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FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

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Technical Report No. 4
April 1976

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P.L. Cottell, R.T. Barth, L. Nelson,
B.A. McMorland, and D.A. Scott

300 - 2045 WEST BROADWAY, VANCOUVER, B.C., CANADA V6J 1Z5
245 HYMUS BLVD., POINTE CLAIRE, P.Q., CANADA H9R 1G6

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Foreword

This report deals with the individual characteristics and work performance of operators of tractor-mounted, tree-felling shears. The study is exploratory in nature, and represents an initial effort to evaluate the importance of human influences in logging. As such, it looks beyond the specific individuals and tasks studied, to provide a groundwork for future research in this field. The overall objective is to develop methods to evaluate the abilities of prospective logging employees and trainees, to enable the selection of those who are more likely to be successful and satisfied in their work. This responds to the need for more rational personnel selection that has been expressed by many individuals closely associated with operations and training activities.

Project fieldwork (June to December 1973) involved the first, third and fourth-listed authors, with the additional assistance of Mr. K.D. Black, graduate student in forestry at the University of British Columbia. Dr. R.T. Barth, Associate Professor, Faculty of Commerce and Business Administration, University of British Columbia, was closely involved in the study design and analysis. Dr. D.A. Scott, Associate Professor, Department of Psychology, University of Saskatchewan, contributed to the analysis and interpretation of psychological factors in the study, while on leave from the university in 1974-75.

From its inception in 1973 until March 1975, this study was part of the program of the Logging Research Division, Pulp and Paper Research Institute of Canada. (Until March 1974, the project was supported by a grant from the Canadian Forestry Service, Department of Environment: during the following year it received joint federal and industry support.) With the establishment of FERIC in April 1975, the project and its staff transferred to FERIC's program.

Other people and organizations that contributed importantly to this work include: Dr. H.I. Winer, FERIC Montreal, for administrative and technical support throughout the project; Mr. R. Diether and Mr. I. Goto of the Canada Department of Manpower and Immigration, Vancouver, for testing materials and advice; Dr. W. Warren, Mr. J. Hejjas, and Miss A. Hejja of the Western Forest Products Laboratory, Canadian Forestry Service, Vancouver, for statistical analyses; Mr. H. Gairns, Industrial Forestry Service, Prince George, for access to forest cover maps and inventory data of the region; and, the many co-operative individuals in forest companies, large and small, who provided information and permitted access to their operations. The authors thank especially the machine operators for their good humour and interest, which made the project possible.

There have previously been several partial presentations of the study results, including: the 39th Industrial Forestry Seminar, Yale University, New Haven, Connecticut (May 1974); Symposium on Forest Harvesting Mechanization and Automation, Division 3, IUFRO, Ottawa (September 1974); Annual Meeting, Canadian Psychological Association, Quebec City (June 1975); and, the Annual Meeting, Woodlands Section, Canadian Pulp and Paper Association, Montreal (March 1976).

Summary

Logging-machine operators vary widely in their levels of performance, most noticeably in productivity. Forest companies logically wish to hire operators who will show consistent, high levels of performance. They also would like to select and develop new trainees who have the potential to become superior operators. Because hiring, de-hiring and training are costly activities, companies seek to maximize the proportion of correct personnel decisions (accept suitable candidates and reject unsuitable ones) that they make. More efficient selection could come from better understanding of how the individual characteristics of operators — physical and mental abilities, background, acquired skills, and interests — influence on-the-job performance in various logging occupations.

A study of 34 operators of tractor-mounted, hydraulic, tree-felling shears examined variation in job performance among individual workers. The objectives were: (1) to document variation in on-the-job performance and assign the variation to sources "within individual operators", "between operators", or "between firms"; (2) to relate observed performance to measured operator characteristics; and, (3) to suggest ways in which average levels of job performance could be improved.

Fieldwork in North-Central British Columbia during the period June to December, 1973, produced data on a total of 757 shifts of tree-felling activity in 86 identified cutting blocks. There were 6.2 productive machine-hours (PMH) spent in felling activity during the average shift, for a production average of 701 merchantable trees, or 115 trees per PMH. Operators varied from less than 50 to more than 150 trees per PMH in their average production levels. The analysis showed that about ⅓ of the performance variation was assignable to day-to-day differences within operators, and that about ⅔ of the variation was assignable to differences between operators. Almost none of the variation appeared to be associated with differences between firms.

Interviews and test exercises conducted with the operators provided information on their background, work experience, attitudes, and certain physical characteristics and intellectual aptitudes. When differences in stand conditions were adjusted for (through the variable "number of trees per acre"), the following operator characteristics showed significant association with observed productivity:

— visual depth perception
— length of experience with shears
— manual dexterity
— motivation score.

Depth perception, experience and manual dexterity could easily be assessed in a selection procedure. Motivation is more readily influenced through alteration of organizational and supervisory structures within the individual firm.

Suggestions for further work in this field include:

— Development of procedures for evaluating qualitative aspects of performance, in addition to quantity, for various logging occupations.

— Improvement in theoretical models relating the characteristics of operators and work groups to job performance.

— Examination of human factors in logging-machine design (ergonomics) to facilitate job performance, reduce training time and improve the occupational safety and health of operators.

— The gathering and presentation in handbook form of information on superior work techniques in different logging occupations, for the benefit of operators and supervisors at all experience levels.

— Consideration of ways to develop a practical program to test the usefulness of personnel evaluation procedures for predicting the likely success of new employees, or trainees, in different logging occupations.

Sommaire

La performance et le rendement des opérateurs de machines utilisées en exploitation forestière varient considérablement. Les compagnies forestières désirent évidemment embaucher des opérateurs qui fourniront un rendement élevé et soutenu. Elles aimeraient également pouvoir sélectionner et former des stagiaires aptes à devenir d'excellents opérateurs. L'embauche, la mobilité de la main d'oeuvre et la formation professionnelle sont des activités coûteuses et les employeurs cherchent donc des méthodes de sélection qui faciliteraient le choix des candidats les plus prometteurs. Une sélection plus efficace est possible à condition de mieux comprendre comment certaines caractéristiques d'un opérateur telles qu'aptitudes physiques et intellectuelles, histoire personnelle, motivation et expérience peuvent influer sur son rendement au travail.

Les variations dans le rendement de 34 opérateurs de machines équipées de sécateurs hydrauliques sont le sujet de la présente étude dont les buts étaient de: (1) documenter les variations dans le rendement et de mesurer la variabilité "intra-opérateurs", "inter-opérateurs" et "inter-compagnies"; (2) établir la relation entre les caractéristiques de l'opérateur et son rendement; et (3) proposer des méthodes susceptibles d'augmenter les niveaux moyens de rendement.

Ces études, effectuées dans le centre-nord de la Colombie Britannique au cours de la période juin-décembre 1973, ont fourni des données sur 757 quarts d'abbattage dans 86 parterres de coupe identifiés. Durant chaque quart d'abattage d'une durée moyenne de 6.2 heures-machines productives (HMP), 115 arbres par HMP furent abattus pour une production moyenne totale de 701 arbres marchands. Le niveau moyen de production par opérateur variait de moins de 50 à plus de 150 arbres par HMP.

L'analyse des données a démontré qu'environ ⅓ de la variabilité dans le rendement était imputable aux différences quotidiennes intra-opérateurs et qu'environ ⅔ était attribuable aux différences inter-opérateurs . . . La variabilité inter-compagnie s'est avérée presque nulle.

Des entrevues et tests ont fourni des renseignements sur l'histoire personnelle, l'expérience professionnelle, l'attitude, la motivation, et sur certaines caractéristiques physiques et intellectuelles des opérateurs.

Compte tenu des différences entre les conditions de peuplement, des ajustements furent effectués et il fut ensuite possible d'établir une relation significative entre le rendement et les caractéristiques suivantes de l'opérateur:

- — perception des distances
- — durée de l'expérience sur la machine en cause
- — dextérité manuelle
- — degré de motivation

La perception des distances, l'expérience et la dextérité manuelle pourraient facilement être évaluées au cours d'un procédé de sélection. La motivation est plus immédiatement influencée par la modification des structures d'organisation et de supervision à l'intérieur de chaque compagnie.

Les suggestions proposées pour accélérer la progression des travaux dans ce domaine sont:

- — Le développement de procédés pour évaluer non seulement les aspects quantitatifs, mais aussi les aspects qualitatifs du rendement, dans divers emplois de l'exploitation forestière.
- — L'amélioration des modèles théoriques établissant la relation entre les caractéristiques des opérateurs et des groupes de travail en rapport avec le rendement.
- — L'examen des facteurs humains dans la conception de machines (ergonomie) pour augmenter le rendement au travail, diminuer le temps de formation, améliorer la sécurité au travail et le bien-être des opérateurs.
- — La préparation d'un recueil de renseignements sur les techniques supérieures de travail dans divers emplois pour le bénéfice des opérateurs et des contremaîtres à tous les niveaux.
- — La formulation d'un programme pratique pour vérifier l'utilité des procédés d'évaluation du personnel afin de prédire le rendement éventuel de nouveaux employés, ou de stagiaires, dans divers emplois de l'exploitation forestière.

Introduction

The performance of logging-machine operators is a major factor determining logging productivity and cost, as well as the success or failure of new technology. Even in situations where conditions of the forest, terrain and machines are relatively uniform, it is common to observe wide variation in performance among individual operators and crews. This suggests that there is considerable potential for improvement in logging operations, if average levels of performance could be increased to approach the level of the better operators (Fig. 1).

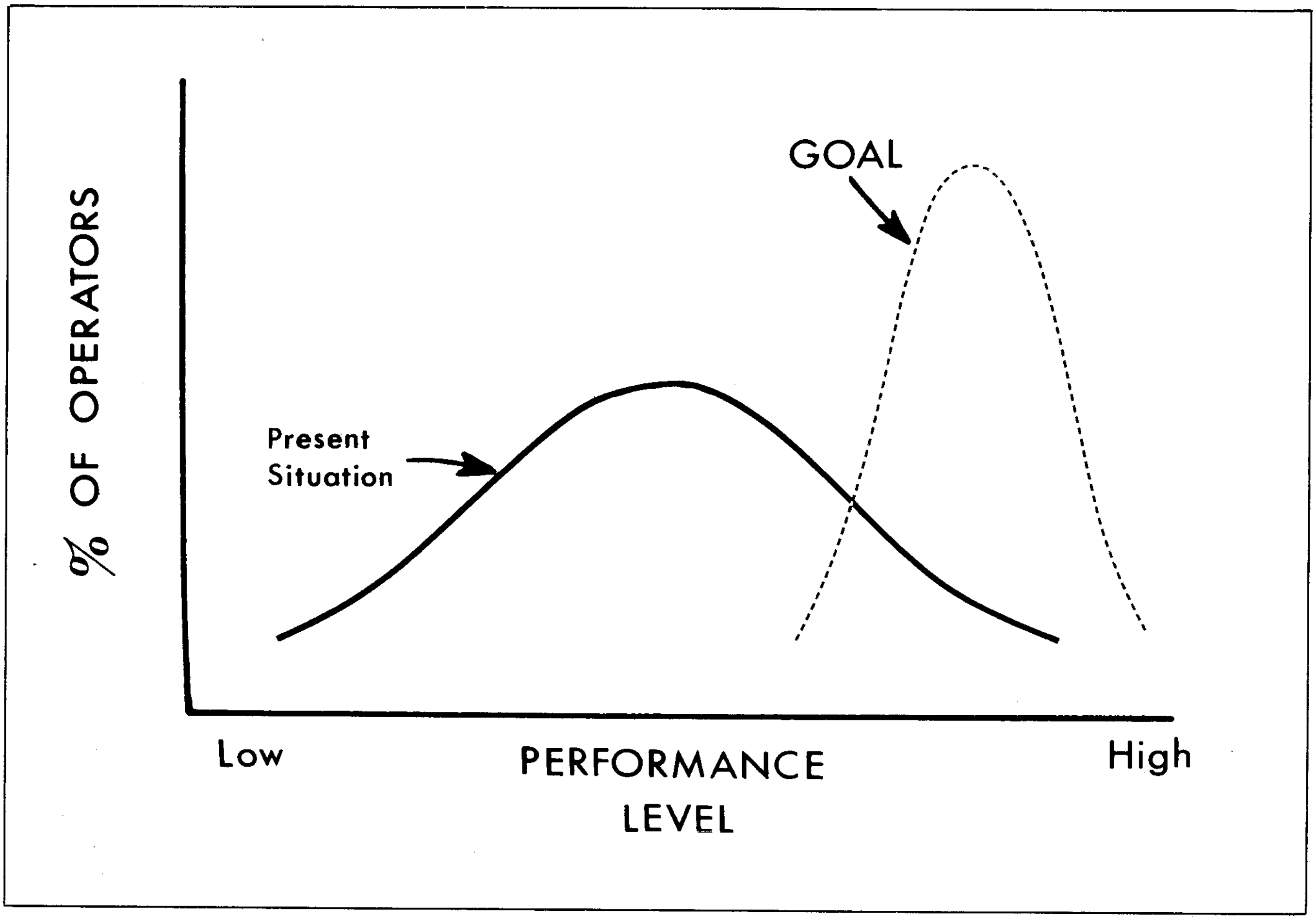

Figure 1. The objective in improving operator performance.

While widely recognized, the variation among individual operators is sparsely documented for logging. Even less is understood about the sources of this variation, the human and other factors with which it may be associated, or the nature of the relationships involved.

Published research on operator characteristics and logging performance is limited. Hansson (1965) reported a study of "the relationship between individual characteristics of the worker and work output in logging". The study compared two 25-man groups of experienced manual wood cutters — "top men" versus "average men" — in terms of piece-rate earnings, work output and a wide variety of personal characteristics. These factors included:

— anthropometric data, and strength
— physiological work capacity
— health
— adjustment to the job, and physical reaction to strain
— psychological tests of intellectual ability
— working technique and tools.

High physical endurance was characteristic of the "top men", who experienced less fatigue for a given work load. Neither technical nor intellectual ability, according to the test results, differed between the two groups.

Andersson *et al.* (1968) undertook a study to validate psychological test batteries that were being used in selection of tractor operators in logging to improve the predictive value of those tests. The 207 tractor operators involved undertook tests, training and later evaluation of job success. Success was measured in terms of performance results and time studies. The psychological methods were useful for predicting results of the training, and of performance in practice — including operator productivity.

Hall *et al.* (1972) studied the development of training programs for operators of tree processors. A group of 28 operator trainees took part in psychological tests prior to training, tests of knowledge of machinery, and interviews during training. They were interviewed again 4 months after training. Their productivity and work methods were evaluated during the first week after training, and at 1 and 4 months afterward. Nearly all attained the production goal within a month in operations, and no individual's productivity deviated significantly from the group average. There was little further improvement after 4 months. The results indicated that neither psychological test results, age, previous experience, nor tests of knowledge of machinery could predict future productivity of the trainees in this case. However, the authors did suggest the likelihood that critical levels exist for several of the factors, which could be important in selection.

The three studies indicate that the relative importance of different physical and psychological human factors varies with the nature of the job. In two studies, the measured personnel characteristics were associated with productivity; in the other case, not. One cannot reject the possibility that differences in operating conditions, organization, group norms and individual motivation may have obscured some of the expected relationships.

A series of studies by Latham and Ronan (1970) and Latham and Kinne (1971) examined the effect of goal setting and supervision on the performance of pulpwood producers in the Southern United States. They dealt with logging crews, rather than individual equipment operators. Producers (contractors) who set production goals and stayed on the job with their crews tended to have higher man-day productivity than producers who did not set goals or actively supervise. The researchers suggested that some logging operations could be improved if supervisors emphasized goal setting (using, for example, production tables) and performed on-the-job supervision. But these tactics alone would not improve on low performance that was the result of inadequate knowledge or ability, for which better personnel selection and training could be required.

A proposal to study operator performance raises two immediate questions. First, what is performance? And second, what aspects of actual performance (the real situation) can be included?

Two important criteria of performance are:

1. Quantity of production (the rate of tree-harvesting or log production per productive hour, or per shift);
2. Quality of production (adherence to specifications, and minimizing damage to end-product values in log production).

The merits of these criteria are their recognized importance, relative convenience for quantitative measurement, and likelihood of reasonable variation over a short period of time. However, other important criteria of performance could be considered, such as care of equipment, regular attendance, length of job tenure, and safe working habits.

The second question (what to include in a study) should consider all of the important elements of the operator's work context. On the other hand, it is impractical, and probably impossible, to measure or control every factor. A simpler view of the real situation is obtained by selecting those factors that are judged to be of greatest importance, and neglecting the rest.

The main categories of factors likely to affect performance are:

1. Environmental and operating factors:
   (a) forest conditions
   (b) terrain conditions
   (c) climatic conditions
   (d) machine characteristics
2. Personal characteristics of operators:
   (a) background and experience
   (b) aptitudes
   (c) attitudes, interests and motivation
   (d) physiological factors
3. Characteristics of the job:
   (a) type of firm

(b) goals and incentives, including method of payment
(c) supervision
(d) operating methods (technique).

Each category includes a variety of factors that may act individually, or in combination, to influence operator performance. Methods exist for measuring most of these factors. Other factors (such as machine type, firm type, forest condition) can be controlled through the study design to some extent, to simplify the situation.

More information about the factors affecting the performance of operators may make it possible to take well-considered steps toward improving the contribution of human inputs to logging. Such information could lead to development of:

1. Criteria for recruiting operators with preferred performance-related characteristics;
2. Criteria for selecting candidates for training, both on-the-job and in formal courses;
3. Guides for instructors and supervisors to help bring low or average performers toward levels achieved by higher performers.

In the longer run, insight into these factors could have implications for machine design and organization of the work.

A Study of Performance of Logging-Machine Operators

Objectives

1. To measure and document variation in work performance among logging-machine operators, and to assign relative contributions to this variation from sources within operators, between operators within firms, and between firms.
2. To relate individual operator characteristics of background, ability and motivation to work-performance in the use of logging machines, taking into account differences in environmental and operational factors.
3. To suggest ways in which performance-related criteria could be used to raise average levels of work performance in the operation of logging machines.

Methods

Forest workers chosen as subjects in the study were currently operators of tractor-mounted, hydraulic, tree-felling shears. This choice had a number of simplifying advantages:

(a) the tree shear is a standard, reliable and (in the study region) widely-used type of machine;
(b) felling is the first tree-processing phase in logging, and workers are delayed or pushed by activity in other phases of the production chain to a somewhat lesser degree than would be the case in, for example, skidding or loading;
(c) output performance can be readily measured, in terms of the number of trees felled in a given time period.

Both of the common styles of carrier — the bulldozer type (Fig. 2) and the loader type (Fig. 3) — were included in the study.

Sampling was limited to the northern portion of the Montane Forest Region (Rowe, 1972) centering around Prince George, B.C. This served to restrict variation in the major environmental factors (forest stand, terrain, climate), and in logging techniques, making it easier to assess the effects of human factors. Except for the choice of study location and machine type, there was no attempt to control environmental or operational conditions. Average conditions were recorded for each cutting block.

The sampling design had to meet two requirements. First, the sample had to be reasonably representative of the population of shear operators in the study region, so that conclusions could be generalized. Second, the sample had to permit a test of the extent to which variation in performance levels was attributable to differences between operators. A list was made of firms in the study region currently using two or more tree shears. (A "firm" included the major wood-using company, together with its logging contractors and sub-contractors.) Numbers were assigned to firms, and a random sample was drawn, with probability of selection proportional to the number of shears — roughly equivalent to the number of shear operators — in each firm. All shear operators in the selected firms were eligible for inclusion in the study.

Clearance for fieldwork was first obtained from managers in the selected firms. Then, the co-operation of supervisors, union representatives and, finally, the operators was sought. Nearly all of the individuals approached agreed to co-operate in the study.

Data collection involved several phases:

(a) interviewing shear operators to obtain information on individual characteristics;
(b) recording environmental (forest, terrain) conditions encountered by each operator over the study period;
(c) monitoring performance of each operator over the study period;
(d) recording machine characteristics, operating conditions, and organizational context for each operator.

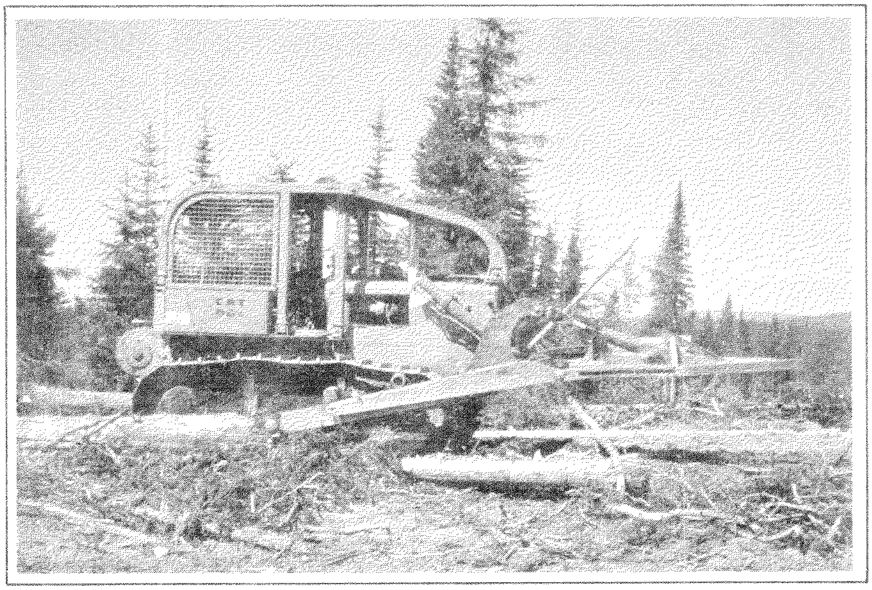

Figure 2. QM tree shear, mounted on Caterpillar D6C tractor.

Figure 3. QM tree shear, mounted on International Harvester 175 loader.

(a) Operator Interviews

A mobile camper-truck was equipped for the purpose of interviews with operators. The interviews were completed early in each operator's involvement in the study. In each case, assurances were given with regard to the confidentiality of information. The interviews generally occupied 1-2 hours, and were completed at a time convenient to the operator — usually in the evening, or during the weekend.

Subjects completed questionnaires dealing with personal background and work experience, job attitudes and interests, supervision and motivational factors (Appendix 1). The questionnaire items were compiled from a variety of published sources, but modified to be more suitable for this group. Some questionnaire items appeared on cards, which subjects placed into appropriately labelled slots in an "answer box", for later coding (Fig. 4).

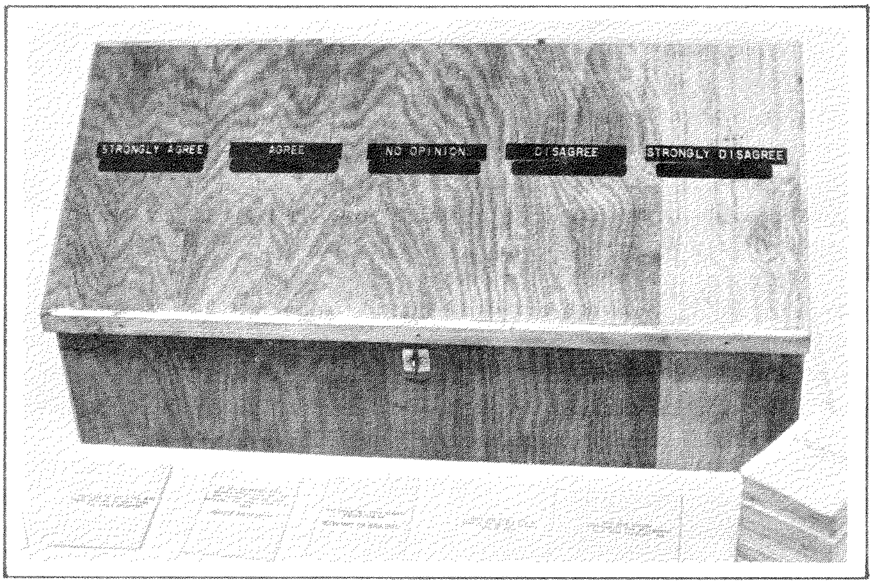

Figure 4. "Answer box" for questionnaire items in the operator interviews.

Another part of the interview involved exercises to assess individual aptitudes. The exercises included parts of the General Aptitude Test Battery (GATB) that seemed relevant to occupations involving operation of heavy equipment. The exercises (Appendix 2) comprised both paper and pencil, and apparatus tests, with time limitations for completion. Standard procedures for administration of the GATB were rigorously followed. Aptitudes assessed in this manner included motor co-ordination, manual dexterity, form perception and spatial aptitude.

Another aptitude measured was the visual depth perception of each subject. An adaptation of the Howard-Dolman Peg Test was used (Fig. 5), generally outside the camper or in a large room. The test requires a distance of 20 feet (6.1 m) between the subject and the apparatus, and well-lighted conditions.

The physical condition of shear operators was estimated using a simple fitness test (Appendix 3). The test develops a fitness score from simple measures of strength, stamina, suppleness and weight. While less detailed than alternative approaches, the test seemed sufficient for the exploratory purpose of the study, and offered the advantages of portability and easy administration.

In the final part of the interview, operators answered questions about operating methods and procedures. Their comments provided more insight into the nature of the work than could be gained from simple observation. Of particular importance were their statements on factors influencing the quality of the work.

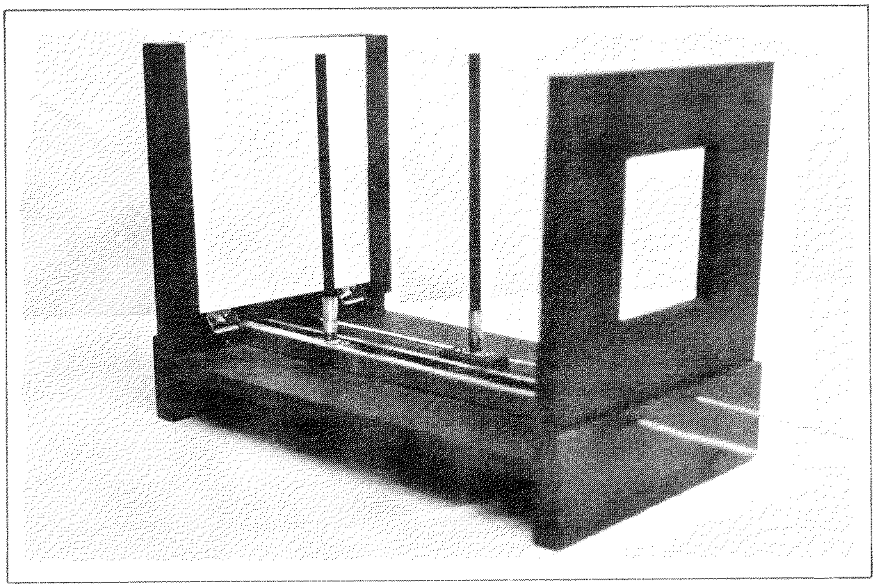

Figure 5. Two-peg apparatus used in measuring visual depth perception.

(b) Environmental Conditions

Forest stand information came, in all cases, from available maps and inventory data supplied by the firms involved in the study and local forest consultants. These data met the standards of accuracy required by the British Columbia Forest Service. The existing information was, therefore, sufficiently reliable and consistent across different firms, for use in the study. Since topographic maps were not generally available, the study crew estimated and broadly classified terrain factors in the field.

Field data included the identification number of each cutting block or area. Each shift worked could then be related to a cutting block of known forest and terrain conditions. Factors recorded included: merchantable and unmerchantable stems per acre, merchantable and unmerchantable volume per acre, species distribution, windfall, terrain class (Bennett, 1970) and predominant slope.

Generally, several forest types (and sometimes terrain types) occurred within the boundaries of an individual cutting block. Attempts to refine the recording of environmental conditions to the forest-type level were unsuccessful, because of the greater intensity of observation that would have been required. Hence, measures of forest and terrain conditions used in the study reflect *average* values for the cutting block, with each type being weighted in proportion to the area it occupied within the block.

(c) Monitoring Performance

As each operator joined the study, the study crew fitted his machine with a Model K Servis Recorder (Fig. 6). The operator was provided a hand tally counter, for counting merchantable trees cut (live coniferous trees, 7.1 inches (18 cm) and greater dbh, containing 50% or more of sound wood). There was also a lockable box for storing new and used charts (Fig. 7). Each operator was instructed in the use of the Servis Recorder, and in the manner of completing the shift reports on the face of the charts (Fig. 8).

Operators recorded productive tree-felling time, "other" productive time (e.g., skidding), and delay times and causes, according to standard time definitions (Bérard *et al.*, 1968). They recorded the number of merchantable trees felled each shift, and the cutting block identification. Periodically the study crew would return to the operator, to check on the Recorder functioning, collect completed shift reports, and discuss them with the operator. The objective was to obtain data on about 30 shifts for each operator during his involvement in the study.

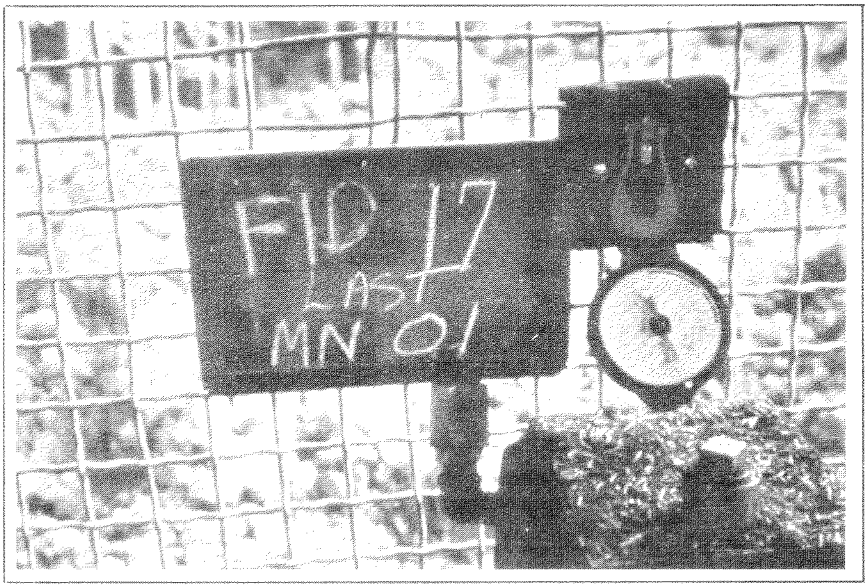

Figure 6.

Model K Servis Recorder (open to show chart) mounted on wire mesh inside shear operator's cab. A stylus on the vertical swinging pendulum records vehicle movement by inscribing a track on the wax-coated chart.

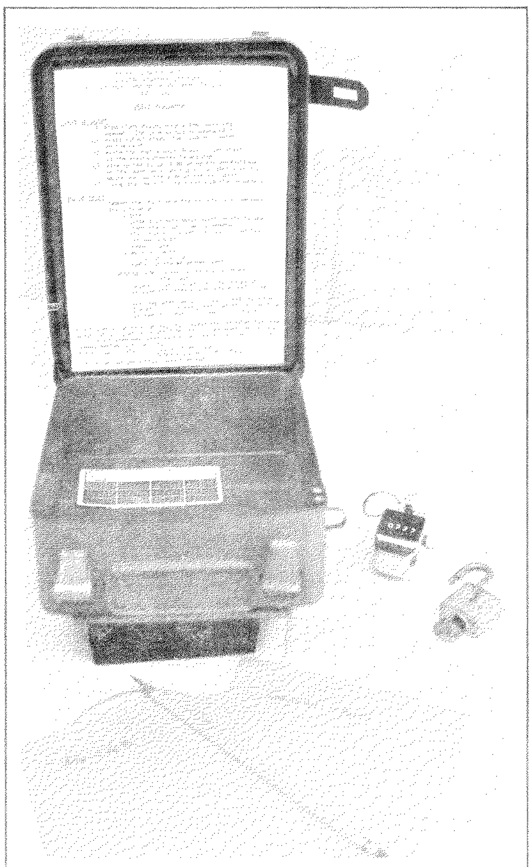

Figure 7. Operator's chartbox, with instructions, tally counter, supply of charts and lock.

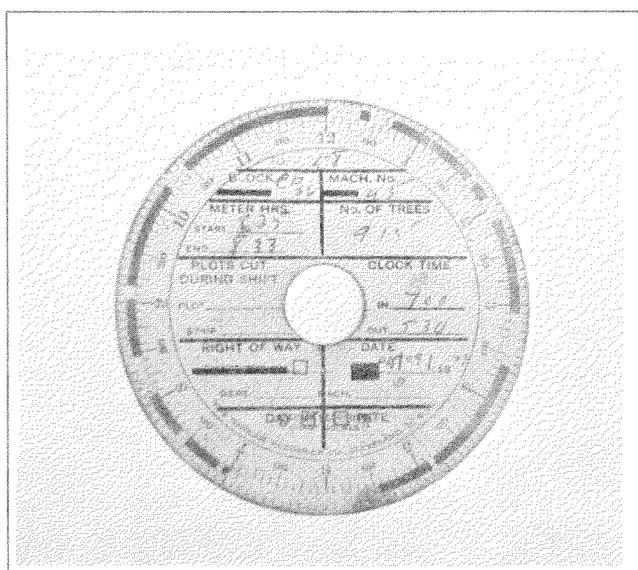

Figure 8. A completed Servis Recorder chart.

In addition to the shift-level recording, the field crew carried out detailed timing of work cycles for the felling of individual trees. Timing was for periods of about 1 hour, replicated several times for each operator, during the periodic field visits. These data aided in describing differences among operators in working technique, and as a short-term check on the accuracy of operators' tree counts. Individual tree characteristics were not recorded, other than to note the occurrence of special problems such as large tree, leaning tree, and forked butt.

Two aspects of the quality of operator performance in tree shearing were considered: the extent of damage to the butts of felled trees; and, the operator's felling pattern. The first affects the product recovery, and so the end value of logs. The second influences the productivity of subsequent skidding operations, and so the cost of logs. During each return visit to the operators, the field study crew randomly selected a number of sound felled trees representing the local range in butt diameter and species being harvested. With a chainsaw, 2-inch (5 cm) discs were cut every 6 inches (15 cm) up the bole to determine the nature and extent of shear damage. The object was to see whether there were any differences between operators in the ability to control butt damage during shearing.

Felling pattern was harder to evaluate in a way that would be representative of the overall study period and conditions. Information on this aspect of performance was obtained informally, through observation of each operator during detailed timing, the operator interviews, and discussions with supervisors and skidder operators.

(d) Operating Conditions and Organizational Context

Each tree shear unit in the study was fully described, including condition and auxiliary equipment. Of particular interest were modifications designed to improve shear performance, and evidence of major repairs.

Both operators and supervisors provided descriptions of standard operational layout and procedures. This included their approach to the cutting of right-of-way for roads, the initial opening up of the block of timber, and the location of separate cutting strips so one shear could serve up to six skidding units.

Finally, information descriptive of the organization was obtained from each co-operating firm. This provided more insight into the work context (technical, economic, social) of the operators, and factors that could have significance for employee motivation. These included: the size of firm, in terms of number of employees; volume of wood produced annually, whether integrated or strictly logging; and machines and systems being used. Systems of payment for operators, whether contract, piece rate or hourly, were also noted.

Hypotheses

The study design and data gathering were aimed at testing only a few simple hypotheses. The first hypothesis was that wide variation in performance (particularly output) would be observed in a random sample of operators, even for a relatively mechanized job such as tree felling with shears. The second hypothesis was that differences among operators would account for the bulk of the observed variation in performance among shear operators. And the third hypothesis was that observed variation in performance would be associated with measurable differences among operators, in terms of aptitudes, experience and motivation — after adjustment for significant environmental and operating conditions. Appendix 4 discusses analytical models for testing these hypotheses.

Results and Analyses

The Sample

A total of 34 operators of tree-felling shears took part in the study. They represented 9 "firms", comprising 25 individual logging companies and contractors. This sample constituted about 50% of the firms and shear operators available in the study region at that time. Interviews with operators were successfully completed, following an initial test of methods.

Although the study sought information for 30 shifts per man, this was achieved for only about one-half of the operators. The most common reasons for lost or unusable shifts included: Machine downtime (both mechanical and non-mechanical); operator turnover; operator error in recording; and, Servis Recorder malfunction. The usable data represent 757 shifts of tree-felling activity by men in the study, over the period June to December 1973. Felling occurred in 86 separate cutting blocks.

The field crew completed 54 periods of detailed timing of tree-felling cycles, during which the study operators cut more than 5,000 merchantable trees. Sampling for shear damage covered the range of species and diameters, and totalled 448 trees.

Forest Conditions

Table 1 summarizes the forest conditions encountered during the study. Principal species in the area were western white spruce (*Picea engelmannii* Parry), and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Spruce stands generally had larger volumes per tree and per acre, with fewer trees per acre than the pine types. The pine stands occurred commonly on flat to gently undulating alluvial plains, while spruce stands occupied more steeply sloping uplands. A limited transition zone occurred between them.

One-half of the cutting blocks occurred on essentially flat terrain. In only 10% of the blocks did the predominant slope exceed 30%.

Inventory information on occurrence of snags (dead standing trees) and windfalls was sporadic. For 33 stands where such information was available, these unmerchantable stems numbered about 30 per acre (74 per hectare). Broadleaved species were not common in the stands observed.

TABLE 1 — Forest Conditions Observed During Shear Study.

Factor	Range	Average[1]	Standard Deviation
Number of merchantable trees/acre (trees/hectare)	116-312 (287-771)	213 (526)	53 (131)
Merchantable volume/tree ft^3 (m^3)	12-49 (.34-1.37)	22 (.62)	8 (.22)
Merchantable volume cunits/acre (m^3/hectare)	18-74 (124-512)	46 (318)	13 (90)
Percent spruce (by volume)	0-80	32	22
Percent pine (by volume)	0-100	57	29

[1]N = 86 cutting blocks. SI units in parentheses.

Observations from the Interviews

Background and Experience

Thirty-two of the operators were native to Canada, although only three were native to British Columbia. Two-thirds came from a rural family background, in which the father was employed in agriculture or the forest industry. Over 50% of the respondents said that their fathers had been self-employed. Their age, at the time of the study, was distributed as shown in Fig. 9, the average being about 35 years. An eighth-grade education was most common (Fig. 10). None of the respondents had completed high school.

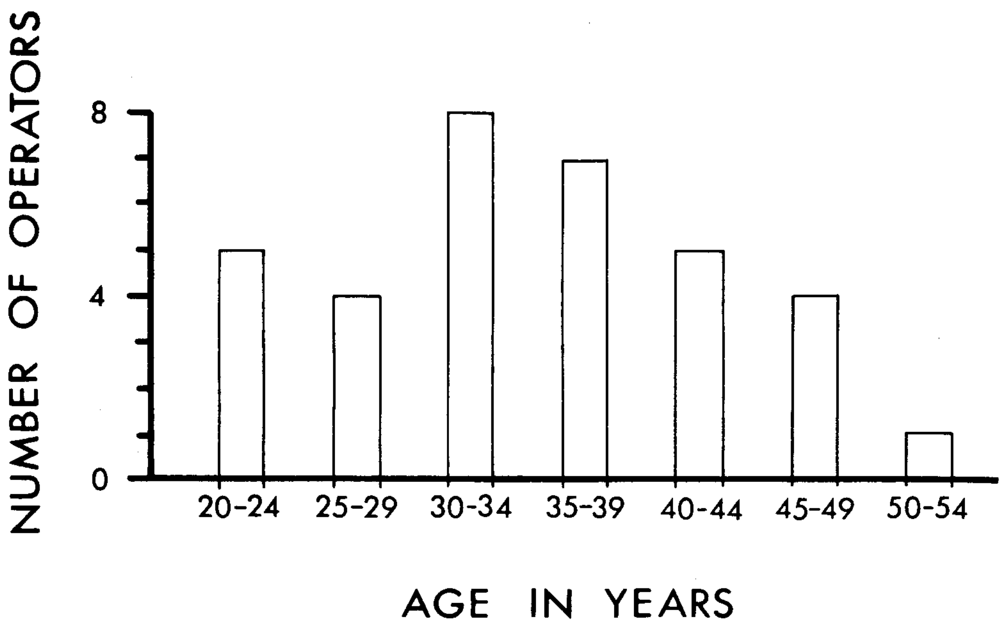

Figure 9. Age distribution of tree-shear operators.

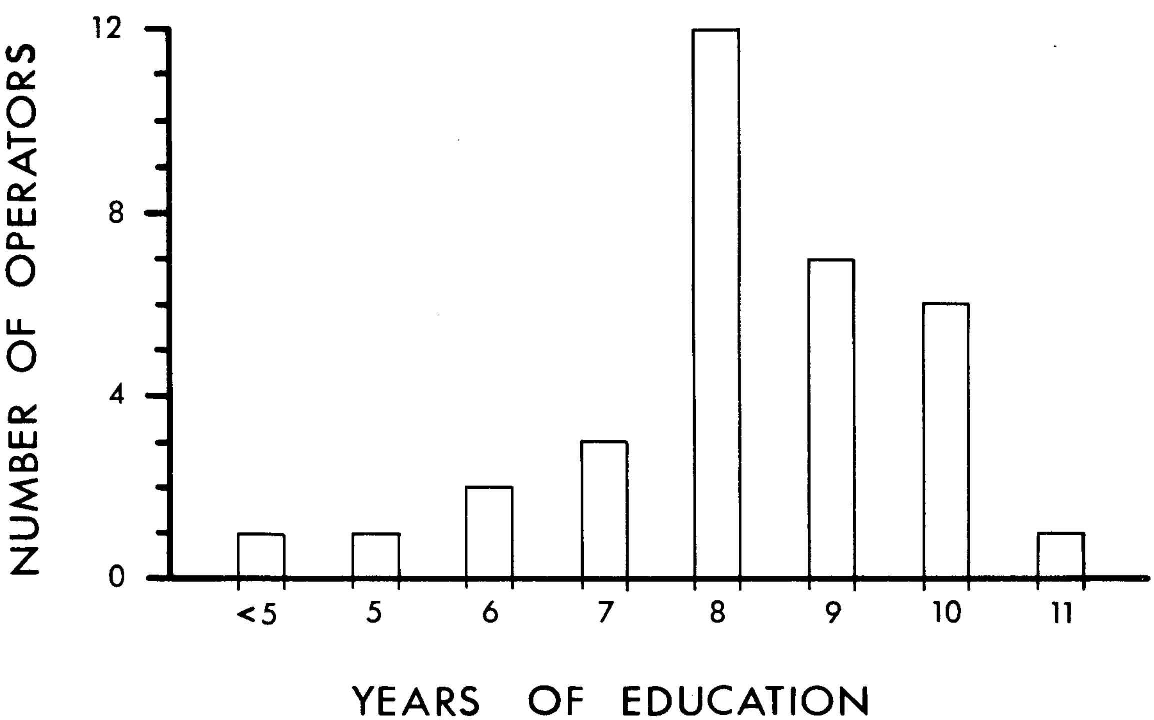

Figure 10. Distribution of years of education completed by tree-shear operators.

Twenty-eight (about 80%) were married, with an average of 2.5 dependants. Three-quarters of the workers owned or were purchasing their own home, which was usually within 25 miles of their work site. Most of the men were able to commute to work daily from their homes.

Their work experience ranged from 5 to 39 years (average 18.9) in the labour force. Not all of this time was necessarily spent in the forest industry, but the majority had been in forest work for over 8 years. None had taken formal instruction in the operation of shears, and only one had had vocational training in the operation of tractors. Two of the men had completed courses in heavy-duty mechanics (in the case of one man, a 4-year apprenticeship).

Experience on shears varied among operators from one month up to 60 months (5 years). Half of the sampled individuals had operated shears for 9 months or less. Eight men had 3 years or more experience with shears. This provided a range of time on the job which could produce important differences in acquired ability (although less able operators, in general, may not stay at the job for long).

Thirteen of the operators had worked for their present firm for 2 years or more. However, most felt they would probably remain with their firm for at least another 2 years. Almost two-thirds indicated that they liked to change the type of work they did every year or two — perhaps to increase the level of job interest. Six men were union members.

Only 10 men said that they had experienced no unemployment in the past 2 years. One or two months were commonly lost each year for winter "freeze-up" and spring "break-up". Working time lost due to illness or injury was rare.

Aptitudes

(1) General Aptitudes

Scoring for the GATB is set up so that a random sample of people from the general working population would, on the average, score 100, with a standard deviation of 20. Results from administration of the tests to shear operators appear in Table 2. There is a good range in scores for each aptitude measure, which permits some evaluation of the degree of association between aptitudes and performance. The motor co-ordination and manual dexterity scores for shear operators were noticeably below established norms for the general working population. A score of 80 is one standard deviation below the average and represents the 16th percentile for the general working population. That is, 16 percent of the general population would score below 80; 84 percent would score 80 or above[1].

[1] Section II: The Manual for the General Aptitude Test Battery, p.359. (See Appendix 2)

TABLE 2 — Aptitude Scores From the GATB.

Trait	Range	Average	Standard Deviation	n[1]
Motor co-ordination	49-117	81	23	33
Manual dexterity	47-112	76	22	33
Form perception	59-134	94	19	34
Spatial aptitude	68-117	94	14	34

[1] An injury prevented one subject from taking the tests of motor co-ordination and manual dexterity.

(2) Visual depth Perception

The visual depth perception score was obtained by summing the distances (measured in inches) by which the movable peg differed from the position of the fixed peg in the Howard-Dolman apparatus (Fig. 5) taken over three trials for each subject. A total score of 3 inches (7.6 cm) or less is considered to be within the range of "normal" depth perception. By this standard, 9 of the 34 subjects scored "poorer than normal" in depth perception.

(3) Physical Fitness

Scores on the fitness test can range from 0 to 50. A total of 46-50 shows extreme fitness; 40 -45, above average; 30-39 is average; 20-29, below average; and less than 20 indicates a possible medical problem.

One-half of the sampled operators scored fewer than 30 points (Fig. 11). The results indicate that certain types of exercise are lacking in their work.

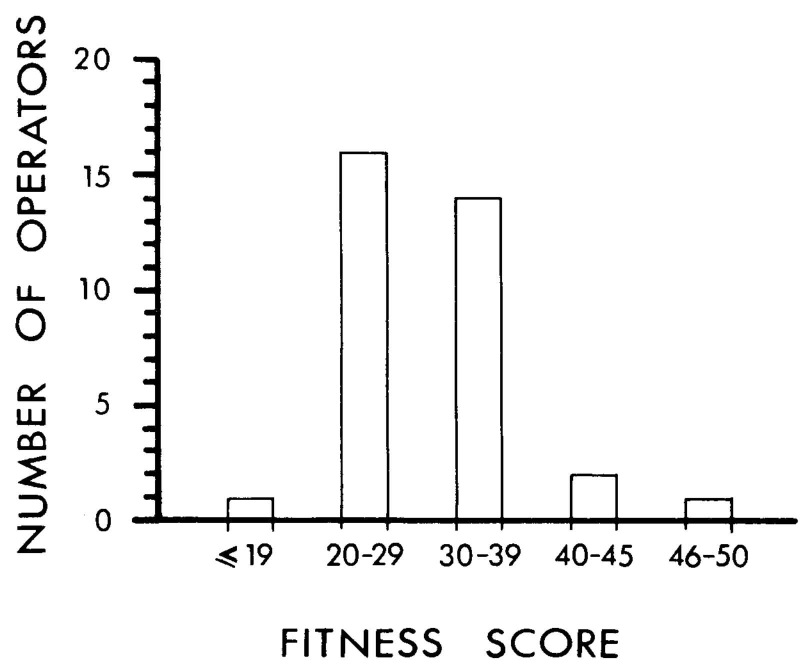

Figure 11. Distribution of scores from the physical fitness test.

Motivation

The motivation section of the questionnaire was designed to permit analysis following the general pattern of the Vroom (1964) expectancy theory[1] (Appendix 4). The theory proposes a link between job performance and the attainment of work goals, based on the worker's perception of three types of factors; namely, "importance", "instrumentality", and "expectancy". Importance is the individual's subjective rating of the importance to him of various work goals. Instrumentality is the connection the worker perceives between high job performance and the goals important to him. Expectancy is the probability, as the worker perceives it, that an action on his part will result in high performance.

Figure 12 summarizes job-factor importance ratings given by shear operators, where higher values denote greater importance attached to the job factors. Highly rated in importance were the job factors: "reputation in the industry", "steady job", "control over work pace", "sense of accomplishment", "good pay", and general "job satisfaction". Of somewhat lower importance, on the average, were factors: "respect from supervisor and fellow workers", "more say in the job", and "time with the family". Rated relatively low in importance were the job factors: "assignment to a more pleasant job", "promotion", and "time to talk on the job".

[1]For this study, items in the questionnaire and their wording were altered somewhat from the usual format. Hence, the results do not constitute a replication of earlier published work in this field.

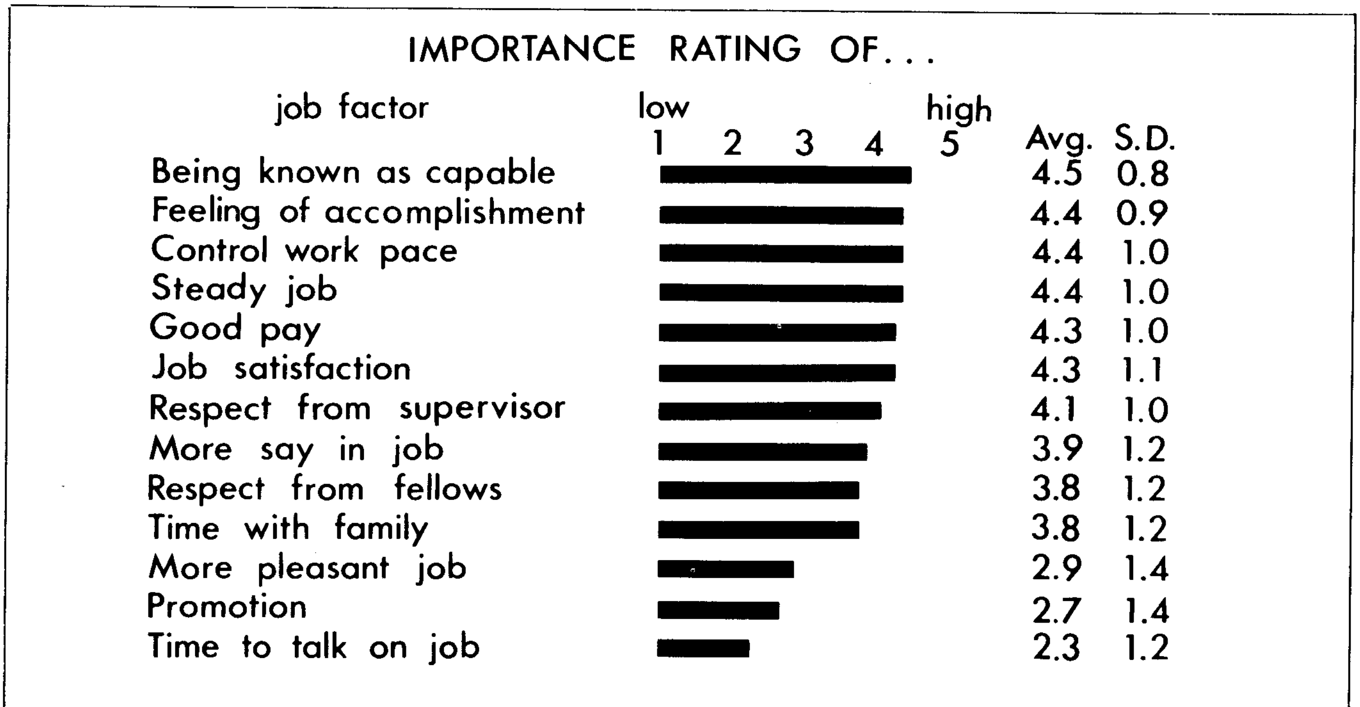

Figure 12. Importance of 13 job factors, as rated by shear operators.

Figure 13 shows the instrumentality ratings connecting productivity to various job factors. Subjects generally agreed that increased productivity had a high degree of instrumentality in achieving: "a sense of accomplishment", "job satisfaction", "reputation in the industry", and "control over work pace". They perceived a weaker connection between increased productivity and the outcome of: "respect from supervisor and fellow workers", "more say in the job", "job security", "pay", and "time with the family". They generally disagreed that increased productivity would lead to "promotion", "assignment to a more pleasant job", or "more time to talk to others on the job".

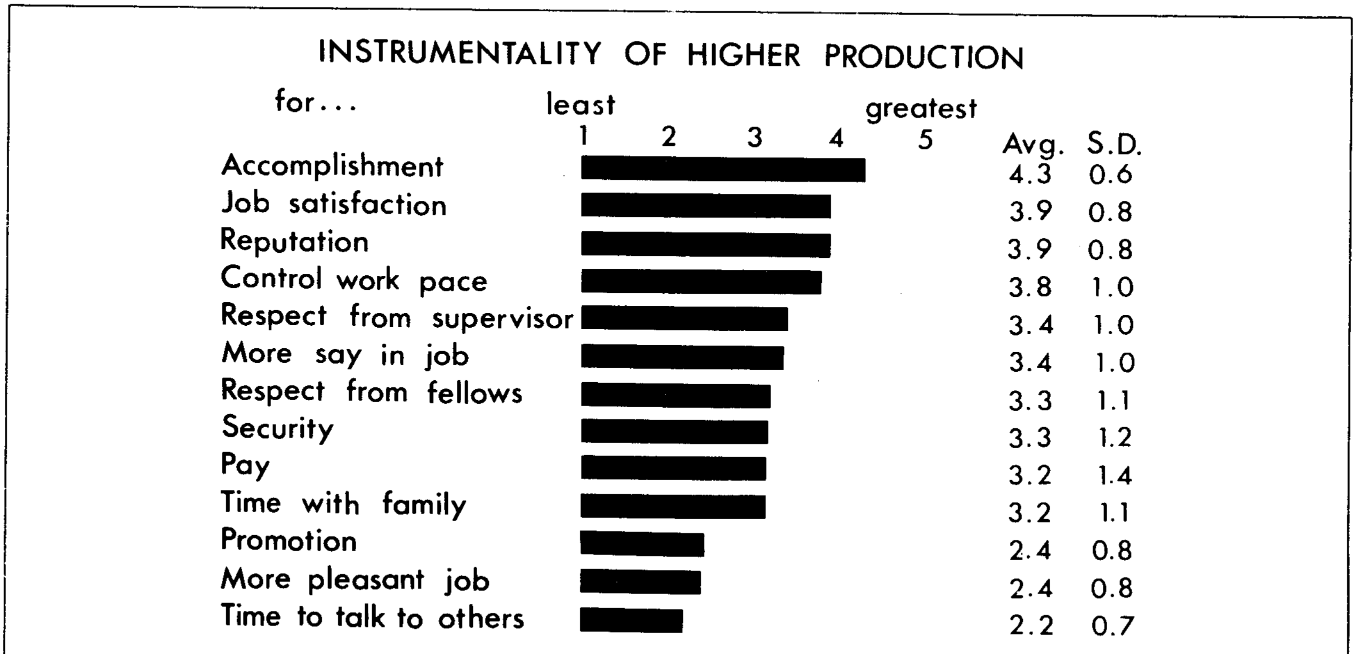

Figure 13. Instrumentality of higher production for achieving job outcomes, as rated by shear operators.

Figure 14 shows operators' expectancy ratings for five behaviours that could lead to higher production. Training programs were rather lightly regarded, as was the supervisor's advice and instructions. On the other hand, experience and the example of superior operators were highly rated. There was mixed feeling about whether "working harder" would lead to increased productivity.

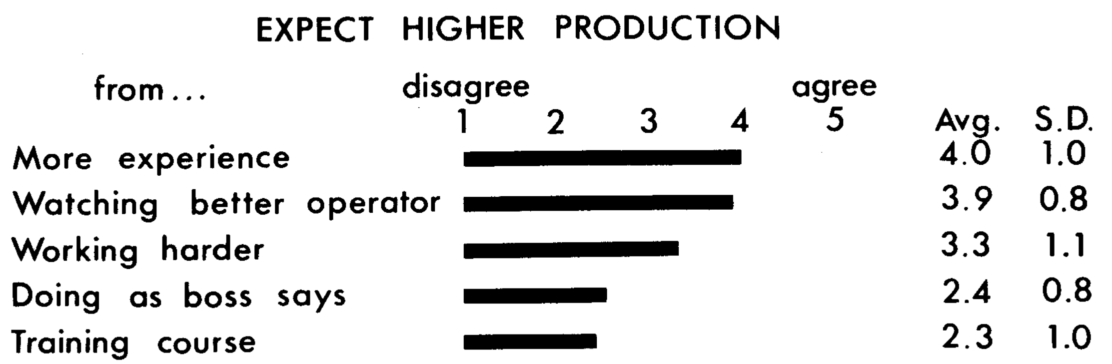

Figure 14. Expectancy of five behavioural "routes" to higher production, as rated by shear operators.

Attitudes

(1) Organizations

More than one-quarter of the men in the sample were owner-operators, each sub-contracting to a main logging contractor. Several contractors employed operators on a piece-work (per tree) or production bonus basis. In all, just over one-third of the shear operators had some form of economic incentive for production. Most operators, however, were the employees of contractors, paid on an hourly or salaried basis. A few shear operators were employees of the larger forest companies that control timber quotas and process logs.

Four questionnaire items dealt with the topic of conflict between operators and the firms employing them. Most operators (25 out of 34) agreed that "this firm is better to work for than most in the local logging business", indicating a certain degree of loyalty to the organization. Improved productivity seemed a worthwhile goal, since 20 of the 34 operators agreed that their crew, as well as the firm, would benefit if the operation produced more logs. Only five men disagreed with this.

Responses to the statements "If the demand for logs fell, this firm would find ways to avoid laying off its employees", and "this firm is only interested in production and profit" were confusing, since about one-half of the operators agreed in both cases. Only four men disagreed with the first statement and agreed with the second — responses that indicate they view their interests as conflicting with those of their employer. There could be several reasons for the absence of a clear pattern in their responses: respondents may have lacked the information necessary to form an opinion; respondents may have been strongly motivated to provide "expected" or "neutral" answers on this subject; and/or, the statements to which subjects responded may not be of sufficient value for defining complex attitudes.

(2) Work Groups

The operators' *sense of competition* in their work was examined through four questionnaire items. There was nearly unanimous agreement with the statements: "You try to better your previous best day's output", and "you like to cut enough trees each day to keep the skidders busy". Answers to the first statement reflect the operators' interest in evidence of their increasing operating skill. Even experienced operators occasionally have an opportunity to better their previous best day's output. For some, this personal challenge adds interest to the job. Only about one-half of the operators were currently satisfied with the production rate. On the other hand, competition with other operators seemed less acceptable, as fewer than one-half of the respondents agreed with the statement "you like to cut a few more trees per day or week than the other operators". Keeping the skidders busy seemed a point of pride in the shear operators' view of the job. They commonly felled trees for four, and sometimes as many as six skidder operators, who usually were paid by piece rate. Keeping the skidders well supplied with felled timber reduced the likelihood of conflict with fellow workers, as well as supervisors.

Six items were included in the questionnaire to assess aspects of *group co-operation*, as perceived by the shear operators. These items were subjected to factor analysis[1] (with orthogonal rotation), which yielded two relatively independent factors:

Items of Factor 1	Factor Loading
Men in this crew are friendly	.694
Men on this operation like their jobs	.764
The crew often makes improvements in the way they do the work	.538

An index score based on the three items of Factor I was not significantly associated with expressions of job satisfaction, or output (i.e., trees cut per hour). However, the composition of Factor 1 suggests the three items can be useful for defining a group co-operation, or group spirit, dimension in future study of work-group characteristics. A questionnaire item referring to the operator's likelihood of changing to another crew, to do the same work for the same pay, had a high loading (.943) on Factor 2. Most respondents would not have made this change, which suggests that Factor 2 represents a measure of cohesiveness in the crew. Questionnaire items "the men in this crew work as a team", and "the men in this crew help each other on the job" failed to load significantly on either Factor 1 or 2.

(3) Supervision

Research in supervisory behaviour has usually focussed on the behavioural dimensions of structure and consideration. The following definitions are used:

> STRUCTURE: includes behaviour in which the supervisor organizes and defines group activities and his relation to the group. He defines the role he expects each member to assume, assigns tasks, plans ahead, establishes ways of getting things done, and pushes for production. This dimension emphasizes overt attempts to achieve organizational goals.
>
> CONSIDERATION: includes behaviour indicating mutual trust, respect, warmth and rapport between the supervisor and his group. This does not mean simply the superficial "pat-on-the-back", first-name-calling kind of human relations behaviour. "Consideration" emphasizes a deeper concern for group members' needs and includes such behaviour as allowing subordinates to participate in decisions, and encouraging two-way communication[2].

Factor analysis of responses to the twelve statements in the questionnaire relating to supervisory behaviour did not reveal a clear separation of "structure" versus "consideration" items. However, the responses are indicative of how the operators view their supervisors.

[1]For a brief discussion of factor analysis see: Nie, N.H., Hull, C.H., Jenkins, J., Steinbrenner, K., and Bent, D.H. Statistical package for the social sciences—second edition. McGraw-Hill, Toronto. 1975. (Chapter 24.)

[2]Stodgill, R.M. Manual for the Leadership Behavior Description Questionnaire, Form XII. Ohio State Univ., Columbus, Ohio. 1963. For a discussion of the linkage between leader behaviour (in terms of structure versus consideration), motivation and job satisfaction see: Evans, M.G. Leadership and motivation, a core concept. Academy of Management Jour. 13: 91-102. 1970.

Operators substantially agreed with statements that their supervisor "is friendly and easy to talk to about problems connected with the job", "gives the men on this operation clear instructions", "usually tries to explain his actions to the crew", "puts your suggestions into operation", "organizes the work in advance", and "stresses to your crew the importance of their jobs". Just over one-half of the operators agreed that their supervisor "sets definite standards of work", and "encourages your crew to make suggestions about your work". This is supported by responses to a later statement in the questionnaire: "your supervisor decides how your crew has to do its work and you have little say in this", with which the same number of operators disagreed. The statements which drew the most mixed response were: "your supervisor spends his time supervising rather than getting involved in the actual work", and, "your supervisor spends little time showing your crew how to improve its performance". Twenty-one operators agreed that their supervisor "is competent in his job", nine did not express an opinion and four disagreed. The supervisor's rated competence was most strongly associated with comments that he "organizes the work in advance", "gives the men clear instructions", and "is friendly and easy to talk to".

Operators were asked whether their supervisors set production goals. Fourteen operators said their supervisor did not set a definite production goal, and simply expected them to do their best to keep the skidders supplied with felled trees. The rest reported that the supervisor set a general goal, which varied between 600 and 1,200 trees per day (average about 900) depending upon the conditions. Operators also estimated the number of trees they might expect to fell on an "average", a "good", or a "bad" day (excluding the possibility of unscheduled delays). Estimates for "bad" days averaged 500 trees, for "good" days 1,100 trees, and for "average" days 800 trees. Operators whose supervisors set definite goals estimated an average day's production at 835 trees, a little higher than the average-day estimate of all operators together. However, the measured performance over the study period did not support their expectation. There appeared to be little difference in average output between operators whose supervisors set production goals and operators whose supervisors did not set goals. The combination of active supervision with goal setting showed no direct association with higher operator performance either. Possibly the effects of differences in supervisory style would be detected with wider sampling over a longer time period. Another possibility is that goal setting and active supervision are more important to system performance than to individual output.

(4) Job Satisfaction and Involvement

Thirty-one operators agreed with the statement "generally speaking, you are very satisfied with your job". The degree of job satisfaction had a significant positive correlation ($r = .29$, $p < .05$ one-tail test) with responses to the statement "your supervisor is friendly and easy to talk to", and a strong negative correlation ($r = -.42$, $p < .01$ one-tail test; $p < 05$, two-tail test) with responses to the statement "your supervisor decides how the work is to be done, and you have little say". This suggests that a good relationship with the supervisor and freedom to choose work methods are important factors in the shear operator's job satisfaction.

Most of the operators found their jobs challenging and expressed a personal involvement in them. About one-third said the job was "often boring" and disagreed with the statement that "other jobs which you could get would not be as interesting as this". On the other hand, one-third found the job sometimes made them "jumpy", causing them to worry. (There was no apparent relationship between expressions of boredom versus worry concerning the job.) All of the operators felt "a sense of accomplishment" when they did the work well. However, fewer than one-half felt they were "perfectionists" about their work. Most also agreed that they were "learning new things about the job every day".

(5) Self-Rated Effort, Ability and Performance

The respondents unanimously agreed that they "put a lot of effort" into their work. Inhibitions against invidious comparison with other workers seem responsible for the fact that only 5 men agreed that they "work harder than the average operator", while 15 disagreed and the remainder expressed no opinion. Few disagreed that they had the ability or the necessary knowledge to do the job well.

(6) Work Rewards

Operators reported that fringe benefits were the least satisfactory category of work rewards. Only one-third of the operators thought their fringe benefits (e.g., travel pay, health coverage) were sufficient, whereas two-thirds thought their pay was adequate. "Time with family and friends", "time to talk with other employees", and "variety" in the job were seen as insufficient by up to one-quarter of the shear operators. Operators were in agreement that they exercised "enough control over the work pace". There seemed to be no problem, generally, regarding job security, respect from supervisors or fellow workers, opportunities for promotion or re-assignment, or in their influence over work methods.

Performance

The study included two aspects of work performance of shear operators: productivity, and quality of felling.

Productivity

This is the rate of production, in terms of number of trees cut per productive machine hour (PMH) spent in felling. The sample

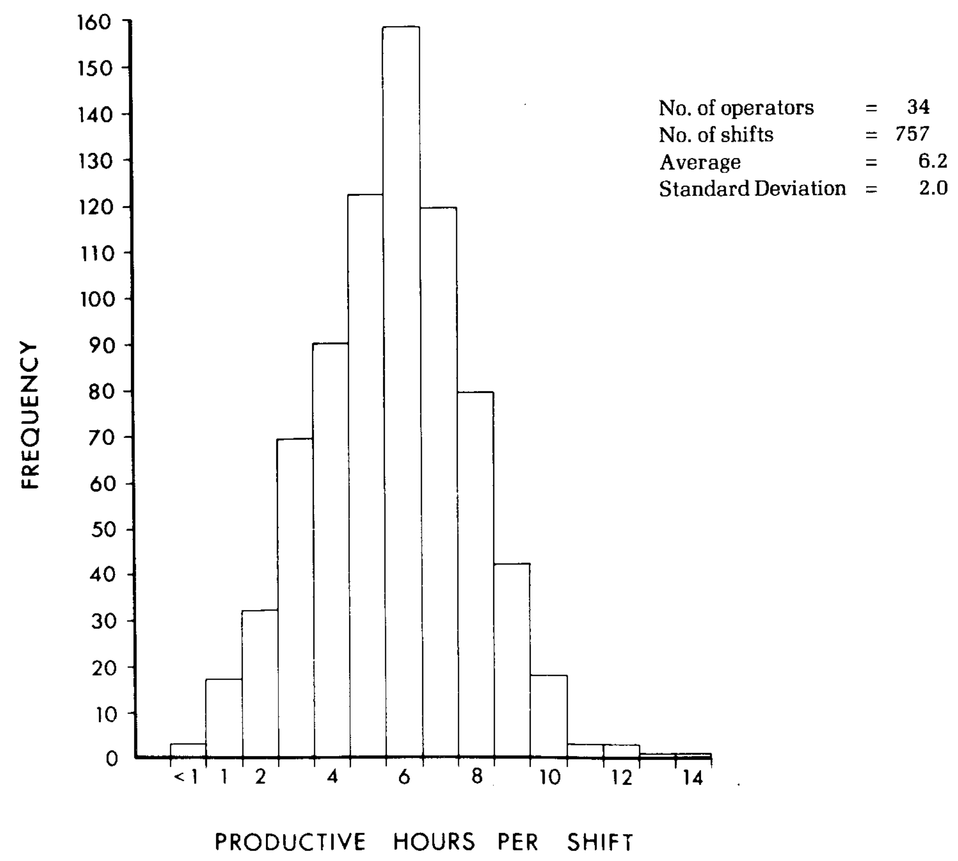

Figure 15. Distribution of Productive Machine-Hours (PMH) per shift (tree felling with tractor-mounted shears).

provided total PMH and total trees felled for each shift, from which productivity was calculated.

PMH varied widely (Fig. 15) because of differences in scheduled shift length, the use of the tractors in productive activities other than felling for part of some shifts, mechanical delays, and various non-mechanical delays.

Total production — the number of trees cut per shift — also varied considerably (Fig. 16). Reasons included varying shift length (overtime, downtime), scheduling of other activities for the machine or operator, varying forest or terrain conditions and differences in the operators' rates of felling.

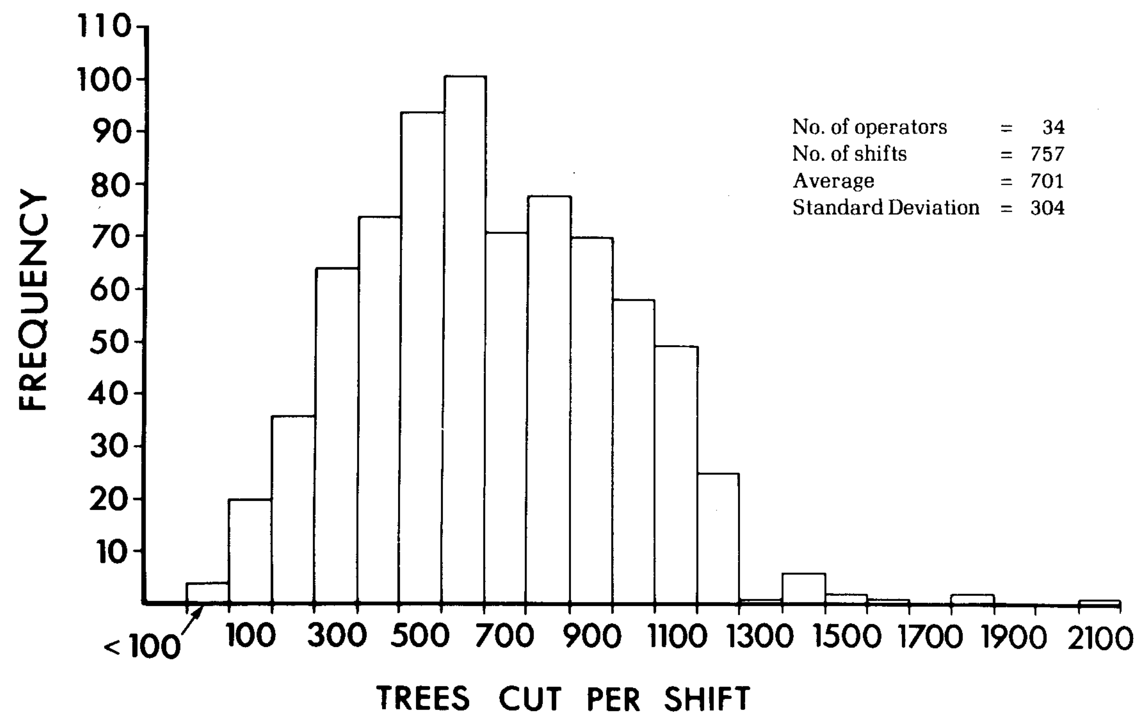

Figure 16. Distribution of number of trees cut per shift (tree felling with tractor-mounted shears).

Figure 17 shows that productivity for individual shifts ranged from 30 to over 200 trees cut per PMH. Considerable variation in output is evident even when expressed in these standard time units.

Differences among shear operators are apparent when they are compared on the basis of average productivity during their period in the study (Fig. 18). There are examples of outstandingly low and high productivity, but most operators fall into the range 70-130 trees per PMH. Almost one-third of the sample group is clustered in the 110-trees-per-hour category. Nevertheless, the general picture supports the first hypothesis: there is important variability in the output performance of shear operators.

Differences in average productivity (unadjusted for operating and environmental conditions) of high versus low performers easily exceed 100 percent.

Analysis of variance (Appendix 4) showed that about one-third of the observed variance in productivity is assignable to the source "shifts within operators". Possible explanations could include day-to-day changes in the condition of the machine or its operator, forest and terrain conditions, and weather. Few of these factors were recorded on a daily basis in the study, so their separate effects cannot be evaluated.

The next source level, "between operators within firms", accounted for almost two-thirds of the observed variance in productivity. The result supports the second hypothesis: most of the

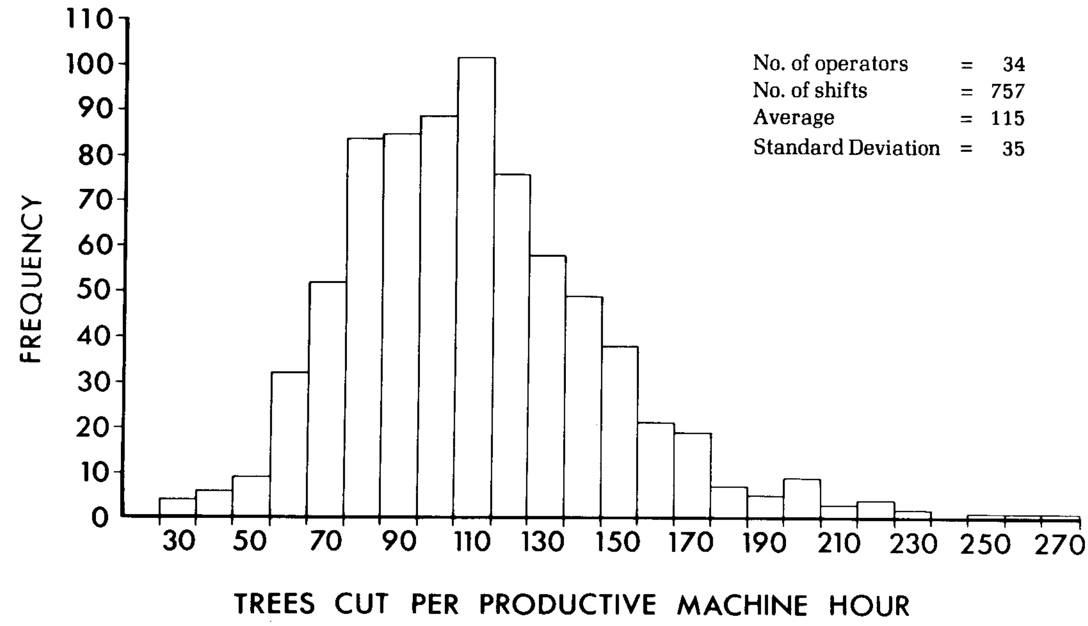

Figure 17. Distribution of number of trees cut per PMH, for individual shifts (tree felling with tractor-mounted shears).

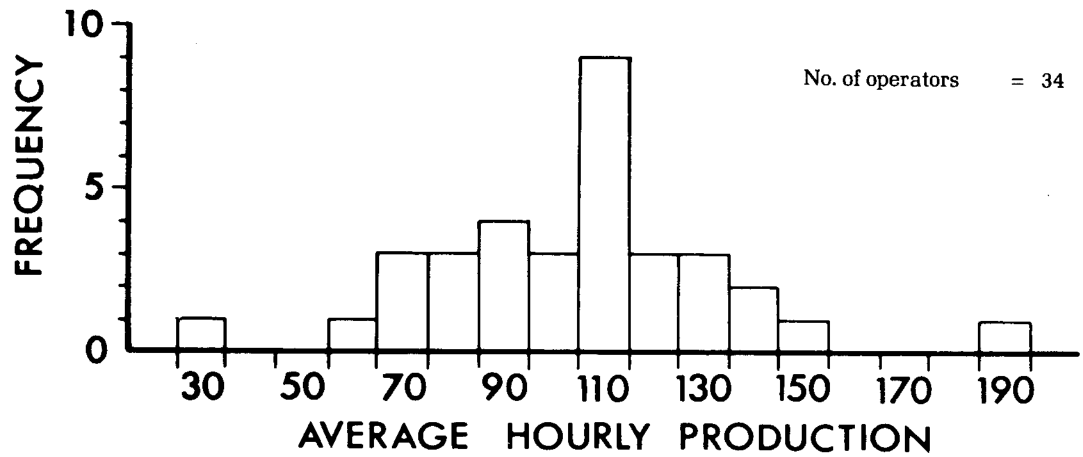

Figure 18. Distribution of average productivity (trees cut per PMH) of shear operators during the study.

observed variation in performance is assignable to differences among operators. Explanations for these differences could include the variety of personal factors that have been outlined, the environmental and operating conditions encountered, or a combination of these factors. However, analysis of variance cannot help with determining the relative importance of personal, environmental and operating factors in relation to observed levels of productivity. For this, the multivariate regression procedure is required.

The final source level, "between firms", accounted for only a small proportion of the observed variance in productivity. That is, any of the firms observed was as likely to experience high or low shear operator performance as any other firm. This could indicate that the firms have a common difficulty in their attempts to recruit and keep highly productive shear operators. It can also mean that the definition of "firm" (that is, the major wood-using company and its contractors and sub-contractors) does not reflect the real situation very well. Between independent operating units within the firm, there may be differences in organization that influence the performance levels of operators.

Relationships between the measured characteristics of operators and their observed production levels (with adjustment for environmental conditions) were examined[1] using multiple regression analysis (Appendix 4). This showed that the number of trees cut per PMH was associated significantly with:

- depth perception test score;
- length of experience using tree shears;
- manual dexterity score;
- "expectancy" or motivation score.

The nomogram (Fig. 19) illustrates the calculated relationships among these variables, and includes an initial adjustment for differing forest conditions using the variable "number of merchantable trees per acre". ("Trees per acre" was highly correlated with other stand factors, such as stand volume and volume per tree, species, topography and site type. Its role in this analysis is to adjust observed performance, to take account of varying stand conditions encountered by different machine operators.)

[1] Analyses used the forward inclusion (step up) procedure provided in: Bjerring, J.H., and Seagraves, P. UBC TRIP — Triangular Regression Package. University of British Columbia Computing Centre, Vancouver. 1974. 120 pp.

The first three factors above — depth perception, experience, and manual dexterity — can be readily determined in interviews or test exercises. They may have predictive value for the selection of personnel. The motivational factor is explanatory in nature rather than predictive, since it would be difficult to assess motivation reliably in a job selection process. It may be too easy for a subject to guess the "correct", or more desired response to questionnaire items, especially if it meant getting the job.

Depth perception logically affects the operator's skill in planning the sequence of felling, in driving from one tree to the next, and in positioning the shear accurately on the tree to be felled. Figure 19 indicates that operators in this sample who scored "poorer than normal" in depth perception averaged about 34 fewer trees per PMH than operators who scored "normal", other factors being equal.

Length of experience is also of logical importance, since it relates to the variety of situations the operator has learned to deal with. Both the operators (Fig. 14) and personnel officers agree on this point. For the range of experience observed, each additional month of experience contributed 0.65 tree per PMH to productivity. An operator with one year of experience, for example, cut about 7 trees per PMH more than an operator with one month of experience, other factors being equal.

The manual dexterity score is presumably associated with an operator's ability to co-ordinate visual information with arm and hand movements in tractor driving. In this study, the difference between operators scoring 80, versus operators scoring 100 (the general population average) was about 13 trees per PMH, other factors being equal.

Regression analysis using "trees felled per shift" as the dependent variable produced essentially the same results. The variables "trees per acre" and "PMH per shift" adjusted for differences in operating conditions and shift length, and the same four measures of operator characteristics were significant.

There is a question whether operators with high production levels per hour accomplish this at the expense of more machine breakdown, getting stuck more often, or increased accidents. This is not readily answered from these data, since the causes of delays were not adequately recorded in all cases. The lack of a significant

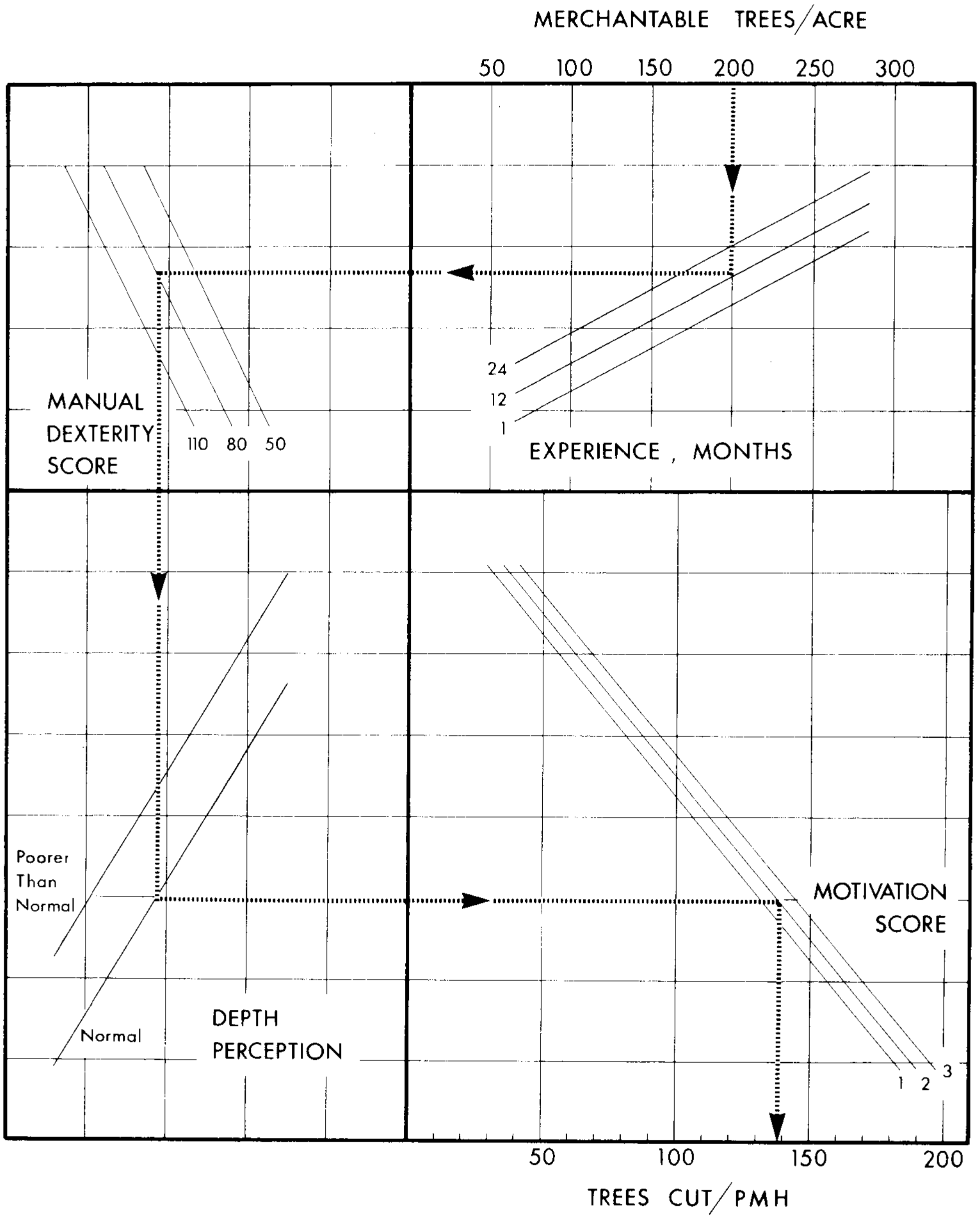

Figure 19. Nomogram showing calculated[1] relationships between performance (no. of trees cut per PMH) and measures of operator characteristics, with initial adjustment for forest stand factors.

[1] The regression equation is: Trees cut/PMH = 22.92 + 0.21 (no. merchantable trees/acre) + 0.65 (months experience) + 0.65 (manual dexterity score) − 33.85 (if depth perception poorer than normal) + 6.37 (motivation score). $R^2 = 0.59$; $S.E._y = 23$. All regression coefficients significant beyond $p_{.01}$ level as conventionally indicated. The unit of observation is an operator cutting in a defined block of timber. Calculations are based on 82 such observations, for 33 operators. (One operator was omitted because he could not take manual dexterity test.) Conversion to SI units: 100 trees per acre = 247 trees per hectare; 200 trees per acre = 494 trees per hectare; 300 trees per acre = 741 trees per hectare.

correlation between "trees cut per PMH" and "PMH per shift" (using average values for all operators) suggests that high hourly productivity was not associated with increased machine downtime.

The detailed timing of tree-felling cycles was meant as a supplementary aid in interpreting the shift-level results. Average felling times observed for 22 of the operators varied (for 1-hour sample periods) from 23 up to 45 centiminutes (1 cmin = 1/100 minute) per merchantable tree, with an overall average of 33 cmin per tree. One extreme value of 72 cmin occurred. Average cycle time was, logically, quite strongly correlated with productivity (trees cut per PMH) from the shift-level observations ($r = -.59$, $p < .01$). That is, faster individual tree-felling cycles tended to be associated with higher shift-level productivity achieved by some operators. Average cycle times and their variability were examined for their degree of association with measured operator characteristics, especially experience. No simple relationship was apparent, probably because cycle times were influenced by both operator characteristics and forest conditions.

Quality of Job Performance

Felling technique concerns the planning and care that the shear operator puts into his job. Some visible aspects of felling technique are: the cutting pattern or plan (often determined by the shear operator rather than the foreman); stump heights; orientation of felled trees to the roadside landing; consistency with which trees are felled into the windrow (the row of felled trees); and the extent of shear damage to felled trees. Safety in work procedures and control of machine downtime, through minimizing time lost in breakdowns and stuck, are other important factors in technique.

An operator opening up a new cutting block commonly begins by felling the right-of-way (100 feet (30 m) or more wide) for the haul road, and the landings. He then cuts around the boundary of the block, eliminating the possibility of straying across the boundary line. (Felled trees should not cross the block boundary.) With the access and the boundaries defined, he may then open two or more cutting strips radiating from the landing, perpendicular to the road and extending to the outer boundary on each side. This provides him a number of cutting "faces". The operator can cut along one, then another, to provide trees for up to six skidders. This cutting method separates the skidders from one another so each can work safely. Skidding is balanced, so that each skidder will have some short and some long skidding each day. Each skidder operator contends with one windrow at a time — the trees are not piled layer-on-layer which would make it difficult to pull them out. Having a number of cutting faces also allows the shear operator to adjust easily to strong winds. He chooses a face where he can cut with the wind in his favour, aiding directional felling.

The operator tries to keep the butt ends of felled trees even with one another to facilitate assembling skidder loads. He usually fells trees to lie at about a 45° angle to the skidding direction so as to "lead" more easily and to reduce stem breakage in skidding.

Stump height is important for a number of reasons. Lower stumps result in recovery of more wood from the area. Low stumps also mean that much of the shear damage occurs in wood that might otherwise not have been recovered if felling had been by powersaw. During felling, low stumps make for a smoother ground surface for the tractor, and reduced binding of the tracks between stumps as the operator pivots to "toss" the trees into the windrow. One high stump can lead to a series of high stumps, because the shear tends to ride up on the stump of the previously cut tree, preventing the operator from getting to ground level on the next one. Low stump height is favoured by the skidder operators because their ride is improved, allowing greater speed. Wear on the skidder is reduced and there is less breakage of stems bound between stumps. On the other hand, too-low stumps may result in excessive butt-flare on the ends of logs, which must be trimmed off with powersaws at the landing. Most operators tried to cut trees off at ground level.

Such planning and co-ordination on the part of the shear operator affect the efficiency of the whole operation. However, the study procedure did not include systematic observation of these aspects of performance. (Supervisors' ratings, as a study device, were considered, but later rejected as not being sufficiently reliable indicators of the performance of shear operators.) Informal observations — and the comments of supervisors, skidder operators and the shear operators themselves — suggest that operators varied widely in their ability to schedule the work, and in their general technique. This aspect of work performance deserves attention in future research.

Shear damage to felled trees was assessed quantitatively. Damage was of two types:

(a) slabbing of the side of the trees caused by the operator's accidentally striking the tree with the point of the shear blade, or the anvil;

(b) splitting at the butt of the tree, usually caused by the wedging action of the blade and resulting compression of the wood.

Slabbing of trees was infrequent, even among relatively inexperienced operators. When slabbing occurred, it was confined to the outer few inches of one side of the tree, and extended upward 3 to 4 feet (0.9 m - 1.2 m) from the butt. It seemed not to be a serious source of wood loss.

Table 3 summarizes data on splitting damage caused by shearing. (All shears used the standard straight blade by QM or Roanoke.) The sample showed a good range in tree size and species, except for Douglas fir which is rare in most of the region. The following analysis excludes Douglas fir.

Twenty-five percent of pine trees sampled had no splitting damage, but only 13 percent of spruce and 8 percent of balsam fir were in this category. In none of the pines sampled did damage extend beyond 36 inches (0.9 m), but 4 percent of spruce and 8 percent of balsam showed damage beyond 60 inches (1.5 m).

TABLE 3: Stump diameter[1] and splitting distance[2] in sample of shear-felled trees.

Species	No. of Observations	Stump Diameter inches (cm): Range	Stump Diameter: Average	Stump Diameter: Standard Deviation	Splitting Distance inches (cm): Range	Splitting Distance: Average	Splitting Distance: Standard Deviation
White spruce	155	6-25 (15-63)	13 (33)	5 (13)	0-66 (0-167)	15 (38)	15 (38)
Balsam fir	63	6-21 (15-53)	10 (25)	4 (10)	0-66 (0-167)	19 (48)	18 (46)
Douglas fir	11	7-19 (18-48)	14 (35)	3 (8)	0-48 (0-122)	14 (35)	13 (33)
Lodgepole pine	219	6-21 (15-53)	12 (30)	3 (8)	0-36 (0-91)	9 (23)	8 (20)
Total:	448	6-25 (15-63)	12 (30)	4 (10)	0-66 (0-167)	12 (30)	13 (33)

[1] Measured inside the butt flare.

[2] Measured in 6-inch (15 cm) increments to the end of visible shear-caused splits. Sound merchantable trees only.

Analysis of splitting distance, by multiple regression, produced the relationship[1]:

Splitting Distance (in inches)
= − 12.5 + 1.8 (stump diameter in inches)
+ 4.4 (if species is spruce)
+ 12.4 (if species is balsam)

[1] N = 437; R^2 = .39; $S.E._Y$ = 10.4; all b coefficients significant beyond the $p_{.01}$ level. The sample did not extend far enough into the winter to allow evaluation of the effect of frozen conditions on splitting distance, although this was said to be considerable. The interaction term (species x diameter) was not significant.

For example, 14-inch (35 cm) stump diameter spruce trees would be expected, on the average, to have observable splitting for a distance of $(-12.5 + (1.8 \times 14) + (4.4 \times 1) + (12.4 \times 0)$ $= 17$ inches (43 cm), extending from the felling cut into the bole.

Residuals from this equation (that is, for each tree in the sample, the actual measured splitting distance minus splitting distance predicted from the above equation) were examined for association with measured operator characteristics. No statistically significant relationship was found between operator characteristics and splitting damage.

The operators, however, pointed out several tactics they used to limit splitting damage. Most felt that sharpening the blade several times a week reduced damage. A long edge bevel was preferred. Cutting stumps too low was said to produce two undesirable effects — hitting stones could nick the blade and rapidly dull it, and the butt swell near ground level could cause the blade to "ride up" on the larger trees as they are cut, putting extra stress on both the blade and the tree. A thin blade reportedly produced less damage than a thick one, but would not stand up to frozen wood in winter. One operator regularly changed to a thin blade each summer. Another operator put diesel oil on the blade several times a day to reduce friction against the wood.

The speed of the blade during cutting reportedly is a factor in wood damage. A few units were observed with two-speed hydraulic pumps. These allowed the operator to make the initial part of the cut using regular blade speed, then complete the cut at higher speed as the tree began to tip. The blade's alignment is also important. As the blade ages, it tends to droop, especially if it is used in large timber. The blade may then not meet the anvil when closed, but droop below it, so that trees are not cut off cleanly. The blade must also be adjusted so that it just meets the anvil at the fully closed position. A gap between blade and anvil produces unnecessary tearing of wood fibre and increases the stress on the blade.

Large trees were sometimes left for powersaw felling, although most operators preferred to cut everything they encountered. For large trees, an "undercut" can be made with the shear by making two cuts part way into the tree, one above the other and about 6 inches (15 cm) apart. The wedge is then pushed out with the shear anvil before the felling cut is made. Noticeable tree splitting can occur during withdrawal of the blade when this procedure is used, particularly if the tree is leaning backward. One operator claimed to have felled a 42-inch (106 cm) spruce tree using an undercut, and backcutting from the opposite direction.

Discussion

The results of this exploratory study encourage the view that it is possible to measure and perhaps influence some of the factors that affect performance variation among logging-machine operators. The economic importance of this variation is obvious, since differences in individual productivity exceeded 100 percent in the relatively simple operation of felling trees with standard tractor-mounted shears. The differences may be more accentuated in machine operations that make even greater demands on the operator. The analysis indicated that the bulk of the observed variation was assignable to sources "between operators within firms". That is, one has to consider the differing characteristics of operators and their operating conditions in explaining the performance variation that is observed. The analysis showed that it is essential to adjust observed performance to take account of operating conditions, in order to evaluate the separate effects of operator characteristics. When this was done, factors descriptive of the operators' experience, manual dexterity, visual depth perception, and motivation (expectancy score) showed significant relationships with productivity. Attempts to relate quality of performance to operator characteristics were less successful, one reason being the difficulty of measuring quality.

The study had certain limitations, which in turn limit the interpretation of these results. Subjects were selected randomly, to represent the population of shear operators in the study region, and the sample comprised a large proportion of that population. However, the number of operators in the study was small compared to the potential number of factors which could influence performance. This means the likelihood of chance correlations is uncomfortably large, and reduces the confidence one may have in saying which factors really influence performance. But where a factor truly has an effect on performance this should still be apparent even in a small sample, as long as sufficient range of that factor is observed. The small sample may simply produce more conservative results — some extraneous factors may be identified as significant, but truly important factors are not likely to be missed.

Results from this study cannot necessarily be generalized to operators of other types of equipment. Different operator characteristics undoubtedly influence performance in other phases of logging, such as skidding, loading and truck driving. Separate studies would be required to establish this. However, evidence is accumulating for the need to direct more attention to human factors in all phases of logging. In their skidding study, Bennett *et al.* (1965) concluded that " ..... it seems likely that a high proportion of the variation in productivity will be attributable to non-physical factors, including skills, motivation, supervision and planning applied to the logging operation." McIntosh and Johnson (1974), discussing results of their study of wheeled skidding, stated that "probably the most important factor determining the productivity of a skidding operation is the skill and motivation of the skidder operator." Another study of wheeled skidding, in eastern Canada, suggested that an important part of productivity variation " . . . was closely related to fluctuations in the motivation of the skidding crew and/or changes in their physical effort in response to certain work conditions. . . . . The strength of the bonus factor (a measure of the crew's bonus pay position on a given work day) as a predictor variable provided further evidence that the effect of worker attitudes upon productivity was both important and measurable." (Cottell *et al.*, 1971). A study of Beloit Harvesters (Aird *et al.*, 1970) showed productivity differences between operators of over 30%, under comparable operating conditions. And Axelsson (1972) concluded his report summarizing repair statistics and performance of 13 Koehring shortwood harvesters with the comment: "The greatest and fastest increase in productivity can be achieved by improved selection and training of operators, by more emphasis on the problem of operator motivation and incentive, and by improved operational supervision and control . . .".

Study of operator performance should lead to improved criteria for the recruitment of logging-machine operators, and selection for training. The forest industry and logger training schools in Canada recruit and select large numbers of forest workers each year. Selection often is based on minimal information about the candidates, and interpretation is subject to the considerable bias of recruiting officers' inevitably limited personal experience. Some good candidates are chosen, but so are many that turn out to be unsuited for the work. Among tree-shear operators, length of experience was associated with output performance — a result that supports the position of personnel officers who look for suitable experience in job applicants. But seldom are there enough experienced operators to fill the positions available, which makes experience a less-than-ideal criterion for recruiting. It is necessary to consider the individual's potential, as related to job requirements. Better recruitment criteria that indicate the individual's likely ability to perform the job would help recruiters maximize the percentage of "correct" decisions — i.e., accept suitable candidates and reject unsuitable ones.

For this approach to be effective there must be considerable development in the measurement of human factors in logging, and in the models which purport to show how these factors influence job performance. There also is a need for a richer definition of performance, other than the simple measure of output per unit of time. Performance includes subtle aspects of job quality, safe working practices, care of machines, regular attendance, job stability and co-operation with other crew members. In particular, the relationships of individual performance to crew or system output need to be considered. If the system cannot process all of his production, the individual operator cannot be faulted for lower than maximum effort. Group cohesion and teamwork among logging crew members, examined only tentatively in this study, need to be assessed quantitatively and related to individual and system performance.

Man-machine relationships need to be examined more critically in order to develop effective, productive logging-system designs. There are new machines presently entering the woods which have serious design problems that limit the operator's potential performance. Inspection of the operator's workplace (cab) will commonly reveal equipment deficiencies which reduce his efficiency and comfort. The present state of workplace design offers significant opportunity for the application of human factors principles.

Analysis of the jobs and requisite skills in logging would provide better understanding of the work requirements, and of the abilities and acquired skills that operators need for successful performance. This could lead to better machines, and better selection and training of personnel, with consequent increases in the level of productivity of operators. Such tasks obviously call for the assistance of people trained in the required fields — psychology, ergonomics, organizational behaviour. Specialists in these behavioural sciences have developed approaches and procedures that can help with some of the human problems in logging.

The topic of motivation is difficult to deal with, but probably has a most important influence on job performance. Superior motivation may enable operators to overcome personal limitations and operational difficulties. However, motivation is not a factor that is readily amenable to detection and use in operator selection. It is within the organizational structure of the firm (e.g., supervision, work rewards) that adjustments may be made to improve operator motivation. How to do this is a question that requires further study.

Progress in this field depends upon increased knowledge of human factors in logging, and getting that knowledge applied in a practical way. Neither logging companies, training specialists, researchers nor governments can do this successfully on their own — it requires co-ordinated effort and commitment over time. A beginning could be made through a limited program to assess the abilities and interests of candidates applying to logger training courses. Follow-up of graduates would determine their subsequent success on the job. If patterns were found between measurable trainee characteristics and job performance (for example, if the relationships tentatively identified in this study were supported) they could provide a basis for selection of suitable trainees, and other employees, in the future.

Conclusions

Observation of more than 700 shifts worked by 34 operators of tractor-mounted, hydraulic tree-felling shears in North-Central B.C. revealed important variation in output performance. Operators' felling productivity ranged from below 50 to over 150 (average 115) trees per productive machine-hour. Two-thirds of this variation was attributable to differences "between operators within a firm", and about one-third to day-to-day differences "within operators". Operator performance (adjusted for different forest conditions through the variable "number of trees per acre") was significantly associated with the following measures of operator characteristics:

— visual depth perception
— length of experience in operating shears
— manual dexterity
— motivation.

Depth perception, experience and manual dexterity are potentially useful in the selection and placement of logging personnel, but motivation cannot be readily assessed in a selection procedure. Adjustment of organizational factors (such as supervision, work rewards) within the employing firm offers the principal opportunity to influence operators' motivation toward higher performance.

Future work in this field should include:

- development of procedures for evaluating important qualitative aspects of performance in addition to quantity of production, for various logging occupations;
- improvement in theoretical models relating the characteristics of operators and their work groups to job performance;
- examination of human factors in logging-machine design (ergonomics) to facilitate job performance, reduce the necessary training time and improve the occupational safety and health of operators;
- the gathering and presentation (in handbook form) of information on superior work techniques in different logging occupations, for the benefit of operators and supervisors at all experience levels;
- consideration of ways to develop a practical program to test the usefulness of personnel evaluation procedures for predicting the likely success of new employees, or trainees, in different logging occupations.

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APPENDIX 1

Operator Questionnaire

Biographical Information

1. In what year were you born?
2. In what country were you born?
3. In what year were you married?
4. What was the last grade of school which you completed?
5. At what age did you start regular work?
6. How many dependants do you have?
7. What is/was your father's main occupation?
   (Industry) (Capacity)
8. In what setting did you spend the first 20 years of your life?
   (Rural) (Small Town) (City)
9. Do you have a residence away from this operation?
   (Own house or trailer?)
   (Rented apartment or house?)
   (Board or rented room?)
10. Where is your residence located?
11. How many straight days do you usually stay in camp?
12. What was your approximate gross income last year?
    (Less than $7,000) ($7,000 - $10,999)
    ($11,000 - $15,999) (More than $16,000)
13. What lost-time illnesses have you had in the last 2 years?
    (Number) (Duration)
14. What lost-time injuries have you had in the last 2 years?
    (Number) (Duration)
15. For how many months have you been unemployed in the past two years?
16. For how many firms have you worked in the past 2 years?
17. How many days have you spent in formal training programs for the following?
    (Tractor mounted shears)
    (Crawler type tractors)
    (Other logging machinery)
    (Other heavy machinery)
18. List (not necessarily in order) any apprenticeships or on-the-job training you have completed.
    (Type of training) (Duration)
19. How many months have you worked with:
    (This machine?)
    (Tractor mounted shears?)
    (Crawler tractors?)
    (This company?)
    (Logging companies?)
20. Are you currently a member of a union? If so, in what capacity?
21. How many of your relatives work:
    (On this operation?)
    (With this company?)
    (In the logging industry?)
22. How many friends in this operation do you meet with outside working hours?
23. For how long do you expect to remain working for this firm?
    (Until you find a better job)
    (Until freeze up)
    (Less than 2 years)
    (2 years or more)

The Job

24. What previous experience has been most useful in learning this job?

25. Under current conditions, and without unscheduled delays, how many trees would you expect to cut in an 8-hour shift on:
    (an average day) (a good day)
    (a bad day) ?

26. What production goal does your supervisor set for a day's work?

27. What do you like most about your job?

28. What do you like least about your job?

29. Do you like to change the type of work you do every so often? If so, how often?

Motivation

(a) Importance of job characteristics

30. How important are the following job characteristics to you? Scale: 1 = no importance; 2, 3, 4; 5 = great importance.
    (Good pay)
    (A steady job)
    (Respect from your supervisor)
    (Respect from your fellow employees)
    (Assignment to a more pleasant job)
    (Promotion to another job)
    (More say in how you do your job)
    (Job satisfaction)
    (Being known in the industry as a capable operator)
    (More time with your family and friends)
    (A feeling of accomplishment)
    (Time to talk to other employees on the job)
    (Control over your pace of work)

(b) Instrumentality of Performance

31. If you increased your weekly production by, say, 20% without abusing your machine, you would expect to gain:
    (Higher pay)
    (Greater job security)
    (More respect from your supervisor)
    (More respect from your fellow workers)
    (Assignment to more pleasant job)
    (Promotion to a better job)
    (More say in how you do your job)
    More job satisfaction)
    (A better reputation with the industry locally)
    (More time with your family and friends)
    (A feeling of accomplishment)
    (More time to talk with the other employees in the job)
    (More control over your pace of work)

(c) Expectancy

32. You could get this higher production by:
    (Working harder)
    (Doing what the boss says)
    (Taking an operator training course with, for example, Canada Manpower)
    (Getting more experience)
    (Watching a better operator for a period of time)

Attitudes

(a) Organizations

33. Do you (strongly agree, agree, have no opinion, disagree, strongly disagree) with the following statements:
    (This firm is better to work for than most in the local logging business)
    (If the demand for logs fell, this firm would find ways to avoid laying off its employees)
    (If this operation produced more logs, your crew would benefit)
    (The firm is only interested in production and profit)

(b) Work Groups

34. SENSE OF COMPETITION. Do you (strongly agree, etc.) wth the following statements:
    (You like to cut a few more trees per day or week than the other operators)
    (You are satisfied with your production rate now)
    (You try to better your previous best day's output)
    (You like to cut enough trees each day to keep the skidders busy)

35. GROUP CO-OPERATION. Do you (strongly agree, etc.) with the following statements:
    (The men in this crew are friendly)
    (The men in this crew work as a team)
    (The men on this operation like their jobs)
    (Your crew often makes improvements to the way they do the work)
    (If you had the chance to do the same work for the same pay in another crew, you would make the move)
    (The men in this crew help each other on the job)

(c) Supervision

36. Do you (strongly agree, etc.) with the following statements:
    (Your supervisor is competent in his job)
    (Your supervisor gives the men on this operation clear instructions)
    (Your supervisor organizes the work in advance)
    (Your supervisor puts your suggestions into operation)
    (Your supervisor spends his time supervising rather than getting involved in the actual work)
    (Your supervisor is friendly and easy to talk to about problems connected with the job)
    (Your supervisor sets definite standards of work)
    (Your supervisor stresses to your crew the importance of their jobs)
    (Your supervisor encourages your crew to perform better than other crews)
    (Your supervisor encourages your crew to make suggestions about your work)
    (Your supervisor spends little time showing your crew how to improve its performance)
    (Your supervisor decides how your crew has to do its work and you have little say in this)
    (Your supervisor usually tries to explain his actions to the crew)

(d) Job Satisfaction and Involvement

37. Do you (strongly agree, etc.) with the following statements:
    (Your job is challenging)
    (Your job gives you a chance to do the things you do best)
    (You like your job)
    (Your job is often boring)
    (Your job sometimes make you jumpy and causes you to worry)
    (You are learning new things about your job every day)
    (You feel a sense of accomplishment when you do your work well)
    (You are a perfectionist about your work)
    (Other jobs which you could get would not be as interesting as this one)

(e) Self-rated effort, ability and performance

38. Do you (strongly agree, etc.) with the following statements:
    (You work harder than the average operator)
    (You know how to do your work well)
    (You can do your work well)
    (You put a lot of effort into your work)
    (You are personally involved in your job)
    (You have the ability to do your job well)

(f) Work Rewards

39. Do you (strongly agree, etc.) with the following statements:

(Your job pays enough)
(Your job is secure enough)
(Your supervisor gives you enough respect)
(Your fellow employees give you enough respect)
(You have enough opportunity for assignment to a more pleasant job)
(You have enough opportunity for promotion to a better job)
(You have enough say in how you do your work)
(There is enough satisfaction in your job)
(Your job gives you enough time with your family and friends)
(Your job gives you enough time to talk with other employees while working)
(You have enough control over the pace of your work)
(Your job gives you enough variety)
(There are enough fringe benefits associated with your job).

Some questionnaire items were developed specifically for this study. Others were selected, or adapted, from among the following sources:

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APPENDIX 2

Aptitude Testing

The General Aptitude Test Battery (GATB) [1] seemed the most appropriate of a number of alternatives, for use in the machine operator study. The GATB was developed by the U.S. Employment Service and has been used by Canada Department of Manpower and Immigration since 1966. The entire battery, or parts of it, are available (after clearance) from Canada Manpower. This Department has established test norms for over 400 occupational groups, classified according to The Canadian Classification and Dictionary of Occupations. With its extensive research base, GATB is now recognized as one of the best-validated multiple aptitude test batteries.

GATB consists of 12 subtests which yield the following nine aptitude test scores (total administration time for all 12 tests is about 2½ hours):

Intelligence
Verbal Aptitude
Numerical Aptitude
Spatial Aptitude
Form Perception
Clerical Perception
Motor Co-ordination
Finger Dexterity
Manual Dexterity

[1] Described fully in four separate sections of: The Manual for the General Aptitude Test Battery. U.S. Department of Labor, Manpower Administration, 1966. Section I: Administration and Scoring. Section II: Norms, Occupational Aptitude Pattern Structure. Section III: Development. Section IV: Norms, Specific Occupations.

The subtests providing motor co-ordination, manual dexterity, form perception and spatial aptitude scores were used in the study. These aptitudes are defined[2] as:

MOTOR CO-ORDINATION — Ability to co-ordinate eyes and hands or fingers rapidly and accurately in making precise movements with speed. Ability to make a movement response accurately and swiftly.

MANUAL DEXTERITY — Ability to move the hands easily and skillfully. Ability to work with the hands in placing and turning motions.

FORM PERCEPTION — Ability to perceive pertinent detail in objects or in pictorial or graphic material. Ability to make visual comparisons and discriminations and see slight differences in shapes and shadings of figures and widths and lengths of lines.

SPATIAL APTITUDE — Ability to think visually of geometic forms and to comprehend the two-dimensional representation of three-dimensional objects. The ability to recognize the relationships resulting from the movement of objects in space.

[2] Section II: The Manual for the General Aptitude Test Battery.

APPENDIX 3

Physical Fitness Test

The test[1] used is based on four components of physical fitness: stamina, weight, suppleness and strength. The test procedure provides scores for each of these components which, combined, give an indication of overall fitness.

The stamina test used a wooden bench, 17 inches (43 cm) high. Subjects stepped onto the bench with the first foot and brought the other alongside, then stepped down with the first foot and brought the other alongside. They repeated this cycle 30 times in 1 minute.Then, their pulse was measured for three 15-second intervals from the end of the exercise: at 15-30 seconds, 45-60 seconds, and at 75-90 seconds. The stamina score is based on the total number of pulse beats in these three intervals.

Subjects were weighed (in indoor clothing) with an accurate, portable medical scale. Their height was measured, and frame estimated. The table below shows desirable weight, given sex, height and frame. The weight component of the fitness score is determined by comparing actual with desirable weight.

Desirable Weights[1] for Men Over 24 years

HEIGHT[2] Feet	Inches	WEIGHT IN POUNDS Small Frame	Medium Frame	Large Frame
5	2	112-120	118-129	126-141
5	3	115-123	121-133	129-144
5	4	118-126	124-136	132-148
5	5	121-129	127-139	135-152
5	6	124-133	130-143	138-156
5	7	128-137	134-147	142-161
5	8	132-141	138-152	147-166
5	9	136-145	142-156	151-170
5	10	140-150	146-160	155-174
5	11	144-154	150-165	159-179
6	0	148-158	154-170	164-184
6	1	152-162	158-175	168-189
6	2	156-167	162-180	173-194
6	3	160-171	167-185	178-199
6	4	164-175	172-190	182-204

Desirable Weights for Women Over 24 years

HEIGHT[2] Feet	Inches	WEIGHT IN POUNDS Small Frame	Medium Frame	Large Frame
4	10	92- 98	96-107	104-119
4	11	94-101	98-110	106-122
5	0	96-104	101-113	109-125
5	1	99-107	104-116	112-128
5	2	102-110	107-119	115-131
5	3	105-113	110-122	118-134
5	4	108-116	113-126	121-138
5	5	111-119	116-130	125-142
5	6	114-123	120-135	129-146
5	7	118-127	124-139	133-150
5	8	122-131	128-143	137-154
5	9	126-135	132-147	141-158
5	10	130-140	136-151	145-163
5	11	134-144	140-155	149-168
6	0	138-148	144-159	153-173

NOTE: For both men and women between 18 and 24, subtract 1 pound per year under 25.

1 Conversion to SI units: 1 pound = 0.454 kg.

2 Conversion to SI units: 1 inch = 2.54 cm.

1 A syndicated publication attributed this test to Sports Participaction Canada, although the test was not officially endorsed by that organization. It was the simplest and most portable test then available to the machine operator study, and is presented here for completeness. Health and Welfare Canada recently produced a better test: The Canadian Home Fitness Test. IN: The Fit-Kit. Information Canada, Ottawa. 1975.

For the suppleness test, subjects stood with feet together, knees straight, and tried to touch their toes. One of four measures was recorded (the best of four tries): straight fingers touch the top of the toes; middle knuckles of the fingers touch the floor; big knuckles of the fist touch the floor; or, palms of the hands flat on the floor.

In the strength test, subjects lay flat on their backs, both hands behind their heads and with legs straight. They raised their heels 6 inches (15 cm) off the floor, and the length of time they could hold that position was recorded.

Points were awarded for each of the four tests using the scoring table below. Then the scores were summed. A total of 46-50 indicates extreme fitness; 40-45 above average; 30-39 average; 20-29 below average; and less than 20 suggests a possible medical problem.

SCORING TABLE FOR MEN

Test Item No.						
1	Sum of pulse beats:	Over 110	91-100	76-90	60-75	Under 60
	Points:	0	5	10	15	25
2	Excess weight:	Over 20 lb. (9.1 kg.)	11-20 lb. (5.0-9.1 kg)	6-10 lb. (2.7-4.9 kg)	1-5 lb. (0.4-2.6 kg)	Right on or less
	Points:	0	3	5	8	10
3	Pick best measure:	Can't touch toes	Finger tips on toes	Middle knuckles on floor	Big knuckles on floor	Palm on floor
	Points:	0	1	2	3	5
4	Seconds legs held up:	Under 15	15-24	25-34	35-45	Over 45
	Points:	0	3	5	8	10

SCORING TABLE FOR WOMEN

Test Item No.						
1	Sum of pulse beats:	Over 120	101-120	86-100	70-85	Under 70
	Points:	0	5	10	15	25
2	Excess weight:	Over 20 lb. (9.1 kg)	11-20 lb. (5.0-9.1 kg)	6-10 lb. (2.7-4.9 kg)	1-5 lb. (0.4-2.6 kg)	Right on or less
	Points:	0	3	5	8	10
3	Pick best measure:	Can't touch toes	Finger tips on toes	Middle knuckles on floor	Big knuckles on floor	Palm on floor
	Points:	0	1	2	3	5
4	Seconds legs held up:	Under 10	10-16	17-23	24-30	Over 30
	Points:	0	3	5	8	10

APPENDIX 4

Analytical Models

Analysis of Variance

Since the choice of sample firms was randomized, a random-effects ANOVA model was called for, of the form:

$$Y_{ijk} = \mu + A_i + B_{ij} + \epsilon_{ijk}$$

Where: $i = 1 \ldots a;\quad j = 1 \ldots b;$
$k = 1 \ldots c$
$\epsilon_{ijk} = N(0, \sigma)$

μ is the mean performance for the population of operators.

A_i are deviations from the population mean among firms.

B_{ij} are deviations from the population mean among individuals.

ϵ_{ijk} are random effects from inherent variation in the population, and random measurement errors.

Y_{ijk} are observed values of performance.

Sample size varied among firms, requiring altered analytical procedures;[1] the number of shifts observed for each study individual also varied.

Variation in trees cut per PMH was examined using this model, with the following results:

Analysis of variance table for trees felled per PMH.

Source	Degrees of Freedom	Sum of Squares	Mean Square
Firms	8	152,006	19,000.75
Operators within firms	25	469,054	18,762.16
Shifts within operators	753	315,982	437.04
Total	756	937,042	

[1] Snedecor, G.W., and Cochran, W.G. Statistical methods. (Sixth Ed.) Iowa State Univ. Press, Ames, Iowa. 1967. pp. 289-294.

Estimates of variance assignable to different sources were calculated as follows:

(a) Shifts within operators, $\sigma_0^2 = 437.04$

(b) Operators within firms, σ_1^2:

$$18{,}762.16 = \sigma_0^2 + 21.1098\,\sigma_1^2$$

and $\sigma_1^2 = 868.08$

(c) Between firms, σ_2^2:

$$19{,}000.75 = \sigma_0^2 + 25.1679\sigma_1^2 + 77.3477\sigma_2^2$$

and $\sigma_2^2 = 42.45$

Motivation

Vroom's model[2] of motivation, one among a number of contending theories, served as a guide to data collection and analysis. According to the model, the motivational force acting upon a worker is related to a) his perception of the likelihood of certain outcomes resulting from his performance, and, b) the value of those outcomes to him.[3] This is summarized in the following notation:

$$F = \sum_i (V \,.\, E_i)$$

$$V = (I_1 \,.\, g_1 + I_2 \,.\, g_2 + \ldots + I_r \,.\, g_r)$$

where: $g = g_1, g_2, \ldots g_r$ represent the desirability, or importance of certain "second-level" outcomes (e.g., pay, job security) to the worker.

[2] Vroom, V.H. Work and Motivation. Wiley, N.Y. 1964.

[3] For more recent review articles, see:
Mitchell, T.R., and Biglan, A. Instrumentality theories: current uses in psychology. Psych. Bull. 76(6): 432-454. 1971.
Heneman, H.G. III, and Schwab, D.P. Evaluation of research on expectancy theory prediction of employee performance. Psych. Bull. 78(1): 1-9. 1972.

I = $I_1, I_2, \ldots I_r$ represent the instrumentality of higher performance (the "first-level" outcome) in achieving desired second-level outcomes. (As an example, the extent to which the worker sees higher production as leading toward higher pay for himself).

V = Valence, or attractiveness of higher performance, being the sum of cross-products of I and g.

E = $E_1, E_2, \ldots E_i$ represent Expectancy, the worker's view of the probability that extra effort on his part will lead to the higher level of performance.

F = Motivational force, the sum over all outcomes associated with the work situation of the expectancy, times the valence of higher performance.

Empirical findings elsewhere have shown that expectancy (E) alone tends to be correlated with performance as consistently as is motivational force (F) from the full model. This was the case in the shear operator study. The expectancy score for each operator was calculated from:

$$\text{Expectancy score} = \sum_{i=1}^{5} \left(\frac{\text{Expectancy}_i}{5} \right)$$

Observed values were first standardized using the Z transformation:

$$Z_{ij} = \frac{x_{ij} - \bar{x}_{i.}}{s_{i.}}$$

(where x = the raw score, $\bar{x}$ = the sample mean, s = standard deviation, subscript i = questionnaire item, subscript j = operator and dot notation signifies "across all j") to counter apparent response bias among individuals completing the questionnaire — i.e., a tendency to use one end of the rating scale).

Multiple Regression Analysis

Regression models for analysing performance were of the form:

$$\underline{y} = \underline{X}\underline{\beta} + \underline{H}\underline{\gamma} + \underline{D}\underline{\delta} + \underline{\epsilon}$$

Where: $\underline{y}$ = set of observations for one performance variable;

$\underline{X}$ = set of environmental and operational variables; $(X_1, X_2, \ldots X_m)$

$\underline{H}$ = set of operator characteristics; $(H_1, H_2, \ldots H_n)$

$\underline{D}$ = set of mn first-order interactions of $\underline{X}$ and $\underline{H}$ $(D_1, D_2, \ldots D_r)$

$\underline{\beta}$ and $\underline{\gamma}$ and $\underline{\delta}$ = regression coefficients;

$\underline{\epsilon}$ = set of independent errors, assumed normally distributed.

In practice, the interaction terms, $\underline{D}$, were not explored. There was no evidence of non-linear effects within the range of the variables presented in the final equation (Fig. 19). Plots of residuals[1] from this equation revealed no evidence of serious heteroscedasticity, or of other factors that should have been included in the expression.

In a repeated sample using the same variables, one would expect shrinkage in the value of R^2, compared to that reported with Fig. 19. The calculated regression, and the accompanying nomogram, apply specifically to the shear operator sample. They are not necessarily applicable for direct use in personnel selection until the underlying relationships are verified in practise.

The correlation matrix for the main factors in the analysis (operator characteristics, trees per acre, trees cut per PMH) is shown on the following chart.

[1] Draper, N. and Smith, H. Applied regression analysis. Wiley, N.Y. 1966. (Chapter 3.)

Simple Correlation Coefficients (r) for Variables in the Regression Analysis.

	S	P	K	M	D	FS	EXP	E	T	Y
Spatial Aptitude (S)	1.									
Form Perception (P)	.52	1.								
Motor Co-ordination (K)	.59	.68	1.							
Manual Dexterity (M)	.21	.53	.61	1.						
Depth Perception (D)	.34	−.10	.21	−.12	1.					
Fitness Score (FS)	.10	.03	−.01	.33	−.02	1.				
Experience With Shear (EXP)	−.16	−.47	−.27	−.13	.23	.09	1.			
Motivation Score (Expectancy) (E)	.13	−.003	−.24	−.15	−.08	.21	−.05	1.		
No. Trees/Acre (T)	−.16	.04	−.13	.01	−.08	−.13	.20	.09	1.	
Trees Cut Per PMH (Y)	−.25	−.01	−.10	.32	−.45	.12	.24	.23	.45	1.

NOTES: 1. Number of operators = 33, since one was omitted because he did not take M test. ($r_{.05} = .33$)

2. Number of cutting blocks = 82. ($r_{.05} = .21$) T and Y are average values for each cutting block. Other environmental variables examined are omitted from table for brevity.

3. D is a binary variable. If normal depth perception, D = O; if poorer than normal, D = 1.