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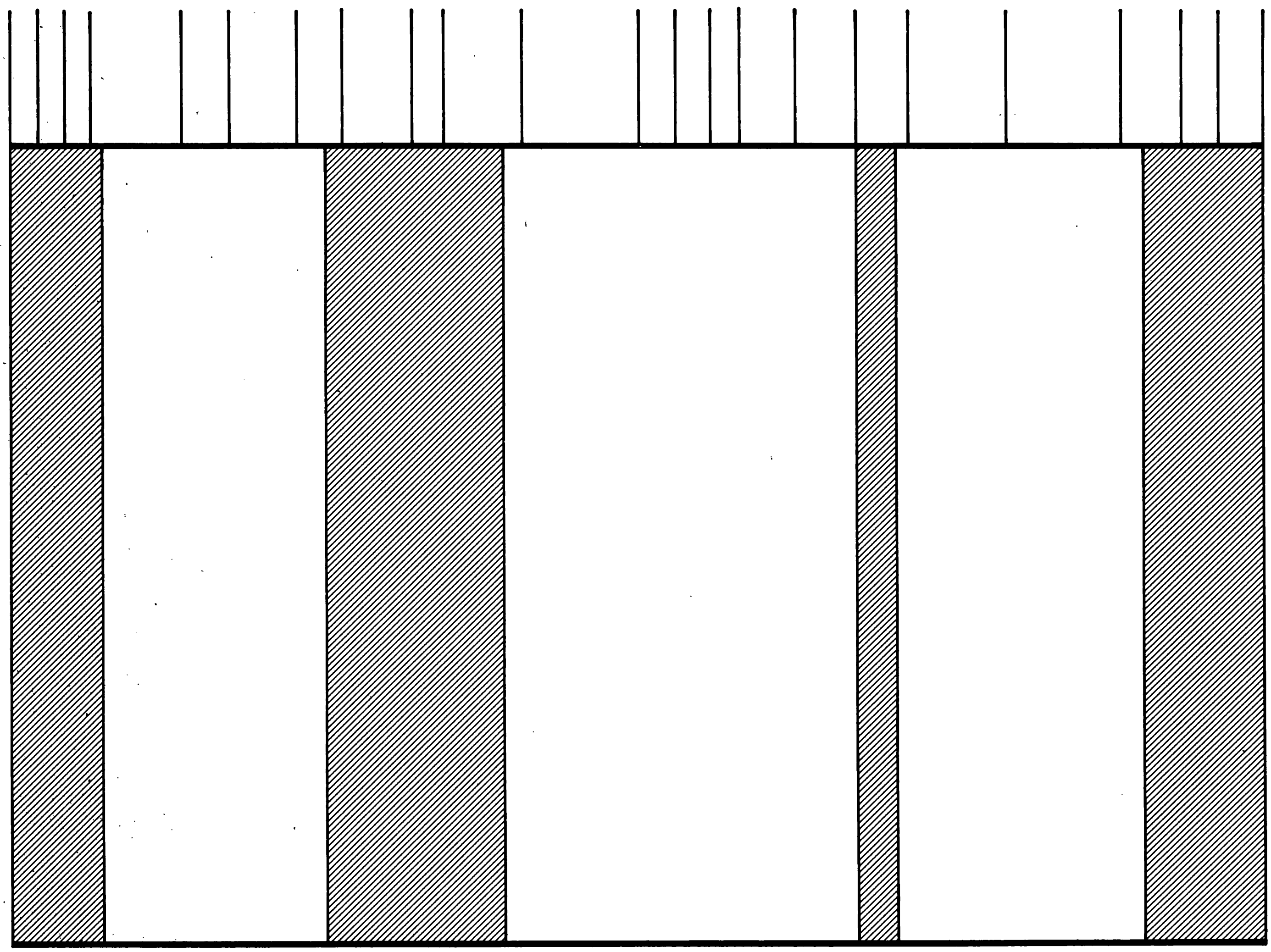

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USING WORK SAMPLING TO ANALYZE LOGGING OPERATIONS

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Managers of logging operations are faced with declining profits due to rapid increases in equipment costs, early obsolescence of equipment, and a gradual shift from harvesting large trees to smaller ones.

There are numerous ways to confront this problem of diminished returns. One of the simplest and least costly is to improve the efficiency of the logging operation. To do this, management must have accurate information regarding the interaction of men and machines and their performance in the woods. One way to obtain this needed information is to conduct work measurement studies.

There are three main ways to measure men and machines at work. The most common of these is the Gross Time Study method. This technique deals with gross production and total elapsed time. For example, if a piece of equipment produces 10 cords of wood in 8 hours (assuming the operator works 8 hours), the productivity of this equipment could be said to be 1.25 cords/hour. However, this information does not say how much time the equipment actually worked, how much time it was idle because of various delays, or what was the cause and extent of the delays. Thus, this method is not very useful for evaluating or improving the efficiency of a logging operation.

The second commonly used method of measuring work is the Continuous Time Study. This method utilizes a stopwatch in observing, measuring, and recording each well-defined phase of the operation for perhaps an entire day over many days or weeks. If the observer is properly qualified, this is probably the best method. However, it has the following disadvantages when applied to field operations such as logging:

- Requires highly skilled observers;
- Requires tedious recording of data over long hours for observers and operators;
- Becomes costly, because at least as many observers are required as there are pieces of equipment;
- Following and observing logging equipment continuously is hazardous and difficult;
- Reducing data is difficult and time consuming;
- Accuracy of data is questionable near the end of a long and exhausting day of collecting data.

The third method is Work Sampling. This is a statistically based method in which instantaneous observations are taken at random intervals. With proper design, each instantaneous observation is recorded, and the percentage of time for a particular activity is the number of observations for that activity divided by the total number of observations. This sampling method was originated by Tippett (1935) in 1927 under the name of "snap-reading" for measuring the productivity of various machines in the British textile industry. Morrow (1957) of New York University introduced this method to the United States under the name of "ratio-delay" in 1940, to study the ratio of delays to total scheduled time, and to find the causes of delays. Since its introduction in the U.S., work sampling has been applied in various industries (Brisley 1952, Herrick 1959, Mac Niece 1953, Rowe 1954) to effectively increase productivity and cut production costs.

The work sampling technique approximates the results obtained by the continuous time study and has the following advantages over the latter:

- It is cheaper as it does not require highly skilled observers; often a single analyst can observe multiple functions or separate machines concurrently;

- It is less tedious and tiresome for observers;
- It is safer than continuous time study in the field;
- Accuracy is controllable and can approach the precision of continuous measurements as the number of observations increase;
- Data reduction and analysis are much easier and shorter.

Despite these advantages, the application of work sampling technique to measure performance of logging operations has been limited. Lussier (1961) introduced the work sampling technique to analyze a single piece of logging equipment in 1965. Holemo and Dyson (1972) reported on the work sampling technique to analyze the downtime in sawmills. Both these well-written papers discuss the accuracy and the advantages of the work sampling method and explain its statistical basis. Nevertheless, the method has not received much attention and is not extensively used in the logging industry.

The purpose of this paper is to (1) present the results of the work sampling method and compare them with the results from the continuous time method, (2) determine the feasibility of using work sampling for the analysis of logging operations, and (3) define the limitations and capabilities of the work sampling method as applied to logging.

METHODS

The study consisted of two parts. The first involved a simulated work sampling experiment, and the second, an actual field trial.

The objective of the simulated work sampling experiment was to determine the accuracy of the results of work sampling by comparing them with the results from a continuous time study.

The procedure of the simulated work sampling experiment was as follows:

1. Data from a continuous stopwatch study of a logging operation were selected. The pieces of equipment used were a feller/buncher, a skidder, and a chipper. A short description of their main operating characteristics are presented in the Appendix.
2. The data of the continuous stopwatch study was plotted on a time scale on graph paper as either productive or delay time (fig. 1).
3. From the graph, sample readings were taken at random times by using a table of random numbers.
4. The mathematical formula used to determine the number of work sample observations required was:

$$N = \frac{Z^2Q}{E^2D} \qquad (1)$$

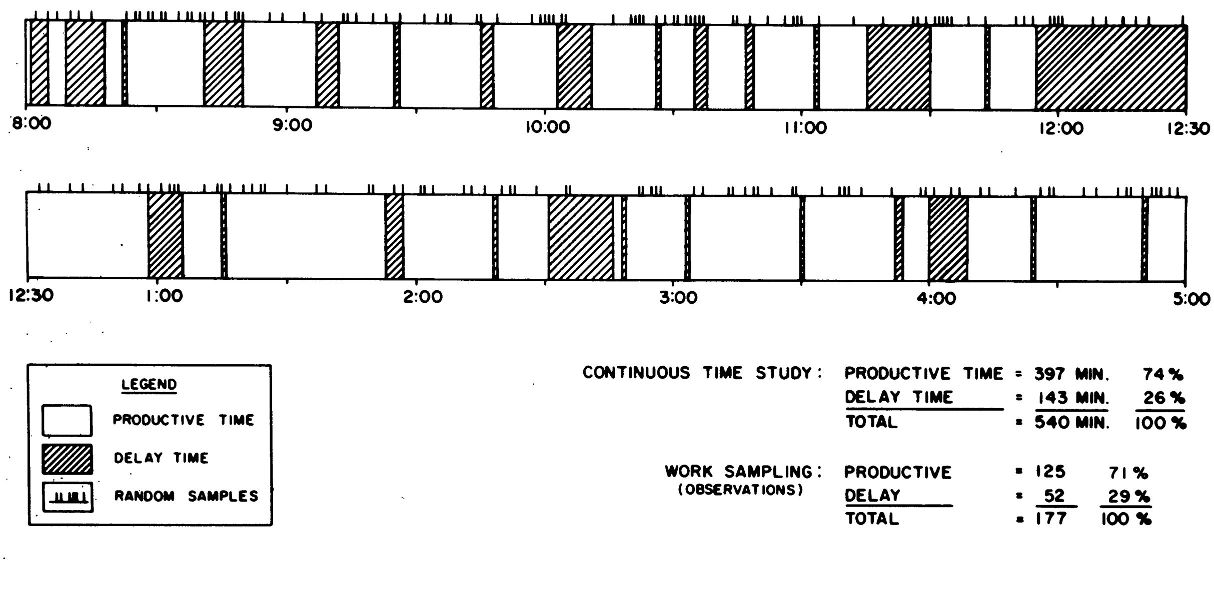

Figure 1.—*A simulated work sampling experiment (Barnes 1968). Data obtained from past continuous time study of a feller/buncher for 1-day operation.*

Where: N = Number of observations (sample size).

Z = A normal deviation which depends on the confidence level selected. If 90 percent confidence level is chosen, then the value of Z is 1.64. The values of Z for 99, 95, 85, and 80 percent confidence levels are 2.57, 1.96, 1.44, and 1.28, respectively.

D = Percentage occurrence of a delay, expressed as a decimal.

Q = (1-D) or the percentage occurrence of nondelay, expressed as a decimal.

E = Desired relative accuracy, expressed as a decimal.

5. The delay ratios for both the continuous time study and the work sampling method were calculated and compared to determine the accuracy of the work sampling technique.

The second part of the study was a field trial of work sampling on a logging operation different from the one on which the simulation study was made. The objective was to determine the feasibility, limitations, and field applications of work sampling on an actual logging operation. Two kinds of observations were made:

1. One piece of logging equipment was observed concurrently by both a work sampling observer and a continuous time study observer.
2. Three pieces of logging equipment were continuously observed by three continuous time study persons each obtaining data for one of the machines. At the same time, a work sampling person collected data on all three machines.

All the data were analyzed and the results presented below.

RESULTS OF THE SIMULATED WORK SAMPLING EXPERIMENT

In a controlled work environment and for standardized processes found in some fields of work, a 99 or 95 percent confidence limit with a 5 percent desired relative accuracy is often required. However, under the extreme variability of a logging operation, such high confidence limits and desired relative accuracies would demand an impractically large number of observations (table 1). We therefore decided to use a 90 percent confidence limit with a 10 percent desired relative accuracy to keep the number of observations at a practical level. In other words, the data obtained by work sampling has a 90 percent chance of representing the true facts, i.e., it will be in error 10 percent of the time, and the final result will be accurate within ± 10 percent.

To determine the number of observations by using equation (1), the percentage occurrence of the delay must be estimated. Delay ratios of 30, 35, and 35 percent as estimated from the past study were used for a feller/buncher, a skidder, and chipper, respectively. Sample sizes calculated for each piece of equipment are as follows:

For the feller/buncher: Z = 1.64 (90 percent confidence limit); D = 0.30 or 30 percent; E = 0.10 or 10 percent; Q = 1 – 0.30 = 0.70 or 70 percent, then the number of observations is:

$$N = \frac{Z^2Q}{E^2D} = \frac{(1.64)^2(0.70)}{(0.10)^2(0.30)} = 628 \text{ samples}$$

Similarly,

$$\text{Skidder: } N = \frac{(1.64)^2(0.65)}{(0.10)^2(0.35)} = 500 \text{ samples}$$

$$\text{Chipper: } N = \frac{(1.64)^2(0.65)}{(0.10)^2(0.35)} = 500 \text{ samples}$$

The continuous stopwatch study data for each piece of equipment were laid out on graph paper and presented as either working time or delay time along the continuous time scale. Sample observations were made at random times determined by the use of a random number table. As an illustration, figure 1 illustrates a simulated work sampling experiment for a 1-day operation of the feller/buncher. Each sample (tick mark) was noted and recorded as "delay" or "productive."

Delay ratios were calculated for the continuous time study as:

$$\text{Delay ratio} = \frac{\text{Total delay time}}{\text{Total time}}$$

and for the work sampling as:

$$\text{Delay ratio} = \frac{\text{Number of observations of delay}}{\text{Total number of observations}}$$

The available data were sampled for each piece of equipment (feller/buncher, skidder, and chipper). When the results from the continuous time study and the work sampling method were compared, the delay ratios (expressed in percent) were very similar (table 2).

Table 1.—*Number of observations for various confidence limits with different desired relative accuracy (as an example, a feller/buncher was used, D = 0.30 or 30 percent)*

Confidence limits (percent)	Desired relative accuracy: 5 percent	10 percent
99	6,165	1,542
95	3,586	897
90	2,511	628

To illustrate the accuracy of the work sampling method, a 95 percent confidence interval of the delay ratios was calculated for the sample data. The formula used to determine the confidence interval is:

$$\hat{P} - Z\sqrt{\frac{\hat{P}(1-\hat{P})}{N}} < P < \hat{P} + Z\sqrt{\frac{\hat{P}(1-\hat{P})}{N}} \qquad (2)$$

Where: $\hat{P}$ = The ratio of delay in the sample.

P = The true proportion of delay. In this experiment, the value of P (continuous time study) is assumed to be "true" value.

Z = The normal deviation; depends on the confidence level chosen.

N = Sample size.

For the feller/buncher, the proportion of delay in the sample was found to be 0.32 or 32 percent, $Z = 1.96$ for 95 percent confidence limits, and $N = 703$.

$$0.32 - 1.96\sqrt{\frac{.32(1-.32)}{703}} < P < .32 + 1.96\sqrt{\frac{.32(1-.32)}{703}}$$

which simplifies to

$0.29 < P < .35$.

Therefore, from the work sample the true proportion of delay (delay ratio) can be inferred to be between 29 and 35 percent at a 95 percent confidence level.

Similarly, 95 percent confidence intervals were constructed from the work sampling data for the skidder and chipper (table 3).

RESULTS OF THE FIELD TRIAL

In addition to obtaining delay ratios and machine utilization figures, we wanted to find out if the work sampling technique could be used to determine the cause and kind of delay.

Field trials were carried out in cooperation with a local logger for 4 pieces of equipment (see Appendix for operating characteristics). A feller/buncher was observed by both a work sample observer and a continuous time study observer. The other three pieces of equipment— a chipper, a dozer, and a chain flail— were concurrently monitored by a single work sampling observer and three continuous time study observers. All observers recorded working and delay time and the causes of the delays. The results of the continuous time study and the work sampling for each piece of equipment are presented in table 4.

To test the accuracy of the work sampling technique, a 95 percent confidence interval (or $Z = 1.96$ in equation 2) was calculated for the sample data. These confidence intervals are compared with the delay ratios obtained from the continuous time study in table 5.

The comparison in table 5 shows no significant difference in the delay ratios obtained from work sampling and continuous time study with the exception of the chain flail. The lack of agreement in the chain flail data may be caused by the inexperience of the continuous time study observer, or it may be due to chance.

Table 2.— *Delay ratio obtained from the two different techniques*

Equipment	Continuous time study			Work sampling		
	Total time	Delay		Total samples	Delay	
	Minutes	*Minutes*	*Percent*	*Count*	*Count*	*Percent*
Feller/ buncher	1,888	566	30	703	228	32
Skidder	1,474	611	41	481	202	42
Chipper	1,478	754	51	510	268	53

Table 3.— *A summary of 95 percent confidence intervals on delay ratio for feller/buncher, skidder, and chipper* (In percent)

Equipment	95 percent confidence interval on delay ratio	True delay ratio (P)[1] (from continuous time study)
Feller/ buncher	$29 < P < 35$	30
Skidder	$38 < P < 46$	41
Chipper	$49 < P < 57$	51

[1]In this experiment, the value of P (continuous time study) is assumed to be "true" value.

Table 4.—*Comparison of continuous time study and work sampling obtained from the actual logging operation*

Equipment	Continuous time study: Total time	Delay	Delay ratio	Machine utilization[1]	Work sampling: Total observation	Delays	Delay ratio	Machine utilization[1]
	--------- *Minutes* ---------		----------- *Percent* -----------		---------- *Number* ----------		----------- *Percent* -----------	
Feller/ buncher[2]	1,277	365	29	71	529	154	29	71
Chipper[3]	2,073	905	44	56	894	380	43	57
Dozer[3]	2,130	424	20	80	895	195	22	78
Chain flail[3]	2,134	1,104	52	48	893	415	46	54

[1]Machine utilization equals 100 percent minus delay ratio or productive time divided by total time (scheduled hours) times 100.
[2]Equipment observed by both a work sampling observer and a continuous time study observer.
[3]Each piece of equipment observed by a continuous time study observer, but all three observed simultaneously by one work sampling monitor.

Table 5.—*Ninety-five percent confidence interval test* (In percent)

Equipment	95 percent confidence intervals	Value of P (continuous time study)
Feller/ buncher	$25 < P < 33$	29
Chipper	$40 \leq P < 46$	44
Dozer	$19 < P < 25$	20
Chain flail	$43 < P < 49$	52

The random work sampling technique gives excellent results for delay ratio or total delay time, and thus gives good results for machine utilization (table 6). Logging operations conducted by independent loggers often have no fixed schedule of work hours as manufacturing operations do. The working hours vary from job to job, day to day, and often, season to season, and may depend upon the piece of equipment. Therefore, machine utilization was defined as total productive time divided by the total scheduled hours during the study period.

Delays due to lunch, when they occurred, are also included in total delay time. This procedure was chosen since there was no fixed lunch period, and some equipment operators took a lunch break at the same time, some at different times, while others did not take a lunch break but ate during productive time.

Table 6.—*Comparison of continuous time study and work sampling for machine utilization, delay ratio, and delay categories*

	Feller/buncher: Continuous time study	Feller/buncher: Work sampling	Chipper: Continuous time study	Chipper: Work sampling	Dozer: Continuous time study	Dozer: Work sampling
	Percent					
Machine utilization (percent)	71	71	56	57	80	78
Delay ratio (percent)	29	29	44	43	20	22
Delay categories	*Percent of total delay*					
Personal[1]	61.5	55.2	1.6	3.7	22.2	25.1
Operational	28.4	35.1	15.0	16.2	1.1	1.0
Mechanical	10.1	9.7	6.3	6.8	0.0	0.0
Not in use	0.0	0.0	0.0	0.0	76.7	73.9
Change vans	0.0	0.0	77.1	73.3	0.0	0.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

[1]Includes lunch break where it can be isolated.

Total delay for the feller/buncher, chipper, and dozer was broken down into broad categories (table 6). Work sampling gives reasonably accurate results for the breakdown of total delay into delay categories.

There is a limit to the size of the work element or delay element that can be accurately determined by work sampling. For small or infrequently occurring elements, the work sampling technique is not as accurate as continuous time study unless an impractically large number of samples are taken (table 7).

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn from this study:

1. Random work sampling, when used properly, can obtain performance and productivity data on logging operations at less cost and with fewer hazards than continuous timing. The degree of accuracy is also sufficient for planning and improving logging operations.

2. When the total delay time is broken down into five broad categories (table 6) work sampling gives reasonably accurate results for each of the individual categories.

3. For work elements that are small or occur infrequently, work sampling will not give as good results as continuous timing, unless very many observations are taken (table 7).

4. Work sampling appears to be an adequate method for studying performance and productivity in logging, since it discovers and measures the larger work elements with sufficient accuracy to plan for maximum productivity.

5. Extensive and thorough training of observers is not as crucial in work sampling as it is in continuous time studies. However, the observer must know logging machines and operations well enough to determine what the equipment is doing at any instant of observation.

6. Random work sampling has a disadvantage. In operations where the logging equipment is widely scattered or where visibility is poor, the random observations may occur at such short intervals that the observer cannot adequately observe all the equipment. However, when visibility is good, the observer could obtain the data on several machines at the same time thus reducing study costs as compared to continuous time studies where a separate observer would be needed for each machine.

Table 7.—*Classification of delay causes.*

(In percent)

	Feller/buncher		Chipper		Dozer	
Delay causes	Continuous time study	Work sampling	Continuous time study	Work sampling	Continuous time study	Work sampling
Personal:						
Lunch	32.8	31.8	—	—	9.6	6.6
Break and others	28.7	23.4	1.6	3.7	12.6	18.5
Operational:						
Wait for equipment or wood	—	—	13.9	12.0	0.8	1.0
Help other equipment	1.5	2.6	—	—	0.3	0.0
Clearing	18.4	22.7	1.0	4.2	—	—
Manipulate logs	3.0	3.9	—	—	—	—
Other	5.5	5.9	0.1	0.0	—	—
Mechanical:						
Refuel	—	—	0.3	0.8	—	—
Maintenance	—	—	6.0	6.0	—	—
Repair	10.1	9.7	—	—	—	—
Not in use	—	—	—	—	76.7	73.9
Change vans:						
Change vans only	—	—	26.9	27.5	—	—
Vans and lunch	—	—	25.7	20.7	—	—
Vans and maintenance	—	—	13.7	13.1	—	—
Vans and move chipper	—	—	10.8	12.0	—	—
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

7. Work sampling could be carried out as an ongoing project of going logging operations to maintain the standardized production rate, to detect any departures from this rate, and the reasons for such departures.

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APPENDIX

Short Description and Definition of Activities of Logging Equipment Used in the Work Sampling Study

Feller/buncher (Drott 40LC): A self-propelled track-type machine with an articulated boom which has holding clamps, accumulator, and shear head attached at its lower end. It is designed to shear a tree at the stump, hold it by means of a clamp, then swing and place the tree with others in a bunch.

Productive activities.— Travel, swing, and position boom to tree; position shear and holding clamp; shear tree; transport and boom in; swing and drop on bunch.

Delay.— Any activities besides above.

Grapple skidder (John Deere 740): A wheeled skidder with frame steering and four-wheel drive, equipped with a hydraulically actuated grapple and a small, hydraulically controlled, front-mounted dozer blade for decking and miscellaneous applications.

Productive activities.— Travel to bunch, position, grapple, open grapple and grasp bunch, lift and set, transport to predetermined area (usually landing), and position and drop the load alongside other tree bundles.

Delay.—Any activities besides above.

Chipper (Morbark 22″ XL): A mobile machine with an articulated boom and grapple, which reduces logs and whole trees to small chips by means of a rapidly rotating disc containing chipping knives. Chips are directly blown to transport unit.

Productive activities.— Swing and boom out to trees, position grapple, grasp, lift and swing, feed to conveyor, chipping.

Delay.— Any activities besides above.

Chain flail: A mobile machine designed to remove bark, leaves, and branches from trees by the use of a rapidly rotating shaft with chains attached which strike and beat the crown of the tree.

Productive activities.— Travel to the bunch (or deck), positioning, lowering the chain flail attachment, chain-flailing the trees in the bunch, moving over the bunch until most of the smaller branches are removed.

Delay.— Any activities besides above.

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Discusses the advantages and disadvantages of various time study methods for determining efficiency and productivity in logging. The work sampling method is compared with the continuous time-study method. Gives the feasibility, capability, and limitation of the work sampling method.

KEY WORDS: Work sampling, productivity, delay ratio, time study methods, work measurement.

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