestry. The major disadvantage of work sampling is the fact that it cannot be applied where several physical variables affect an operation and we have to evaluate their effect. Through enlarging the sample size we may determine the influence of one or perhaps two variables. Further the observer may be familiar with the operation and should be able to identify operating time which results from an erroneous operation as delay time. If we require high accuracy but must measure short elements, work sampling may no longer be economically feasible.

Group-timing technique may replace work sampling where accuracy is not at a premium and work is fairly repetitive but the cycle time is not constant. The latter condition holds for most forestry work. The costs are low because we obtain a high number of observations in a short time. The technique seems most suited to production control and determination of delay and element times, as proven with a yarding study (see chapter V). It may be used as a preliminary study to time study or work sampling.

Analytical estimating is of very restricted use to forestry as its main application is the determination of standard times for non-repetitive work. As mentioned earlier we partially apply time study or work sampling. Possible fields of application are repair shop work and special projects of road construction like bridges.

Although theoretically applicable to many purposes, physiological work measurements will likely not be used very often by industry. The techniques require specialists who are only found in research institutes. These research results however may often be of use for the work study analyst. It is expected that with increased mechanization heavy work will diminish. That woods laborers no longer accept physical discomfort has been recently demonstrated by a strike of fallers in Washington caused by a new power saw with high vibration. The company stated that due to higher speed the efficiency would considerably increase with this saw. However, the company retired the saw and undertook some further testing but the results have not yet been made public.

3. Cost Analysis and Production Planning

Frequently work measurement results are used for these two purposes. In the case of cost analysis where we evaluate alternatives it is imperative to have accurate cost data from the same operation as the production figures originate. Some of the principles of cost allocation have been discussed in Chapter VII. Cost analysis often includes more than one operation and thus models or operations research techniques have to be applied.

Production planning has two major aspects, namely, production analysis as furnished by work measurement and forecast of conditions to be encountered in the field. Forecasts of forest companies are generally poor or non existing like for road construction. Even stand inventory data often neither are accurate enough nor sufficiently detailed for planning in logging. Production planning as a major item of management activities will be further dealt with in the next section.

4. Operations Research

Operations research became fashionable in recent years but unfortunately its practical applications are few. The difficulties created are mainly due to the lack of understanding of the interdependencies within a system than due to lack of knowledge of the OR techniques. OR as an aid to decision making is most valuable on the highest management levels. However there the system may be so complex that is has to be segmented for analysis. On lower levels of decision making OR may be used in solving problems in sub-systems or operations if we are aware of the function they have in the entire system. Remember that a model should always be simpler than the real life situation and therefore OR should not be applied to elementary problems.

Expected savings through application of OR are scarcely spectacular in relative terms, according to Donnelly (1963). But a few percentage points of savings in a large company can amount to a respectable yearly sum. This stresses once more that OR usually is feasible only for larger organizations and higher levels of decision making.

In a company's primary forest production we may distinguish three levels of decision making which are related to different parts of the system. (see figure 12). Starting from the bottom, or the level of the foreman, it is very unlikely that OR techniques will be applied.

The foreman, working according to plans from the division, can carry out his planning and scheduling on a sheet of paper. For production control he uses methods described in work study. The division, although very seldom considered as a system, is the first level where OR can successfully be applied. There are several operations or sub-systems which stand more or less by themselves such as logging layout, truck haul, maintenance work and road construction. The division attempts to find the best alternatives possible with the available equipment to minimize costs of these operations. Besides lack of training for carrying out OR the manager faces some other difficulties like few alternatives because of given equipment, unsufficient data for supplying the model or unreliable forecasts of conditions to be met in the field. If a problem can be solved equally well by break-even point calculation, simple models, or simple arithmetic there is no sense in using more complicated techniques. Because of the short term character of most planning and scheduling activities dynamic programming and decision theory will be of minor importance only. More promising are CPM, LP and simulation. CPM can be used for construction jobs like roads, bridges and camps. Other scheduling problems involving waiting lines can be tackled with queuing theory or simulation. Examples are log haul to a dump and gravel haul from a pit and maintenance work. With simulations we can solve problems where arrivals are not random as may be the case in a log hauling operation. The truckers tend to make as few runs as possible or to be at a specific point at quitting time.

FIGURE 12. APPLICATION OF OPERATIONS RESEARCH TECHNIQUES

LEVEL OF DECISION MAKING	POSITION WITHIN SYSTEM	OPERATIONS RESEARCH TECHNIQUE APPLICABLE (LP= Linear programming, DP=Dynamic programming, DTH=Decision theory, SIM=Simulation, QU=Queuing theory, CPM=Critical path method.)
COMPANY WOODLANDS DEPARTMENT	SYSTEM or SUB-SYSTEM	Mill Supply — Allocation, Transportation Problems - LP; Scheduling - CPM, SIM Inventory — Log Inventory - QU, SIM Logging — (see under Division) Management — Optimum financial rotation - LP; Stand Models - SIM; Fire protection - SIM LP, DP, DTH, SIM
DIVISION DIVISION MANAGER	SUB-SYSTEM or OPERATIONS	Scheduling Problems — QU, CPM, SIM Allocation Transportation Machine Loading — LP Maintenance — SIM Equipment Replacement — DP Lay-out Models — LP
FOREMAN	SINGLE OPERATION	No need

The best combination of men and equipment of interrelated operations which have been studied separately by work study can be obtained by repeated simulation, for example, falling-skidding-loading. Linear programming has many potential uses in logging. We should be able to solve special layout problems or the optimum use of different machinery like yarders, processors, shovels and loaders to carry out a certain job. Transportation problems are frequent in log and gravel hauling. If there are different sources and different landings or places of final use, we may be able to optimize the efficiency with linear programming.

There is no doubt that OR will most profitably be applied at the highest level of decision making, the woodlands department or the top management of an integrated firm. Because decisions are far-reaching, dynamic programming will replace linear programming to some extent. Decision theory becomes an important tool as the future is generally uncertain. More emphasis will also be put on systems analysis to define or identify the problems within a large organization which is a very difficult task. A system including all decisions from growing trees to putting them into final use can be drawn as a flow chart but it has not yet been applied in a practical case. All the previously described applications (Chapter IX) were only concerned with a part of the system, for example, with management, and did not consider other parts. This is not surprising as even in a sub-system like management the implications of decisions concerning different degrees of intensity are not known yet. Simulations of stand growth resulting from different silvicultural treatments are an aid to the understanding and evaluation of a great number of alternatives. This makes the systems approach more valid than just the "simple" decision either to carry out silviculture or not to do it. We may say that today OR is applied mainly to solve problems of sub-systems as they are listed in Figure 12. Their characteristics are that they assume either the input or output as given. For example in a model for optimum allocation of timber from several divisions or camps to different final use, the quantity and quality of timber are given values obtained from the production forecast of logging operations. The problems are complex enough that the application of OR techniques is justified. As soon as we understand the sub-systems fully, it will be possible to incorporate all of them in one single model.

5. Operational Efficiency in University Courses and Research

There are few courses which deal with operational efficiency at Canadian universities and it would be easy to propose new ones. However, the forestry curriculum is already overloaded with specialized technical courses and additional ones are not desired. In the long run the student is better served with fundamental courses upon which he can build up a specialized knowledge after graduation. It will be argued that industry requires this specialist. It seems that a great deal of this specialized work could be done as well by a technician.

Work study as a procedure is rather simple and does not have to be carried out by the graduate forester. But to define the objectives of a work study and to evaluate the results, are more difficult problems and require professional knowledge. These problems could be dealt with in logging and statistics courses. It would be desirable to include the practical aspects of work study in the field work. Operations research requires some mathematical and statistical knowledge. As its main applications are in management and logging its basic concept should be included there. A specialization, however, is only possible in graduate work or in a company's research department. This leads us to another point. We need to know not only the principles of OR but how it can be applied in forestry. This apparent gap should be closed by a joint effort of universities and industry by promoting more research in this field.

Research in physiology and psychology of forest workers can be carried out better by specialists in these fields than by foresters. Through allocation of funds it would be possible to attract a few of these specialists to concentrate their efforts on the particular aspects of forestry.

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