Silva Fennica 1987, vol. 21 n:o 1: 17–35

A method to evaluate productivity of logging machines: an application to a PIKA 35 processor

Jimin Tan

SELOSTE: PIKA 35-PROSESSORIN TUOTTAVUUDEN MÄÄRITTÄMINEN

Tan, J. M. 1987. A method to evaluate productivity of logging machines: an application to a PIKA 35 processor. Seloste: PIKA 35 -prosessorin tuottavuuden määrittäminen. Silva Fennica 21(1): 17–35.

This study deals with the evaluation of logging machines. The analyses were based on the results of a productivity study with special reference to a PIKA 35 processor, a delimber-bucker, working in Kyröskoski forest area in Finland. The factors affecting the productivity of the machine were surveyed. The mathematical models for determining the productivity were developed and their practical application to the particular problem under study was demonstrated.

Tutkimus käsittelee puunkorjuukoneiden suorityskyvyn arviointimenetelmää. Tuottavuuden määrittämiseksi ladittiin matemaattisia malleja ja tarkasteltiin niiden soveltuvuutta vastaavien tutkimusongelmien ratkaisemiseen. Malleja testattiin PIKA 35 -prosessorista kerätyn aineiston avulla. Tuottavuuteen vaikuttavat tekijät kartoitettiin.

Key words: evaluation of logging machines, processor, productivity, time studies, mathematical model
ODC 360+307+35

Correspondence: Department of logging and Utilization of Forest Products, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki, Finland.

Approved on 17. 3. 1987

1. Introduction

Productivity is a very important indicator for evaluating the logging systems. With the introduction and development of new, or with the modification or change on current logging machines or systems, there is a need to evaluate their productivities under the variable working conditions in the forests. This paper is to present a method of evaluating the productivity of a delimber-bucker, based on the results of a productivity study with special reference to a PIKA 35 processor, and its emphasis is on the establishment of mathematical models.

Productivity usually means the ratio between the output as a result of an activity and the corresponding input of productive forces, or briefly a ratio of output to input. The definition has been given by many authors

(Mäkelä 1969, NSR 1978, Haarlaa 1981, Simula 1983). The productivity may be given in quantity per unit input, such as volume per working hour (m^3/h), volume per power hour (m^3/kWh) etc. The productivity of a logging machine or system is usually expressed in m^3/h. However, the working conditions in the forests are extremely variable. Such a calculated productivity must be modified by machine availability, reliability, or efficiency of the whole logging operations to approximate actual operating conditions. Similar formulae for calculating the productivity in m^3/h were given by McCraw & Silversides (1970), FAO (1977), Aird et al. (1971):

$$P = 3600 \cdot V/T \tag{1}$$

where P = productivity in m^3/h
V = volume per tree in m^3
T = total cycle time per tree in sec

The machine availability and utilization have been defined in Forest Work Study Nomenclature (NSR 1978):

$$MA = Et/(Et+BWrep+DLm) \tag{2}$$

$$MU = Et/(Et+BWrep+DLn) \tag{3}$$

where MA = machine availability (%)
MU = machine utilization (%)
Et = gross effective time
$BWrep$ = repair time
DLm = machine delay time
DLn = unavoidable delay time

These formulae and definitions lead to the necessity of studies of the affecting factors on the productivity and the establishment of their quantitative relations with the productivity.

A preliminary test of the production of the PIKA 35 processor has been conducted both in Finland by Metsäteho (1982) and in Norway by Norwegian Forest Research Institute (Krogstad 1984). The objectives of this study were to determine the effect of some important factors on the productivity of delimbing-bucking machines, and to develop the mathematical methods for determining the productivities for the processors under the varying production conditions.

2. Materials and methods

2.1 PIKA 35 processor

The PIKA 35 processor was mounted on a forest tractor which was a Valmet 882 with an engine power of 74 kW (100 hp). On the base tractor was installed a FISKARS F60v crane with a 2-extension telescopic boom which gives the loader an outreach of 9.1 meters, for assistance of loading trees. The PIKA 35 processor consists of two main units: base unit and processor. The processor unit is mounted on bearings on top of the base unit.

The manufacturer's specifications are presented in Fig. 1.

2.2 Data procurement and analysis

At the beginning of the field testing, a pilot study was done for four days. This enabled the observer to define the time elements properly, to make a detailed recording plan for following days' tests, so that the desired data were collected.

During the time studies two observation sheets were employed: one for total working time in which the time elements of total time and the testing circumstance information were recorded; one for working place time in which the time elements of work cycles and the stand factors were included. About the concepts on work studies refer to Forest Work Study Nomenclature (NSR, 1978). To avoid confusions in concept we refer the total element time to the element time in total working time and the cycle element time to the element time in the total cycle time in the following sections.

PIKA 35 THINNING PROCESSOR

TECHNICAL SPECIFICATION
Turning Base Unit

Weight	1.050 kg
Length	1.40 m
Width	1.00 m
Height	1.55 m
Hydraulic power requirement: Open two-pressure hydraulic system Including free flow	
– output approx.	190 l/min
– pressure max.	210 bar
Automatic wood handling	
Electric system	24 or 12 V
Valves	PIKA 27
Choice of lengths	10
Delimbing dia.	35 cm
Basal dia. max. approx.	45 cm
Delimbing speed	3 m/s
Feeding power	20 kN
Crosscutting time	1...2 s
Chain saw	3/8"
Delimbing knives: one fixed, two movable	
Feeding: Ribbed rollers of steel	
Turning of processor	270°
Tilting of processor	+15°...–30°
Turning of base unit	80°

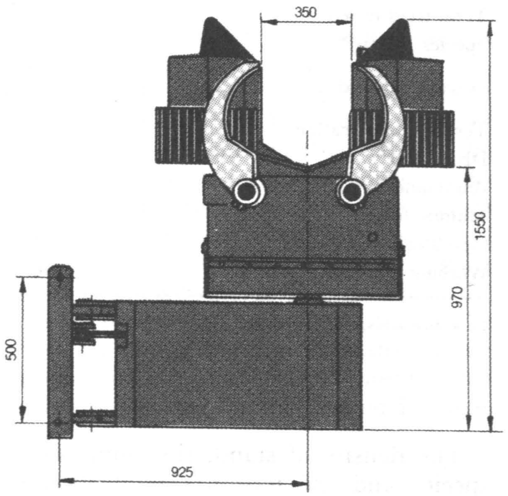

Fig. 1. Specification of PIKA 35 processor.

2.2.1 *Stand factors*

The following stand factors that were expected to have significant effects on the work of the processor were measured.

The diameter at breast height (DBH) was estimated ocularly and followed by a certain frequently checking with a caliper. A diameter class with a 2 cm difference from 7 to 45 cm in DBH was used. The branchiness was recorded by two columns simultaneously: one for the ratio of the length covered by branches to the total merchantable tree length, one for the thickness of the branches. The results of these recordings were classified afterwards in five classes according to the regulation given in "Metsä- ja uittoalan . . ." (1984–1986). Only three species were processed during the test: pine, spruce, and birch.

In addition to above mentioned stand factors, several other stand factors, which were considered to have influences on the testing, e.g. density of stand (trees per hectare), cutting density or degree of cutting (trees cut per hectare), etc., were observed.

2.2.2 *Testing circumstances*

The testing was done in Kyröskoski, Kyro OY's logging area from Nov. 27 to Dec. 15 in 1984. The testing circumstances are listed in Table 1.

Table 1. Testing Circumstances.

	Selective Cutting	Clear Cutting
Total trees tested	468	330
Species (p/s/b)*	86 / 375 / 7	7 / 323 / 0
Density of stand	414 trs. harvested/ha 130 trs. remained/ha	756 trs/ha
Terrain classification	I	I
DBH (cm)	21.1	22.7
Branchiness	2.1	2.3
Manual felling	parallel	parallel
Operator's experience	Same operator in both cuttings, experience about 3 months	
Working methods	one-way and two-way method were used in both cuttings	

* p = pine, s = spruce, b = birch

The density of stand, the composition of species and the terrain classification were obtained from the inventory documents of Kyro OY and supplemented by the observer during the field testing. The branchiness and DBH were the average results of all the observations.

2.2.3 Time studies

The total working time was measured by means of an electronic wrist watch with normal clock chronograph, graduated into seconds, minutes, and hours. The measurement of cycle element times was based on stopwatch studies. Three similar stop-watches were mounted on a so-called study board, the stop-watches were fly-back second type.

The total working time was broken down into gross effective time, repair time, moving time, change-over time and meal time. The change-over time and meal time were supposed to be fixed time in duration for each day, since they were daily routines, and taken as constant time daily from the average results of the testing, rounded to the nearest upper quarter of an hour. The moving time and repair time were supposed to be directly proportional to the effective time. The gross effective time was broken down into its elements which were selected for the convenience of observation and timing. The elements were determined beforehand (Heidersdorf 1974) and checked during the pilot studies and redefined for the later practical recording. The total work cycle included following elements:

Loading – Begins when the boom starts to swing out to reach a new tree and ends when the tree has been placed in the holding position of the processor.

Processing – Begins when the tree is placed in the holding position of the processor and ends when the top of the processed tree has been cleared.

Travelling – Begins when the last tree is processed and the tractor starts moving and ends when the tractor stops moving, and the crane boom starts to swing out.

Delay – Delays are treated in different ways depending on their duration:

0...5 sec, are included in the element during which they occur.

5 sec...15 min, are recorded as "Delays".

>15 min, are not included as part of effective time.

The delay time was further broken down into its subelements such as machine delay, work delay, personal delay and other delay. The determination of the processing time was by regression analysis (Draper & Smith 1966). The step-wise regression analysis was used for the purpose of selecting the "best" regression equation to predict the processing time (dependent variable) by the predictors (independent variables). All the regression analyses in this paper were performed by BMDP programme (Dixon et al. 1983) on Burroughs B7800 computer system.

3. The mathematical models on productivity

The following productivities are always given in m^3/EMH, where EMH means gross effective machine hour.

3.1 Output per EMH as a function of DBH

The reasons why the DBH was chosen as the only independent variable of the production function are:

(1) The DBH is one of the most important determinants of the tree volume and the forest stand. The particular importances of DBH in forest inventory were stated by Loetsch et al (1973) and Avery (1975).

(2) The total cycle time varies depending much on DBH, i.e. the DBH is the main affecting factor on the total cycle time.

(3) The use of the single variable (DBH) in the productivity function simplifies the further analysis and the procurement of the firsthand materials.

A general mathematical model for the productivity function is shown in equation 4, which can be obtained by regression analysis, based on the P values by formula 1.

$$P(D) = \sum_{i=0}^{m} C_i \cdot D^{m-i}$$
$$= C_o \cdot D^m + C_1 \cdot D^{m-1} + C_2 \cdot D^{m-2} + \cdots + C_{m-1} \cdot D + C_m \qquad (4)$$

where C_i = coefficients of regression analysis, $i=0,1,2,\ldots,m$.
D = DBH, cm.
m = the highest order of the regression polynomial, $m \geqslant 0$.

Generally speaking, the m in the equation would be less than five and should be as low as possible for simplifying the analyses if it does not affect the accuracy of the result.

3.2 Maximum output per EMH

Although the productivity in equation 4 is formally expressed as a function of DBH, it is a production function – since it is derived from formula 1, in which V (volume per tree) and T (total cycle time per tree) express the relationship between input and output indirectly. The conformation of the production function in the present study with the law of diminishing returns (Gregory 1972, Duerr 1960) is demonstrated in Fig. 5. Thus, the maximum production point exists and can be attained by taking the first derivative of the equation 4 with respect to D, setting it equal to zero, and solving for the desired D value. Hence:

$$\frac{dP(D)}{dD} = \frac{d}{dD}\left[\sum_{i=0}^{m} C_i \cdot D^{m-i}\right]$$
$$\sum_{i=0}^{m-1} C_i \cdot (m-i) \cdot D^{m-i-1} = 0 \qquad (5)$$

To solve this algebraic equation, the numerical iteration method can be used. In the present study, the so-called "Bairstow-Newton Iteration Method" (Kreyszig 1983) was employed and performed by Fortran-IV programme on the B7800 computer system.

The number of solutions of the equation 5 are $(m-i-l)$ expressed as $D_1, D_2, \ldots, D_{m-i-1}$, then the maximum productivity is:

$$Pmax(Dm) = Max\,\{real[P(D_1), P(D_2), \ldots, P(D_{m-i-1})]\} \qquad (6)$$

where

"Max" and "real" = the largest value of the real solutions
Pmax = maximum output per EMH
Dm = DBH at which the maximum productivity occurs.

3.3 The expected productivities

To calculate the expected productivity, the following formulae on the base of statistical expectation were established:

$$Pe = \sum_j F(D_j) \cdot P(D_j) \qquad (7a)$$

$$Pe = \int F(D) \cdot P(D)dD \qquad (7b)$$

where

Pe = expected output, m^3/EMH.
$F(D_j)$ or $F(D)$ = frequency function or density function of stem-diameter distribution.
$P(D_j)$ or $P(D)$ = output per EMH as a function of DBH.

The function of P(D) has been defined by equation 4. The derivation of F(D) is given below.

3.3.1 Discrete stem-diameter distribution

The absolute stem-diameter frequency can be obtained from the inventory documents and the relative stem-diameter frequency is thus arrived at as follows:

$$Fr(D_j) = Fa\,(D_j)/(N \cdot w) \qquad (8)$$

where

$Fr(D_j)$ = relative stem-diameter frequency at diameter class j.
$Fa(D_j)$ = absolute stem-diameter frequency at diameter class j
N = total stem-diameter frequency.
w = diameter classwidth, cm.

The relative stem-diameter frequency $Fr(D_j)$ can be used as the frequency function, or in other words, the weights for expecting the productivity.

3.3.2 Continuous stem-diameter distribution

The expected productivity can be attained by either equation 7a as above introduced, or equation 7b. As an alternative the formulation of more flexible continuous mathematical models would be of great importance in theoretical analyses and very useful for predicting the expected productivities.

The density function of continuous stem-diameter distribution has been studied by Loetsch et al (1973). It was stated that "distribution is made between three main types of stem-diameter distributions: unimodal, decreasing and multimodal".

For the multimodal it is difficult or even impossible to establish a continuous mathematical model. The discrete stem-diameter distribution is preferred and available. The unimodal and descreasing stem-diameter distributions can be expressed by so-called beta-function.

The beta-function, which in slightly different form is also called "EULER's first integral", is defined by

$$B(p,q) = \int_a^b (D-a)^p (b-D)^q dD \qquad (9)$$

where
D = DBH as the variable under investigation.
a, b are lower and upper limits of the beta-function
p, q are exponents of the beta-function.
B(p,q) = area under the distribution curve.

The sought density function of stem-diameter distribution from beta-function is obtained:

$$F(D) = \frac{(D-a)^p (b-D)^q}{B(p,q)} \qquad (10)$$

It was stated by Loetsch et al. (1973) that the surprising flexibility is due to the exponents p and q which, – according to their magnitude and relation to each other –, generate a great variety of distribution forms.

Based on F(D) in equation 10 and P(D) in equation 4, we can develop equation 7b into equation 11 as follows:

$$\begin{aligned} Pe = & \int_a^b F(D) \cdot P(D)dD \\ & \int_a^b \frac{(D-a)^p\,(b-D)^q}{B(p,q)} \sum_{i=o}^{m} C_i \cdot D^{m-i}dD \\ = & \sum_{i=0}^{m-1} \sum_{j=o}^{m-i-1} \{C_i \binom{m-i}{j} (b-a)^{m-i-j} \cdot a^j. \\ & \prod_{k=1}^{m-i-1} \frac{p+1+m-i-j-k}{p+q+2+m-i-j-k}\} \\ & + \sum_{i=o}^{m} C_i \cdot a^{m-i} \qquad (11) \end{aligned}$$

Equation 11 illustrates that the expected productivity depends on the features of the two functions F(D) and P(D) and is determined by the parameters m, C_1, a, b, p, q, where the m and C_1 were already defined by equation 4. There are four approaches to derive a beta-distribution from an actual empirically established distribution (refer to Loetsch et al 1973) The fourth alternative, i.e. the computation of beta-function by regression analysis, is used in the present study. The method has its merits if the beta-distribution is used for describing relations between variables (Zöhrer 1969).

The equation 10 in logarithmic reads:

$$\ln(F(D)) = p\ln(D-a) + q\ln(b-D) - \ln(B(p,q))$$

and in terms of regression analysis:

$$y = b_o + b_1 x_1 + b_2 x_2 \qquad (12)$$

where

$y = \ln(F(D))$, $b_o = -\ln(B(p,q))$,
$x_1 = \ln(D-a)$, $b_1 = p$,
$x_2 = \ln(b-D)$, $b_2 = q$,

Since the frequency distribution of stem diameter is given with k classes of classwidth w, and class midpoints $D_1, D_2, \ldots, D_1, \ldots, D_k$, a and b can be obtained from the following formulae, provided N (the total number of observations) is sufficiently large:

$$a = D_1 - w/2, \; b = D_k + w/2 \qquad (13)$$

3.4 Maximum expected productivity

Since the trees bigger than 35 cm at DBH were bucked beforehand at butt end and their sizes were reduced into the required diameter classes for the machine (below 35 cm at lower end), the coming question is whether this maximum limitation of DBH was the best with a view to maximizing the expected productivity. The answer to this question would be based on the facts from the present study. The basic procedure is:

(1) Presuppose a diameter Dm at which the expected output would be maximized. Dividing the total diameter distributing range into the following two parts:

(2) the first part is the expected output below Dm, which can be attained by equation 7;

(3) the second part is the expected output at Dm. We assume that all those trees above Dm in DBH were bucked beforehand and reduced in DBH into Dm. It can be attained by multiplying the productivity of equation 4 at Dm, which is P(Dm), by the total relative frequency of stems over Dm, which is:

$$\int_{Dm}^{b} F\,(D)\,dD, \text{ or } \sum_{D>Dm} F\,(D_j).$$

Consequently, the maximum expected output can be obtained by maximizing the following equations:

$$Pe\,(Dm) = \sum_{D>Dm} (D_j) \cdot P\,(D_j) + P\,(Dm) \sum_{D>Dm} F\,(D_j) \qquad (14a)$$

$$Pe\,(Dm) = \int_a^{Dm} F(D) \cdot P(D)\,dD + P(Dm) \int_{Dm}^{b} F(D)\,dD \qquad (14b)$$

By discrete stem-diameter distribution, the values of Pe(Dm) can be calculated by equation 14a from the smallest diameter a to the largest diameter b, then

$$Pemax = Max\{Pe(Dm_1), Pe(Dm_2), \ldots, Pe(Dm_k)\} \qquad (15)$$

where $Pe(Dm_j)$ = the expected productivity at diameter Dm_j.
Pemax = the maximum expected productivity.

The maximization of the expected output for the continuous stem-diameter distribution in equation 14b can be attained by setting the first derivative of the equation with respect to Dm equal zero, i.e.

$$\begin{aligned} \frac{dPe\,(Dm)}{dDm} & = \frac{d}{dDm}\{\int_a^{Dm} F(D) \cdot P(D)\,dD + P(Dm) \int_{Dm}^{b} F\,(D)\,dD\} \\ & = F\,(Dm) \cdot P(Dm) - (P(Dm) \cdot F(Dm) + \frac{dP\,(Dm)}{dDm} \int_{Dm}^{b} F(D)dD) \\ & = -\frac{dP\,(Dm)}{dDm} \int_{Dm}^{b} F\,(D)\,dD = 0 \qquad (16) \end{aligned}$$

Since $\int_{Dm}^{b} F\,(D)\,dD > 0$, when Dm is not equal to b.

$\int_{Dm}^{b} F\,(D)\,dD = 0$, when Dm = b.

This is one of the solutions of equation 16, at which the Pe(Dm) = Pe (b) can be obtained either by equation 14b or by formula 11, since the second item on the right of equation 14b is equal to zero, while the first item is equal to Pe(b), which is conformed with formula 11.

However $\frac{dP\,(Dm)}{dDm} = 0$ whose solutions are conformed with those by equation 6. They are $D_1, D_2, \ldots D_{m-i-1}$, then

$$\text{Pemax} = \text{Max}\,\{\text{real}\,(\text{Pe}(b), \text{Pe}(D_1), \text{Pe}(D_2), \ldots, \text{Pe}\,(D_{m-i-1}))\} \tag{17}$$

4. Results and discussion

4.1 Time study

4.1.1 Gross effective time

Total time per merchantable tree

The distributions of total cycle times in selective cutting and clear cutting are presented in Table 2.

The total cycle time in selective cutting (73 sec) was higher than that in clear cutting (68) sec). The main contributing element time to it was the travelling time. From Table 1, 746 and 414 trees per hectare were processed in clear cutting and selective cutting respectively. The different degree of cutting in these two cutting areas caused the difference in travelling times. The travelling time in selective cutting (17 sec, accounted for 23 % of the total cycle time) was much higher than that in clear cutting (10 sec, accounted for 15 % of the total cycle time). This was also an important indication of that the density of the trees per hectare and the travelling distances, which were the affecting factors on the travelling times, did affect the total cycle time. Generally, the higher the density and thus the shorter the travelling distances, the shorter the travelling time. In addition, the terrain conditions might have influenced the travelling time. Although the terrain classification in both cuttings were the same, the actual working conditions were not. The terrain in the selective cutting area was more difficult, e.g. slightly slope over 15 % in the selective cutting area might have slowed down the travelling speed of the tractor, while there was no sloe at all in the clear cutting site. Furthermore, there might be some other unknown factors that have a affected the travelling time, e.g. the organization of the work, the travelling patterns etc. Those influencing factors on the travelling time were not tested due to the short period of studies. However, they might have potential influences on the travelling time and should be considered in further studies.

The affecting factors on the loading times might have been the felling pattern and the tree characteristics. The influence of the tree characteristics on the loading time was not demonstrated in the present study. Since the parallel felling was used in both cuttings, the same average loading time for both cutting patterns was very reasonable even though some unknown factors might have influenced the results.

The average processing time in clear cutting (23 sec) was higher than that in selective cutting (20 sec). This was mainly due to the different stand factors in those two cutting areas, e.g. the average DBH in selective cutting (21 cm) was smaller than that (23 cm) in clear cutting. The analysis of the affecting factors on the processing time was detailed and is presented in the next part of this section and followed by the delay time analysis.

Processing time

The processing time was analyzed under two conditions: first under favourable conditions, in which the unfavourable cases were excluded; second, under actual conditions, in which all cases were included. Two equations for processing time under these two different conditions were developed as shown in the following equations 18 and 19, which were the equations at the last step of step-wise regression analysis.

Table 2. Summary of time per mechantable tree.

Time elements	Time per tree, sec Selective cutting mean	S.D.	%	Clear cutting mean	S.D.	%
Loading time	18	7.2	25	18	8.1	27
Processing time	20	16.3	28	23	21.4	34
Travelling time	17	38.2	23	10	19.9	15
Delay	18	63.2	24	17	57.6	24
Total cycle time	73	80.1	100	68	69.0	100

S.D. = standard deviation

$$\begin{aligned} Tp = {} & 1.45044 + 0.00032082(D^3) + 3.38184(NL) \\ & + [0.11482(B3) + 0.51679(B4) + 1.66918(B5)](D) \\ & + 0.67616(D)\cdot(AB) + 0.21924(D)\cdot(UFM) \\ & + [11.53935 + 2.0237\cdot 10^{-7}\,(D^5)](UFH) \end{aligned} \tag{18}$$

$R^2 = 0.8492$, Res. MS = 52.71185.

$$\begin{aligned} Tpf = {} & -0.11377 + 0.00022133(D^3) + 0.07854(D)\cdot(B) \\ & + 3.39301(NL) - 1.65195(PINE) \end{aligned} \tag{19}$$

$R^2 = 0.8972$, Res. MS = 7.729527.

where Tp = predicted processing time under actual condition, sec.
Tpf = predictred processing time under fafourable condition, sec.
D = DBH, cm
NL = number of logs per tree procesesed
B3, B4, B5 are dummy variables for branchiness classes 3,4,5.
AB = 1 if abnormal shaped tree occurs, otherwise AB = 0.
UFH = 1 if crane loader helps feeding and delimbing, otherwise UFH = 0.
UFM = 1 if the log is refeeded or redelimbed, otherwise UFM = 0.
B = continuous variable for branchiness, B = 1, . . . , 5.

The two equations illustrate that the processing time can be predicted by the predictors at least of DBH, branchiness, number of logs per tree processed, and working condition factors since they were included in the equations as significant influencing variables. From the results of the stepwise regression analysis, we can also conclude that there was no significant difference for predicting the variation of the processing times between the selective cutting and the clear cutting since the cutting type (CT) variable was excluded from both of the equations. The conclusion is true because the variation of the processing time to its predictors is not or very slightly affected by the cutting types. The species variable didn't affect the processing time very markedly under unfavourable conditions but became significant variable under favourable conditions as shown in equation 19 above, in which birch was not included due to the lacking of the observations (only 7 trees of birch species were tested). The introduction of the working condition variables reduced the significant level of the species variables. But they would have been included in the model for the purpose of better prediction.

The significant influence of the number of the logs per tree is certainly evident since the frequency and hence the bucking time would be increased, while the delimbing time keeping constant, as the number of logs under certain length of the tree increases. The difference of the influence between branchiness class 1 and 2 was not apparent and excluded from equation 18, but they are included in equation 19 since the branchiness was considered as a continuous variable. As a matter of fact, the influence of the branchiness is more enhanced with the increase of the DBH which was illustrated in those two equations. The effects of the working variables were extremely strengthened at the large sized trees (they varied with a rate directly proportional to

Table 3. Summary of delay times.

Causes	Selective cutting mean	S.D	P.D.	P.C.	Dealy times, sec/tree Clear cutting mean	S.D	P.D.	P.C.	Average mean	S.D	P.D.	P.C.
Machine	5.7	51.3	32.0	7.8	5.1	31.5	30.9	7.5	5.5	44.2	31.6	7.7
Work	8.6	19.4	48.7	11.8	5.7	14.9	34.1	8.3	7.4	17.8	42.8	10.4
Personal	1.6	24.2	9.2	2.2	5.4	46.5	32.3	7.9	3.2	35.2	18.4	4.5
Other	1.8	20.8	10.1	2.5	0.5	3.2	2.8	0.7	1.2	16.1	7.2	1.8
Total	17.7	63.2	100.	24.3	16.6	57.6	100.	24.4	17.3	60.9	100.	24.4

S.D. = stardard deviation; P.D. = percentage to delay time; P.C. = percentage to the total cycle time.

D^5). They are the indicators of the capacity limitation of the machine. The processing time increases at a great rate as DBH increases, which can be indirectly illustrated by Fig. 2, and would give rise to a diminishing production function, which would be verified later. Therefore the productivity as a function of DBH is certainly important.

Delay time

The distributions of delay element times are presented in Table 3.

The prediction of the delay times is difficult since they happened most accidentally. But they represented the general probabilities of the occurrence supposing the testing period would be long enough. The major part of the delay was accounted by work delay (42.8 % in average). This was mainly composed of the time of moving trees and logs. It was apparent that the moving of the trees and logs was more difficult in selective cutting area due to the standing trees, and its time (8.6 sec in mean value, accounted for 48.7 % of the total delay) was higher than that in clear cutting (5.7 sec in mean value, accounted for 34.1 % of the total delay time). The next large delay element time was the machine delays (accounted for 31.6 % of the total delay time in average). The time of clearing branches from the processor could not be overcomed unless the equipment would be improved. Another cause of the machine delay was the repairing in a short time, of which partially was for the maintenance and repairing of the normally worn out machine parts, and partially was for repairing unnormal worn out machine parts. Because some of the oversized trees (larger than 35 cm in DBH) were processed, the overloading and hence broken down of the machine happened from time to time, which caused the increasing not only of the short machine delay but also of the long time repairing (BWrep) time in terms of total working element and hence reduced the machine availability and utilization. Therefore, it would be strongly recommended that the sizes of the trees processed be not too large since it would cause more delays.

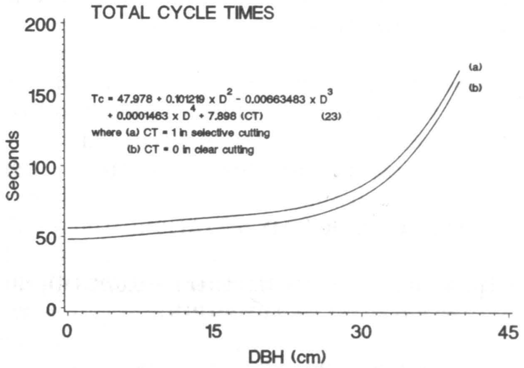

Fig. 2. Theoretical total cycle times.

The personal delay time in selective cutting (1.6 sec in mean value, accounted for 9.2 % of the total delay time) was lower than that in clear cutting (5.4 sec in mean values, accounted for 32.3 % of the total delay time). One possible reason causing the big difference in personal delay was that the testing for clear cutting was at the beginning of the work site and thus more instructions and commands were needed for the works. But it wouldn't be considered as the general phenomenon under various working conditions. Further research is needed here.

Theoretical total cycle time

From Table 2 the total time can be expressed by

$$Tc = Tl + Tm + Td + Tp \qquad (20)$$

where

Tc = total cycle time per tree, sec

Tl, Tm, Td, and Tp are loading time, travelling time, delay time and processing time, sec.

For the first three time elements on the right of equation 20 above, the average results from Table 2 were used:

$$Tl + Tm + Td = 44.978 + 7.898\ (CT) \qquad (21)$$

where

CT = 1 for selective cutting, 0 for clear cutting.

The theoretical processing time as a function of DBH was developed:

$$Tp(D) = 3+0.101219\ (D^2)-0.0063483\ (D^3) + 0.0001463\ (D^4) \qquad (22)$$

$$R^2 = 0.79169,\ \text{Res. MS} = 142.079017.$$

Using the equation 20, and 22, we get the theoretical total cycle time required for completing a work cycle of tree processing, which are graphed in Fig. 2.

Although there was no significant difference between the processing times in selective cutting and clear cutting (as shown in equations 18, 19 and 22), the total cycle time differed significantly between the two cutting types since the differences in equation 21 were too apparent to be ignored. The coefficient ($R^2 = 0.79169$) of multiple determination in equation 22 was lower than that ($R^2 = 0.8492$) in equation 18, the residue mean square (Res. MS = 142.079017 was over twice as much as that (Res. MS = 52.71185) in equation 18. Therefore, equation 18 is a better prediction for processing time and would be employed for more accurate analysis. But in the present study, we prefer equation 22 for the following analyses for the sake of simplication and other reasons as concluded above in the processing time analysis.

4.1.2 Total working time

The equations expressing the linear relationships between the cumulative moving time and cumulative gross effective time, and between cumulative repair time and cumulative gross effective time were developed by linear regression analysis and graphed on the scatter plots of the observations as shown in Fig. 3 and Fig. 4.

The slope (0.09045) of the regression line in Fig. 3 is the expected rate of the variation between moving time and gross effective time, and that (0.84087) in Fig. 4 the expected rate of the variation between the repair time and the gross effective time, based on which the average results for the total element times were obtained and are presented in Table 4.

Different shift hours give rise to different distributions of total element times. The machine repairing time accounted for 37 . . . 40 % of the total working time, which was almost as much as gross effective working time (44 . . . 48 %). Since the processor was working under oversized trees and was overloaded, it broke down very frequently, which raised the repairing time and hence reduced the effective running time of the machine, and also tensioned the operator's working condition. This result indicated that the capacity of the machine was quite limited and therefore the sizes of processed trees should be controlled in a feasible range for the machine in order to improve the efficiency of the production.

Table 4. Summary of total working time

	Shift hours											
	5		6		7		8		9		10	
Element	min	%	min	%	min	%	min	%	min	%	min	%
Et	132	44.0	163	45.3	194	46.2	225	46.9	256	47.5	287	47.9
BWrep	111	37.0	137	38.1	163	38.9	189	39.5	216	39.9	242	40.3
BWmov	12	4.0	15	4.1	18	4.2	20	4.2	23	4.3	26	4.3
BWco	15	5.0	15	4.2	15	3.6	15	3.1	15	2.8	15	2.5
BWmeal	30	10.0	30	8.3	30	7.1	30	6.3	30	5.6	30	5.0
Total	300	100	360	100	420	100	480	100	540	100	600	100

Table 5. Solutions of the maximum output

CT	D(I)	Roots		Output per EMH of real roots
		Real part	Imaginary part	
SC	D(1)	35.1385115756	0.0000000000	37.0711807340
SC	D(2)	–0.4876935448	4.9528954004	–
SC	D(3)	4.8051560167	0.0000000000	0.6706190296
CC	D(1)	3.7088392504	4.9528954004	–
CC	D(2)	35.7471347967	0.0000000000	42.2204819535
CC	D(3)	0.0000000000	0.0000000000	0.9743640000

Where SC = Selective cutting; CC = Clear cutting.
D(I) = Solutions of DBH from equation 28.

4.2 Productivity

4.2.1 The output per EMH with respect to DBH

As the input of formula 1, the total cycle time has been defined by equation 23 in Fig. 2, and the volume as functions of DBH were developed based on the inventory documents from Kyro Oy:

$$Vs = 0.000\,054\,49\,(D^{2.8212}) \qquad (26a)$$

$$Vp = 0.000\,135\,641\,(D^{2.5218}) \qquad (26b)$$

$$Vb = 0.000\,023\,046\,(D^{3.1372}) \qquad (26c)$$

where Vs, Vp, Vb are volumes per tree for spruce, pine and birch respectively in m^3/tree.

Substituting the V's in equation 26 and Tc in equation 23 into formula 1, we get P at each diameter class. Based on the results thus calculated, the function for the variation of output per EMH with respect to DBH was further developed through regression analysis as shown in equation 27 in Fig. 5.

Fig. 5 demonstrates that the production function conformed to the law of variable proportions. Thus the maximum output existed and can be attained by equation 5.

$$\frac{dP(D)}{DD} = -\ 0.0314949\cdot(CT) - (0.0507086+0.00641998\cdot(CT))\cdot(D) + 0.0150909\cdot(D^2)-0.0003824744\cdot(D^3) = 0 \qquad (28)$$

The solution of equation 28 is presented in Table 5.

In result the maximum productivity in selective cutting was about 37 m^3/EMH at about 35 cm in DBH (which will be called Dm as before, the diameter at which the maximum productivity occurred), and that in clear cutting was about 42 m^3/EMH at about 36 cm in DBH. The output per EMH would be reduced if the DBH were increased above or decreased below the Dm. For the single-sized forest stand the output per EMH can be determined by equation 27 in Fig. 5 and maximized only when the DBH of the stand is at or near to Dm. The other types of forest stands will be considered in the following sections.

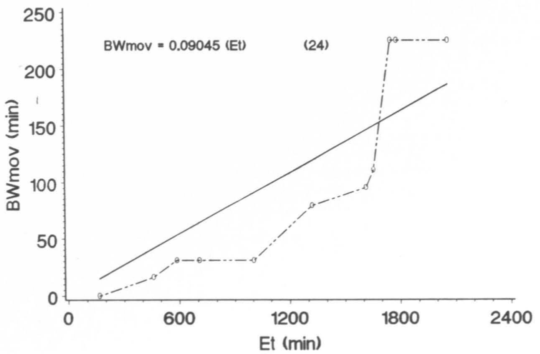

Fig. 3. Relationship between cumulative moving time and gross effective time.

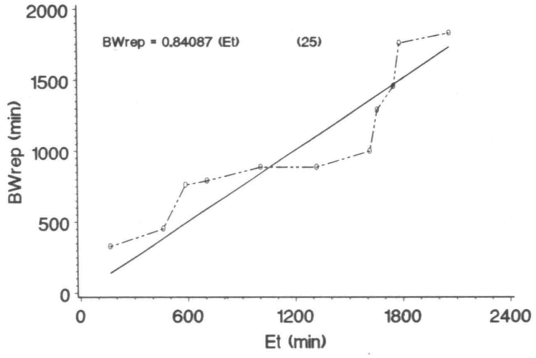

Fig. 4. Relationship between cumulative repair time and gross effective time.

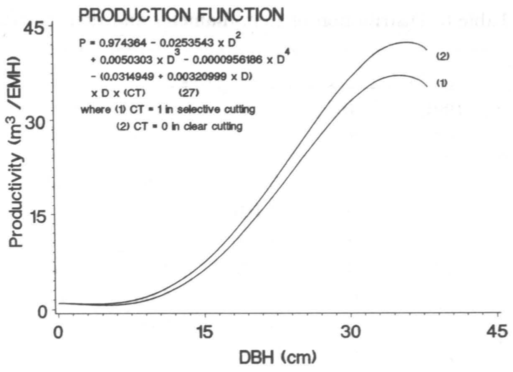

Fig. 5. Production function.

4.2.2 Expected productivity

By discrete stem-diameter distribution

From equation 7a and 7b, the function F(D) should be determined while the function P(D) has been already defined by equation 27.

The absolute stem-diameter frequency was obtained from the inventory documents of Kyro Oy, from which the relative stem diameter frequency was calculated by equation 8, and presented in Table 6.

In Table 6, Fa(D) and Fr(D) stand for the absolute and relative frequencies of the stem-diameter distribution respectively, which are also plotted in Fig. 6a and 6b.

The supposed maximum expected productivity was calculated for each diameter class that was assumed as a maximum diameter by formula 14a, which are presented in the fifth column of Table 6 and represented by Ped(Dm). The maximum expected productivity was founded 14.8 m^3/EMH in selective cutting and 17.1 m^3/RMH in clear cutting, both at a maximum diameter of 35 cm in DBH. From the results of Ped(Dm), we can conclude that the recommended maximum diameter of the trees to be processed by this model of machine would be at or near to 35 cm in DBH in both cutting types with a view to maximizing the productivity.

By continuous stem-diameter distribution

As an alternative method, the continuous mathematical model for deriving the expected productivity is more convincing in theory.

Based on the relative frequency in Table 6, the frequency functions, or density functions,

Table 6. Distribution of stem-diameter and their corresponding productivity.

Selective cutting					Clear cutting				
DBH cm	Fa(D) no	Fr(D)	Ped(Dm) m^3/EMH	Pec(Dm) m^3/EMH	DBH cm	Fa(D) no	Fr(D)	Ped(Dm) m^3/EMH	Pec(Dm) m^3/EMH
7	111	0.105	0.850	0.845	7	49	0.066	1.228	1.225
9	113	0.107	1.358	1.339	9	82	0.111	1.912	1.905
11	101	0.095	2.186	2.152	11	64	0.087	2.934	2.957
13	87	0.082	3.289	3.244	13	58	0.079	4.265	4.333
15	64	0.060	4.604	4.549	15	56	0.076	5.841	5.952
17	50	0.047	6.091	5.984	17	46	0.062	7.568	7.709
19	67	0.063	7.699	7.464	19	46	0.062	9.381	9.493
21	54	0.051	9.283	8.904	21	49	0.066	11.174	11.201
23	43	0.041	10.793	10.229	23	49	0.066	12.827	12.744
25	82	0.077	12.186	11.383	25	45	0.061	14.246	14.054
27	60	0.057	13.247	12.323	27	41	0.055	15.384	15.092
29	63	0.060	14.018	13.029	29	50	0.068	16.222	15.849
31	42	0.040	14.484	13.501	31	34	0.046	16.709	16.340
33	38	0.036	14.727	13.759	33	21	0.028	16.953	16.605
35	33	0.031	14.795	13.840	35	17	0.023	17.044	16.702
37	16	0.015	14.758	13.795	37	13	0.018	17.033	16.695
39	14	0.013	14.665	13.680	39	7	0.010	16.975	16.647
41	11	0.010	14.560	13.554	41	11	0.015	16.897	16.604
43	3	0.003	14.481	13.461	43	1	0.001	16.887.	16.576
45	7	0.007	14.403	13.417					
SUM	1059	1.000			SUM	739	1.000		

The symbols, e.g. DBH, Fa(D), Fr(D), Ped(Dm), Pec(Dm), etc. are explained in the text.

since the population of the sample was supposed to be sufficiently large and in fact the total population of the trees in these areas were used, of stem-diameter were developed by model (equation) 12 through regression analysis.

The regression models:

$$Ys = -6.02181 - 0.11812 \cdot Xs_1 + 0.871907 \cdot Xs_2 \qquad (29a)$$

$R^2 = 0.84983$, Res. MS = 0.163662.

$$Ys = -7.72976 + 0.216918 \cdot Xc_1 + 1.21346 \cdot Xc_2 \qquad (29b)$$

$R^2 = 0.94010$, Res. MS = 0.073376.

where Ys, Xs_1, Xs_2, and Yc, Xc_1, Xc_2 are corresponding regression variables to those in equation 12 for selective cutting and clear cutting respectively.

Transform into beta-functions:

$$Fs(D) = \frac{(D-6)^{-0.11812}\,(46-D)^{0.871907}}{412.32365094}$$

$$Fc(D) = \frac{(D-6)^{0.216918}\,(44-D)^{1.21346}}{2275.0522151068}$$

where Fs(D) = density function of stem-diameter distribution in selective cutting area.
Fc(D) = density function of stem-diameter distribution in clear cutting area.

These two density functions of stem-diameter distributions are graphed on the scatter plots of the relative frequency function in Fig. 6a and 6b so that the difference between observed and predicted values would be more clear.

From Fig. 6 we found that the stem-diameter distribution in selective cutting was represented by decreasing stem-diameter distribution and that in clear cutting the left-skewed unimodal stem-diameter distribution. Under the conditions of these types of forests, the description of the productivity by equation 27 in Fig. 5 is insufficient because it only describes the variation of the productivity with respect to DBH and does not give the actual output per EMH in the real production. More practically, the total expected productivity defined by model 11 provides the average results of the output per EMH in reality, which is very interesting and useful for analysis of the production costs. It seems that the model 11 would be too complicated to be used in practice, but actually is not. It can be run on the computer system by a short programme, for instance, at the present study a programme by Fortran-IV was made with 54 lines which is not shown in this paper, only the results of the expected productivity are presented as follows:

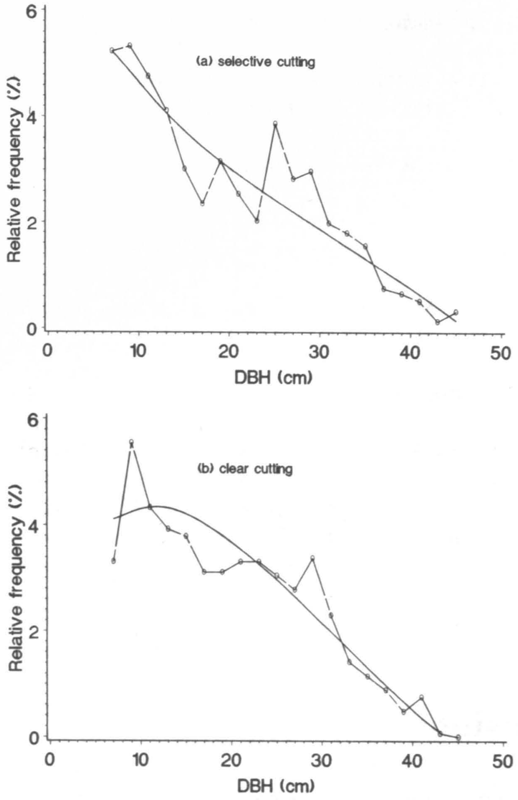

Fig. 6. Frequency function of stem-diameter distribution.

$$Pes = \Big\{\sum_{i=o}^{3}\sum_{j=0}^{3-i}\Big[C_i\binom{4-i}{j}\cdot(46-6)^{4-i-j}\cdot 6^j \prod_{k=1}^{4-i-j}\frac{(-0.11812)+1+4-i-j-k}{(-0.11812)+0.871907+2+4-i-j-k}\Big]\Big\} + \sum_{i=o}^{4} C_i\cdot 6^{4-i}$$

$$= 13.408 \qquad (m^3/EMH)$$

$$Pec = \Big\{\sum_{i=o}^{3}\sum_{j=0}^{3-i}\Big[C_i\binom{4-i}{j}\cdot(44-6)^{4-i-j}\cdot 6^j \prod_{k=1}^{4-i-j}\frac{(0.216918)+1+4-i-j-k}{0.216918+1.21346+2+4-i-j-k}\Big]\Big\} + \sum_{i=o}^{4} C_i\cdot 6^{4-i}$$

$$= 16.584 \qquad (m^3/EMH)$$

where Pes = the expected productivity in selective cutting.
Pec = the expected productivity in clear cutting.

The value by this calculation in clear cutting is slightly lower than that calculated by discrete distribution method in Table 6, that is because the regression analysis enlarged the range of the diameter classes (a, b) into (a′, b′), where a′ < a, and b′ > b as shown in equation 30. While the value in selective cutting is lower (1 m^3/EMH difference) than that by discrete distribution method. This can be explained as that the stem-diameter distribution in selective cutting could not be a decreasing distribution but multimodal distribution, as shown in Fig. 6, that was why the R-square ($R^2 = 0.84983$) in equation 29a lower than 90 % of the absolute accuracy.

Real production was even different since the bigger trees were bucked beforehand manually. For the purpose of estimating the real expected productivities, formulae 14 should be employed. The calculations were performed on the computer system and the integration was by numerical integration method – so-called "Simpson's rule of integration" (Kreyszig 1983).

The results for each diameter class are presented in the last column of Table 6, which is represented by Pec(Dm).

The maximum expected productivity in reality were 13.8 m^3/EMH in selective cutting and 16.7 m^3/EMH in clear cutting. The Dm is 35 cm in both cutting types. If diameter is lower than Dm (35 cm), the expected productivity would be reduced and on the other hand it strengthened the manual bucking, which is not a wise decision. However, if diameter is kept higher than Dm the expected productivity would be reduced also, although the decreasing was slight in terms of m^3/EMH, it could have reduced the utilization of the machine since the break down of the machine would take place more frequently. The total output per shift would be decreased markedly in fact even though it was not demonstrated by quantitative way. The suggestion is that the maximum size of tree processed by this model of machine be below 35 cm in DBH.

4.2.3 Machine availability and utilization

The machine availability and utilization were calculated by formulae 2 and 3.

Since BWrep = 0.84087 (Et)
DLm = 0.07693 (Et)
DLn = 0.24365 (Et)
DLm and DLn are from Table 3

Then MA = 52 %
MU = 48 %

These were the average results from actual field tests, during which the hydraulic pump was broken, which might have strongly caused the lower values. However, as concluded before, the processing of oversized trees have also reduced these values.

5. Conclusions

5.1 Factors affecting the productivity of the processor

From the analysis of time study, it was found that the processing time accounted for the major part of the total cycle time. The affecting factors being tested to be significant on the processing time were the size of the trees, the number of logs per tree processed, the branchiness, the stem deformation, the species, and the machine capability (working condition factors), while the cutting types didn't have significant influence on the processing times. From the difference of the travelling element times between selective cutting and clear cutting, we could conclude that the travelling times were strongly influenced by the factors of stand density and terrain, and hence the travelling distance and the degree, or types, of cutting. To analyze the affecting factors on the loading time, loading element must be further broken down into more detailed elements such as extending the boom, grasping tree, pulling tree in, and positioning the tree on the processor unit. The potential affecting factors on the loading time could be the distance of the tree to be loaded away from the processor, the size of the trees, and the skilfulness of the operator.

Over sixty percent in average value of the delay times were accounted for by the machine delay and work delay, which together accounted for 18 % of the total cycle time. One main cause of so high percentage was the occurrence of larger sized trees in the forests. This indicated that the capacity of the processor was limited.

5.2 Determination of the processor's productivity

The production function of the processor was determined as a function of DBH at the present study. Since the other predictors of the processing time, such as number of logs per tree processed, branchiness, and machine capability were more or less related to the size of the trees, the DBH used to describe the processing time is of more representativeness and simplifies the analyses. Based on the single variable production function, the productivity models were established mathematically.

In a even-sized forest stands, the processor's productivities can be determined by the production function as shown in equation 27 and Fig. 5. It was found that the production function conformed to the law of variable proportions. Therefore, the maximum production existed, which was determinable as demonstrated in equation 28 and Table 5, where the maximum output per EMH were provided as 37m^3/EMH at about 35 cm in DBH in selective cutting and 42m^3/EMH at about 36 cm in DBH in clear cutting, for the single-sized forests. As a matter of fact, the forest stands are not single-sized, the stem-diameters are distributed within a certain range of diameter classes. Consequently, the production function with respect to DBH is insufficient, the expected productivity is of great value of practical applications. The beta-function can be used to describe any form of unimodal and decreasing stem-diameter distributions, and for the multimodal types of forests, the discrete calculation is preferable. Since the oversized trees were bucked in advance, the expected productivity models given by formulae 7 and 11 must be modified into formulae 14, by which the expected output per EMH were established and are shown in Table 6. What we calculated by formula 14a were the descriptions of the expected productivities occurred in reality, which were illustrated by "Ped" in Table 6, where we found that the maximum expected productivities were 14.8 m^3/EMH in selective cutting and 17.1 m^3/EMH in clear cutting, both at a maximum diameter of 35 cm in DBH. However formula 14b can be used for predicting the expected productivities under similar working conditions. The values of "Pec" in Table 6 were the results calculated. It was predicted that the maximum expected productivities of the processor would be about 13.8 m^3/EMH in selective cutting and and 16.7 m^3/EMH in clear cutting, both at a maximum diameter of 35 cm in DBH.

As a result, the productivity must be modified by machine availability and utilization. They were found 52 % and 48 % respectively at present study. Since the increasing of DBH over Dm would result in longer machine delays and machine repair time and hence lower machine availability and utilization, since it would bring out higher increasing rate of processing time and hence total cycle time per tree, and since it would lead to a quick reduction rate in expected productivity in terms of output per shift, it is recommended that on no account the DBH be above the maximum expected productivity diameter (35 cm in DBH at present study).

5.3 Practical application

The principle objective of the present study was to develop analytical techniques in theoretical studies for the use of evaluating the productivity of delimbing-bucking machines. Results applied specifically to a PIKA 35 processor working in the forest stands under testing, but with many applications to other processing machines if the type of the forest stand is similar, i.e. the main component of species is spruce and secondary pine without or with a few of birches, for example, in the present study the composition of species were 83 % of spruce, 13 % of pine and 4 % of birch in selective cutting, and 97 % of spruce, 3 % of pine and none of birch at all in clear cutting. However, the methods developed in theoretical analysis of time studies and productivity studies are particularly applicable to all small-medium sized processors.

Although the time study was based on a limited observation period of 2061 minutes and a limited sample size of 798 trees, the results present the general trend of relations between variables, and can be used to evaluate the similar processors and their systems, since more observations could increase the reliability and precision but would not change the interrelationships between variables. However, the more observations would result in better predictions and should be preferred for further studies.

The established mathematical formulae for calculating productivities are flexible models and applicable to most cases and those for determining the maximum expected productivities applicable to the cases where the production function is identical with the law of variable proportions since no other hypotheses were made.

References

Aird, P. L., Cottell, P. L., Winer, H. I., Bredberg, C. J. & Berlyn, R. W. 1971. Techniques for evaluating the productivity of logging machines: results of a study of Beloit harvester. Woodl. Pap. W. P. No. 25, Pulp Pap. Res. Inst. Can., Canada. 11 pp.

Avery, T. E. 1975. National resources measurement. McGraw-Hill Book Co., New York, NY. 339 pp.

Dixon, W. J. et al 1983. BMDP statistical software. University of California Press, Berkeley-Los Angeles-London. 733 pp.

Draper, N. R. & Smith, H. 1966. Applied regression analysis. John Wiley & Sons Inc. New York. 407 pp.

Duerr, W. A. 1960. Fundamentals of forest economics. McGraw-Hill Book Co. Inc. New York-London-Toronto. 579 pp.

FAO 1977. Planning forest roads and harvesting systems. Forest Logging and Transport Branch, Forest Industries Division. For. Dept. FAO For. Pap. 2, Rome. 148 pp.

Gregory, G. R. 1972. Forest resource economics. University of Michigon. The Ronald Press Co., New York. 548 pp.

Haarlaa, R. 1981. Productivity measurement in logging operations. Recommendations based on international practice. Division of For. Res., CSIRO Canberra ACT 2600. 29 pp.

Heidersdorf, E. 1974. Evaluation of new logging machines: BM Volve SM-880 processor. Logging Res. REports, LRR/55, Pulp Pap. Res. Inst. Can., Canada. 17 pp.

Kreyszig, E. 1983. Advanced engineering mathematics. Fifth edition. John Wiley & Sons Inc., New York. 988 pp.

Krongstad, I. 1984. Opparbeiding med PIKA 35 i tynning og sluttavvirkning. Norvegian For. Res. Inst. Div. of For. Operations & Techniques, Norway. 21 pp.

Loetsch, F., Zöhrer, F., & Haller, K. E. 1973. Forest inventory. vol. II. Blv Verlagsgesllschaft Mchen Bern Wien, Germany. 469 pp.

McCraw, W. E. & Silversides, C. R. 1970. Analysis of tree harvesting machines and systems, — a mathodology. Can. For. Service, Dept. of Fish. and For., For. Management Inst., Information Report FMR-X-27, Canada. 184 pp.

Metsä ja uittoalan työehtosopimus ja sen mukaiset m^3-perusteiset metsätyöpalkkojen taulukot. Palkkausalue 4, (29. 3. 1984–28. 2. 1986). Helsinki, 1984. 112 pp.

Metsäteho, 1982. Draft paper on testing results of PIKA 35 processor. Unpublished paper provided by KY. S. Pinomäki. 15 pp.

Mäkelä, J. 1969. Measurement of productivity. — seen from the forester's point of view. Seloste: Tuottavuuden mittaaminen. Työtehoseura Report 134. 22 pp.

NSR 1978. Forest work study nomenclature. Nordisk avtale om skoglig arbeidsstudienomenklatur: 80–99.

Simula, M. 1983. Prodictivity differentials in the Finnish forest industries. Acta For. Fenn. 180.

Zöhrer, F. 1969. The application of the beta-function for best fit of stem diameter-distributions in inventories of tropical forests. Mitt. Bundesforsch. anst. Forst- u. Holzwirtsch., Reinbek/Hamberg, No. 76, 50 pp.

— 1970. The beta distribution for best fit of stem-diameter-distributions. IUFRO 3rd Conf. Advis. Gr. For. Statist., sect. 25, Jouy-en-Josas, France, Inst. Nat. Rech. Agr., Publ. 1972–3: 91–106.

Total of 20 references

Seloste

Pika 35-prosessorin tuottavuuden määrittäminen

Tutkimus käsittelee puunkorjuukoneiden suorituskyvyn arviointimenetelmää. Analyysit perustuivat PIKA 35-prosessoria koskevan Kyröskoskella tehdyn tuottavuustutkimuksen tuloksiin. Tutkimuksessa tarkasteltiin puutavaran valmistuksen tuottavuuteen vaikuttavia tekijöitä. Tuottavuuden määrittämiseksi laadittiin matemaattisia malleja ja tarkasteltiin niiden soveltuvuutta vastaavien tutkimusongelmien ratkaisemiseen.

Aikatutkimuksen tulokset osoittivat, että yksittäisen puun käsittelyaikaan merkitsevästi vaikuttavat runkokohtaiset tekijät olivat puiden koko, oksikkuus, rungon epämuotoisuus, puulaji ja yhdestä rungosta tehtyjen puutavaralajikappaleiden lukumäärä. Muut puun käsittelyaikaan vaikuttavat tekijät olivat hakkuutapa, leimikon tiheys, maasto, työskentelytapa ja työpisteiden väliset siirtymismatkat.

Puun rinnankorkeusläpimittaa pidettiin merkitsevimpänä puun käsittelyaikaan vaikuttavana tekijänä ja sitä käytettiin yksittäisenä tuottavuuden ennustajana analyysissä. Tähän yksittäiseen muuttujaan nojaavan tuottavuusfunktion pohjalta laadittiin matemaattisesti tuottavuuden ennustemallit. Määritettäessä prosessorityön teoreettinen tuottavuus puustoltaan tasaisessa leimikossa huomattiin, että huipputuotos tehollista konetyötuntia kohti olisi 37,1 m^3 rinnankorkeusläpimitaltaan 35 cm:n puissa harvennushakkuussa ja 42,2 m^3 rinnankorkeusläpimitaltaan 36 cm:n puissa avohakkuussa. Prosessorityön tuottavuus vaihtelee kuitenkin puustoltaan epätasaisissa leimikoissa suuresti. Niinpä aineistossa tuottavuus oli vain 14,8 m^3/h harvennushakkuussa ja 17,1 m^3/h avohakkuussa tehotuntia kohden laskettuna. Teoreettisesti runkojen läpimittajakautumaa voidaan kuvata beta-funktiolla. Sekä rungonkokoluokittaiset käsittelyajat että rungonkokojakaumat huomioon ottavat funktiot yhdistämällä saatiin harvennushakkuussa puutavaran valmistuksen tuottavuudeksi 13,8 m^3/h ja avohakkuussa 16,7 m^3/h.