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Some observations on time and performance studies in forestry

Erfaringer angående tids- og prestasjonsstudier i skogbruket

Ivar Samset

Ås 1990

Norsk institutt for skogforskning (NISK)

Norwegian Forest Research Institute
Direktør/*Director*: Hans-Olav Moen, Boks/*P. O. Box* 61, 1432 Ås-NLH, *Norway*

NISK-Ås, Boks/*P. O. Box* 61, 1432 Ås-NLH, *Norway*. Tlf./*Phone* (09) 94 90 00
NISK-Bergen, 5047 Fana, *Norway*. Tlf./*Phone* (05) 91 62 40

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NISK har arbeidet med driftsteknisk skogforskning siden 1947. Dette har gitt et rikt erfaringsgrunnlag angående tids- og prestasjonsstudier i skogbruket.

Vanskelighetsforholdene som blir beskrevet med influerende faktorer varierer sterkt med skog, klima og terrengforholdene. Noen faktorer er kvalitative og ikke målbare og forskeren må søke å erstatte disse med målbare enheter.

Ydelsesgraden hos arbeidskraften varierer sterkt. Det er vist hvordan skjønnsmessig ydelsesvurdering kan erstattes med måling av ydelsesgradforskjeller.

De iaktagelser forskeren gjør under markarbeidet gir ham grunnlag for et logisk valg av en funksjonstype som gir brukbar beskrivelse av hvorledes tidsforbruket varieres med de påvirkende faktorene. Valg av funksjonstype er diskutert i rapporten.

Planlegging av skoglige tidsstudier og prestasjonsanalyser, valg av funksjonstyper og bearbeiding av innsamlet materiale er vist ved eksempler fra den 40-årige forskningen på området.

Nøkkelord: Virketid, arbeidsplasstid, tjenestetid, tidsstudier, ydelsesvurdering.

Abstract

SAMSET, I. 1990. Some observations on time and performance studies in forestry. Erfaringer angående tids- og prestasjonsstudier i skogbruket.) Medd. Nor. inst. skogforsk. *43*(5): 1–80.

The Norwegian Forest Research Institute has carried out research on forest operations since 1947. This has given a rich a background of experience concerning time- and performance studies in forestry.

The difficulties in the working conditions are described by means of influencing factors. These vary considerably with the forest conditions, climatic conditions and terrain conditions. Some factors are qualitative and not measurable. The research officer should seek to transfer these factors to measurable units.

The performance rate of the workers or the machine operators vary and may influence the results of the study if different workers participate under different working conditions. It is shown how subjective estimates of performance rate can be replaced by means of measurement of performance differences between the workers.

The research officer's personal observations during field work give him a basis for a logical selection of a type of function which describes how the time consumption varies with the influencing factors. The choice of model functions is discussed in the report.

Planning of forestry time studies and performance analysis, the selection of model function, and the treatment of the collected observations are shown by means of examples from 40 years of scientific investigation on forest operations.

Key words: Effective time, work place time, total time, time studies, performance rating.

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Preface

During the period 1947-1989 the Norwegian Forest Research Institute, Division of Forest Operations has carried out time and performance studies on a great number of operational methods. The results have been published in scientific and practical reports. 40 years of such forestry time- and motion studies have given a rich basis of information and knowledge concerning better planning, data collection and handling of time studies.

In this report I have summarized the most important experiences and knowledge and elucidated these findings with a few examples. The first draft of the report was discussed among scientists from various countries during a IUFRO Syposium on Work Studies in Thessaloniki, Greece in June of 1988. Some of the research officers at our Institute have examined the report and given good advice concerning the content. I will especially mention research officers Ann Merete Furuberg Gjedtjernet and Jan Bjerketvedt.

Research director Carl Georg Berstrand, Forskningsstiftelsen Skogsarbeten in Stockholm and professor John Garland, Oregon State University in Corvallis have read the manuscript and given good advice. Research officer Dag Fjeld has read the report and corrected the english text. Secretary Karin Westereng has written the report.

I am gratefull to these persons and colleagues for their contributions and help.

Ås, June 1990

Ivar Samset
Norwegian Forest Research Institute
Division of forest operations
P.O.Box 61 N-1432 Ås-NLH

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Tidsstudiemann Arne Nordsveen, 1962. Tidsstudier etter 0-punkt metoden med en stoppeklokke for deltidene, og en kontrollklokke for totaltiden i løpet av studiedagen.

Investigations on the production and productivity of forest operations consists partly of time and performance studies and partly of the exact measurements of all forestry, terrain and climatic conditions which influences time consumption. In addition, the production is dependent on the performance ability of the workers or the machine operators and special care has to be taken in order to find how time consumption varies with the influencing factors only and not by the workers/operators performance rate.

There is considerable variation in the influencing factors of forest and forest terrain conditons. In addition, these factors change as the workers or working machines move along and meet changing working conditions. Some of these factors are quantitative and measurable. Others are of a qualitative nature and can usually not be measured directly. They have to be estimated by judgement. The need to transfer qualitative factors into quantitative measurable units is obvious. This is an important challenge to the research officer during the planning and preparation phase of the study.

The responsibility of the research officer during field work is not limited to data collection only. His observations of the research operation itself is educating and of great importance. These observations help him in his selection of one or several model functions which may describe the form of relationship between the influencing factors and the time consumption. This selection of the model function is an important part of the data analysis. It depends on the information the research officer receives when participating in the field work, as well as the research officers scientific and professional knowledge, his imagination and his ingenuity. The resulting hypothesis may show that more than one model function may be used.

The model functions may then be tested against the observations by means of the least square fit method in order to find the conclusive function which describes the relationship between the influencing factors and the time consumptionn in the best way.

Libraries of mathematical functions are available in today's computers (from personal computers to main frames). There is, however, a danger that the research officer limits his analysis to a theoreticcal selection of mathematical formulaes which gives a fairly good least square fitting. Such a theoretical treatment of the observations should be avoided.

The choice of model function must be logical and should usually be done before the treatment of the observations in a regression analysis.

The Norwegian Forest Research Institute has carried out scientific research on forest operations from 1947 to the present date. Many scientists and research officers have taken part. More than 100 comprehensive scientific publications with the inclusion of time and performance correlation studies have been published. In addition more than 290 research reports have been produced, most of them based on time studies of a comparative nature.

These 40 years of time and performance studies have given a rich background of experience in planning, collecting and treatment of observations from research work on forestry operations. In this report I have presented some observations based on the experiences on important problems related to time, performance and other studies of forest operations.

Statistical methods, variance analysis or regression analysis have not been discussed in this paper. Excellent handbooks are to be found describing these problems. The same applies to computers for time studies and programmes for evaluation. In this paper we will concentrate on some important problems related to the dependent and independent variables in time or performance studies.

The aim of time studies is to analyse how the time consumption varies with the influencing factors, sometimes by means of average times for each of the influencing factors and sometimes by means of functions describing the relationship between time consumption and influencing factors. The variation of the collected times around the mean figures or functions (correlation coefficients, variation analysis etc.) is important in order to see how well we have succeeded in describing these relationships. The importance is,

Fig. 2. Timekeeper Leif Kjøstelsen, 1989. Time studies according to the element time method by means of a field data machine.
Tidsstudiemann Leif Kjøstelsen, 1989. Tidsstudiene gjennomføres etter 0-punkt metoden med feltdata-maskin som automatisk kontrollerer deltidssummen.

however, to reach good means or good time functions. This will be exemplified by experiences from our research at the Norwegian Forest Research Institute.

Requests have been raised to publish a library of time functions which could help young research officers in their work. This is not the intention of this publication, and may even be pointless. An uncritical selection from a library of functions may lead to a misinterpretation of the basic relationship between influencing factors and time consumption.

The few examples shown in this report are simply meant to give some ideas about the process of formation from the research officers field observations through selection of influencing factors and the choice of form and type of time functions to the final treatment of the observations.

The result depends on

1. The research officcer's practical, professional, and scientific knowledge
2. The research officer's ingenuity and imagination
3. The research officer's working capacity

2. Independent variables (influencing factors)

Knowledge about forestry helps to decide which variables should be taken into account in a time study. These are the factors such as tree dimensions, form and shape of the trees, number of trees or the volume per ha. etc. Geological conditions, terrain morphology, water content in the soil, humus layers, vegetation etc. are also important as well as other physical and technical conditions.

There are two types of influencing factors:

– Objective measurable factors. – Subjective estimated factors.

2.1. Subjective estimated factors

Some influencing factors (independent variables) are of a qualitative nature which cannot be measured. Roughness of ground, colour, branchiness etc. are examples of such factors. The time keeper has to estimate the factor into classes. The average time consumption within each of the classes has to be found.

In some cases it is possible to define the classes in such a way that there exists a metric distance between them. Each of these classes may be defined by means of measurable units (quantitative factors)), for example number of stumps or stones per haa, instead of the qualitative classes such as boul ders and cliffs, stony terrain, smooth terrain surface etc. These classes may be defined as *class variables* and can be described by a mathematical function (see example 1). Other qualitative factors are binary, often of an «either/or» nature: pine or spruce, straight or crooked stem etc. These are often called *dummy variables* and may be handled in a mathematical function with certain limitations:

$$y = f(x_2) + b_3x_3 \tag{1}$$

y = time consumption (cmin/tre)
$f(x_2)$ = time function, describing the variation of time consumption with the influencing factors x_2 (for example vol./tree)
x_3 = dummy factor (for example pine = 0, spruce = 1)

If $x_3 = 0$, y describes the time-consumption when working with pine trees and if $x_3 = 1$ there is an addition $(b_3 \cdot 1)$ to the time function $f(x_2)$ for pine in order to receive the time consumption when working with spruce. This shows that the function for the time consmption has the same form for spruce and pine but the level is different.

Another method of using a dummy factor with the same variable set is the following:

$$y = f(x_2)(1 + b_3 \cdot x_3) \tag{2}$$

In this case the time consumption when working with spruce is received by multiplying the function for pine with a constant factor $(1 + b_3)$.

The time consumption (y) may vary with several influencing factors (for example $y = f(x_2, x_5, x_6)$, while the dummy variable varies in relation to one of the factors only (for example x_2). In this case the factor (x_2) is only taken into account when studying the influence of the dummy variable. In reality this means that the other factors (x_5 and x_6) are kept constant at their averages for the observed data.

It is also possible to use dummy factors for three alternatives with the following functions:

$$y = f(x_2) + b_3x_3 + b_4x_4 \tag{3}$$

or

$$y = f(x_2)(1 + b_3x_3 + b_4x_4) \tag{4}$$

$f(x_2)$: function for the time consumption
x_3 : 1 = spruce, 0 = others
x_4 : 1 = broad leaved trees, 0 = others

If $x_3 = 0$ and $x_4 = 0$ the function shows the time consumption with pine.

By using a dummy factor one assumes that the time function for the alternatives (spruce, pine or broadleaved trees) follow the same pattern and the difference between the alternatives is a constant addition or multiplication of the function with the dummy factors. This is not always the case and one should try to separate functions for each of the alternatives in order to check whether dummy variables can be used. Sometimes there is no other choice than to use dummy factors or qualitative factors which have to be estimated subjectively. This should, however, be avoided as much as possible.

2.1.1. The transfer of subjective into objective factors

Some of the influencing factors are qualitative variables. Since these usually have to be estimated by subjective judgement, it is an advantage to replace them by quantitative factors which can be measured.

It is an important challenge for the research officer to seek factors which are objective, measurable and which show or indicate influence on the variation of the time consumption. During the planning of a research operation the research officer should try to replace the qualitative factors with quantitative. The knowledge about the trees, the forest, the physical and technical conditions as well as the equipment and the method is important. Here are three examples:

Example 1. Terrain classes

The purpose of the investigation is decisive for the selection of influencing factors. The productivity of construction work, scarifying, snowshovelling etc. depends on other factors than for example factors which influence the transport productivity along the forest terrain.

These factors may be divided into *descriptive factors* and *functional factors*. (SAMSET 1975).

The descriptive factors are usually quantitative and can be measured before or during a time study. Slope per cent or slope angle, thickness of raw humus layer, grain size in clay, sand or gravel etc. are typical examples.

In some cases the measurement of all descriptive factors are too detailed to be used. The research officer has to define classes which are based on the measurement of the detailed factors within systematic network of sample plots over the research area.

The descriptive factors are objective because they are reproducable and give possibility to compare the time consumption of various operational methods at present or from time to time.

The functional factors may be quantitative or qualitative. They depend on the machines or methods used during the study. The factors may change in the course of time for example with the development of new and better machines or methods.

It is an important task for the research officer to replace functional factors by descriptive factors and to replace qualitative factors by quantitative. Such measurable factors allow to reach repeatable results which may be repeated in practical or applied forestry.

Example 2. Roughness of ground

Obstacles, such as stumps and stones represent hinderance for operating machines in the terrain. Increased amount of obstacles reduce speed, the travelling distance increases due to increased winding factor and the delays increases because vehicles get stuck in the terrain.

The roughness of ground may be subjectively estimated for example in the following classes:

1. Smooth terrain
2. Very stony terrain
3. Boulders, cliffs and rocks.

In spite of possible definition of these quality classes it is difficult to reproduce the results. Other professional people may estimate the limits between the classes differently than the research officer.

Another possibility is to divide the research area into sample plots. This was done in a study on mechanized scarification, where different harrows giving different resistance were pulled by means of tractors with various sizes and constructions.

Obstacles reaching more than 50 cm above or below the average surface (stones, rocks, holes) were counted. The number of obstacles per ha was calculated on each of the research plots.

In addition the travelling time per 100 meter, the travelled distance as compared with straight line distance and the number of stops were measured:

L_1	= Travelling distance	m
L_2	= Straight line distance	m
w	= $L_1 \div L_2$ = winding factor	Indefinite
E_0	= Effective travelling time	cmin/100 meter
D	= Delay time in per cent of E_0	%

By comparing the number of obstacles per ha with E_0, D and w the roughness of ground could be defined in the following terrain classes (SAMSET 1951):

Table 1. Terrain roughness classes. (SAMSET 1951).
Terrengujevnhetsklasser.

Class	Obstacles/ha	Average distance between obstacles
1	<400	>5 m
2	400–1000	5–3,2 m
3	>1000	<3,2 m

There exists a correlation between the slope and the roughness of ground. The influence of ground roughness on travelling time consumption increases with the slope.

Similar research has been carried out for cable operations in steep terrain, carrying capacity on soft ground, road density, road spacing, terrain factors and winding factors. As a result the first terrain classification system was worked out and used in the national forest survey of Norway in 1954. Since that time the Norwegian forest terrain has been classified four times: 1954/57, 1965/67, 1970/73 and 1982/85 (SAMSET 1975 and 1987).

Example 3. Changes in the terrain classes

Roughness of ground is a functional factor. The trafficability of terrain machines has grown better due to better constructions. With time the class 2 (400–1000 obstacles per ha) was unnecessary since the tractors moved just as easy on terrain of class 2 as class 1.

FRØNSDAL (1985) tested various tractor constructions in steep terrain. He found that the class 2 (400–1000 obstacles per ha) should be used in steep tractor terrain (20%–40%).

He also measured the influence of the various heights of obstacles and suggested that the limit should be increased to ± 70 cm instead of the previous ± 50 cm.

Example 4. Bearing capacity.

Bearing capacity of the forest floor is often a limiting factor for operational activities. Terrain classification systems are often based on qualitative factors which in many cases even are functional.

On many soil types forest machines have damaging effect on the forest floor and forest environment. LÖFFLER (1988) has suggested the use of sensitivity classes in order to show where forest operations must take precavations involving low impact operational machines and methods. LÖFFLER has based the classification on descriptive parameters some of which are nonvariable and some variable:

- nonvariable parameters:
  - particle-size distribution
  - specific density (gamma$_s$, g/cm^3)
  - proctor curve
  - Atterberg limits (liquid limit and plastic limit, %)
  - content of organic matter (in the upper soil horizon).

- variable parameters:
  - soil dry density (gamma$_d$, g/cm^3)
  - soil moisture content (w, % volume or weight)
  - pore volume (n, %)
  - air-filled volume (n_a, %)
  - pH-curve
  - water tension (pF-value)
  - saturated water conductivity, measured as infiltration rate (K_{sat}, mm/hour),
  - Cone Index (CI, bar)

LÖFFLER used the information from the descriptive, quantitative factors (which may be measured on sample plots) to give a qualitative classification of the forest sites according to sensitivity and risk of soil damage:

Table 2. Carrying capacity of the ground (LÖFFLER 1988).
Markens bæreevne.

Sensitivety class	Risk	Recommendations, restrictions
1	(Very) low	No limitations (as to vehicle,tyres, payload, moisture conditions)
2	Low – medium	Reduction of axle load and use of low pressure tyres after (heavy) rainfall and at thaw
3	Medium	Reduction of axle load and use of low pressure tyres even under normal moisture conditions (=field capacity). No off-road traffic at all at higher soil moisture (rainfall, thaw)
4	Medium–high	No off-road passes of vehicles at all, regardless of moisture conditions
5	(Very) high	Like class 4, in addition: (permanent) trails to be strengthened (ballasting, grid net) or operations restricted to frozen ground

Example 5. Relative height instead of crown classes.

Tree classes have been used in order to estimate the difficulties for felling and cutting operations, especially during limbing. It has been called tree class I, II, III etc. The time keeper had to rate the «tree class» or «difficulty class»

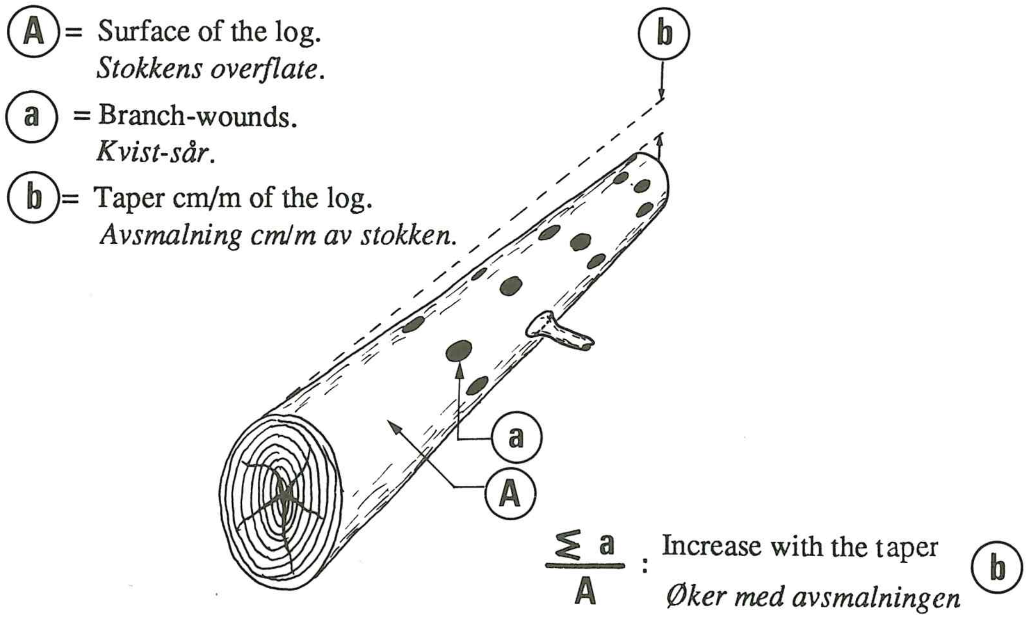


Fig. 3. The number of branches increases with increased taper of the tree.
Kvistmengden øker med økende avsmalning.

for each tree. These classes are qualitative factors which are difficult to measure. The classification had to be estimated subjectively and the result are not easily repeatable in practice. Is there a possibility to transfer the qualitative tree classes into quantitative and measurable factors?

In his doctor thesis Klem (1934) found that there exists a close correlation between the branch wounds on the surface of the stem and the taper of the stem. Samset (1950) used this information to measure the branchiness of the tree by means of the taper of the stem of the tree. It led to the invention of the *relative height* which is the height of each individual tree in relation to an average height curve.

The average height of spruce trees in Norway was used as the average height curve. The trees which are higher than this average curve are less branchy and have longer stems without limbs than trees which are shorter than the average curve.

The average height gives a good and measurable description of the branchiness and difficulty class of the tree. The effective time consumption of

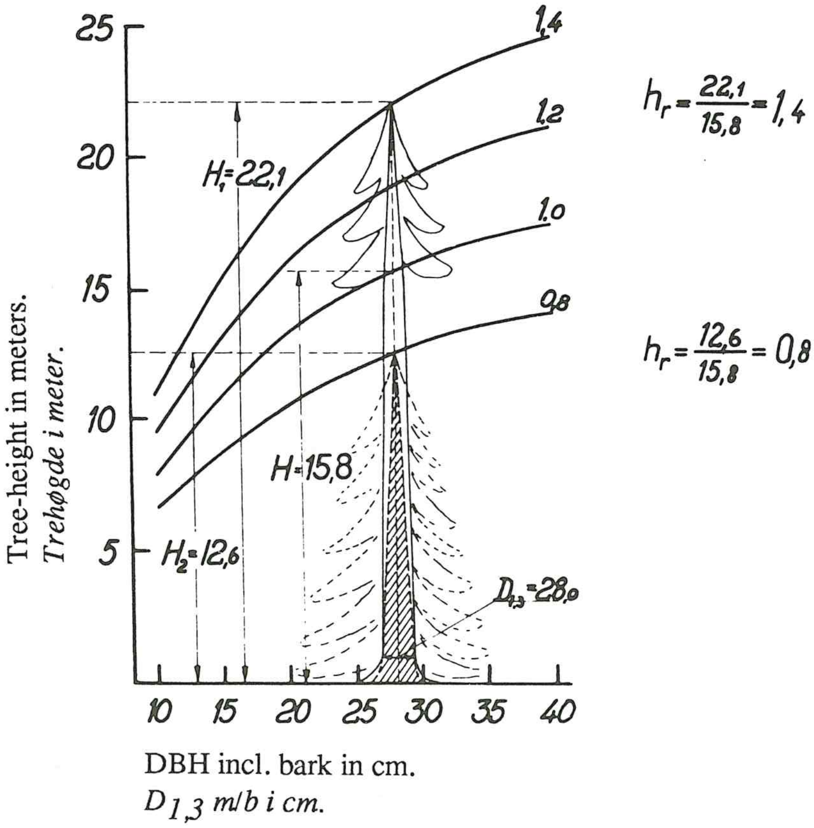


Fig. 4. The relative height. (Samset 1950).
Relativ høyde.

limbing by motor saw could be described by the following function in 1/10 min. (SAMSET 1950):

$$y = 3.2\,\text{DBH} - 5.1\,h_r + 0.0183\,\text{DBH}^2 h_r - 21.5 \qquad (5)$$

$$R = 0.84 \quad S = 39.2\ \%$$

This formula is logical. The regression coefficient of the factor DBH (breast height diameter) is positive which shows that it is more difficult to handle the motor saw during limbing of a big tree than of a small tree. The regression coefficient of relative height (h_r) is negative because the tree has less branches the bigger the relative height is. The main time of cutting off the branches is proportional to the area of the branch wounds. The area of these wounds is proportional to the breast height diameter and relative height, described by the factor $\text{DBH}^2 \cdot h_r$.

A time study of cutting black pine (*Pinus nigra*) and Greek fir (*Abies Sephalonica*) was carried out in Greece 1968 and 1969 (STRØMNES et al. 1972). This investigation gave a simular result as the Norwegian study. The time consumption during cutting could be described by the same type of function with the same type of influencing factors (independent variables). In this case the average height curve ($h_r = 1{,}0$) was calculated as the mean heights of all the trees in the investigation. The results showed that there was a high negative correlation between the relative height and the time consumption of branching. Even in this case the qualitative tree classes could be replaced by the measurable quantitative influencing factor h_r.

2.1.2. Conclusions

When planning a time and performance study the scientist must seek to replace qualitative variables with quantitative, which can be measured. The object is to reach findings which can be repeated by other scientists or in practical forestry.

The examples 1-5 show that there exist three types of quantitative influencing factors:

Indirect quantitative variables
Descriptive quantitative variables
Direct quantitative variables

Examples on indirect quantitative variables are given in examples 1–4. The qualitative variables have been estimated in the form of class variables by means of other quantitative factors which can be measured.

Descriptive, quantitative variables do not give direct information about the qualitative influencing factor. The qualitative factor, however, varies with the variation of the descriptive factor. In example 5, the number and size of branches of a tree increase continuously with the decrease of the tree's relative height.

The direct quantitative factor can be measured and gives usually the dimension of the produced volume directly (m, m^2, m^3, h, km, etc.). The time consumption varies directly with these types of factors.

2.2. Objective measurable factors

The advantage and need of transforming qualitative to quantitative influencing factors was discussed in the previous chapter 2.1.

When all the quantitative factors are measured and the corresponding time consumption are recorded the next step is to suggest a suitable logical function which describes how time consumption varies with the influencing factors. The research officer uses *the informations and experiences he received during the field work* in order to reach a hypothesis of a model function.

A detailed time study is comprised of the time consumption for each of the work elements (see chapter 3.1.). This refer to the measurement of the influencing factors and the time recorded during field work as well as the treatment of the collected observations. The reason is that some of the time elements varies with some influencing factors while other time elements varies with other influencing factors. If the treatment of the observations are limited to the effective time which is the sum of the time elements, the influence of the individual factors may get lost. This is espesially the case with smaller time elements. Their variation due to the influencing factors may not be visible in the greater variation of the sum effective time consumption.

BERGSTRAND (1987) made an interesting report on the planning and analysis of time studies on forest technology. The author underlined the importance of simplifying the influencing factors and the estimation of how time consumption varies with these factors. He gives examples of how the computer may be used in the analysis procedure.

In addition the importance of choosing a constructive function should be stressed. There exist computer programmes, where it is possible to test a variety of standard functions by means of regression analysis. In this way it may be possible to find one or a few functions which give good correlation. The choice of function is fundamental to the understanding of study results and should not be limited by the testing of only a few mathematical formulaes.

Example 6

The advantage of seeking and finding a logical function can be illustrated with an example given by FLAA (1990) in his Master Thesis at The Agricultural University of Norway. Flaa investigated how the skidding distance (sk in kilometers) varied with the truck road density (V in meter per ha) on 10.443 ha productive forest land at Cappelen forest estate, Landsmarka, Telemark. The skidding distance and road density were measured on 104 units and Flaa tried out various mathematical functions, such as exponential and logarithmic functions by means of his personal computer in order to find a good relationship between sk and V. He found that a logarithmic function fitted very well in the scatter plot of measured factors, with the following formulae:

Easy terrain.

$$sk = -0.578 \cdot \log V + 0.984 \quad (6)$$

Terrain steeper than 40%:

$$sk = -0.559 \log V + 1.160 \quad (7)$$

The function for easy terrain is illustrated in Fig. 5.

These functions may be well placed in relation to the observed values of sk and V, but do not explain anything about the problem.

After studying the litterature and the problem, Flaa tested a hyperbolic type of function, originally evaluated and developed by SEGEBADEN 1962:

$$sk = \frac{2.5 \cdot f}{V} \quad (8)$$

f is the road network factor, and consists partly of the winding factor (w), which is the skid roads deviation from a straight line and the road factor (r) which explain how well the roadnet is located in the terrain. (SAMSET 1975). The road factor is usually higher than 1.0:

$$f = w \cdot r$$

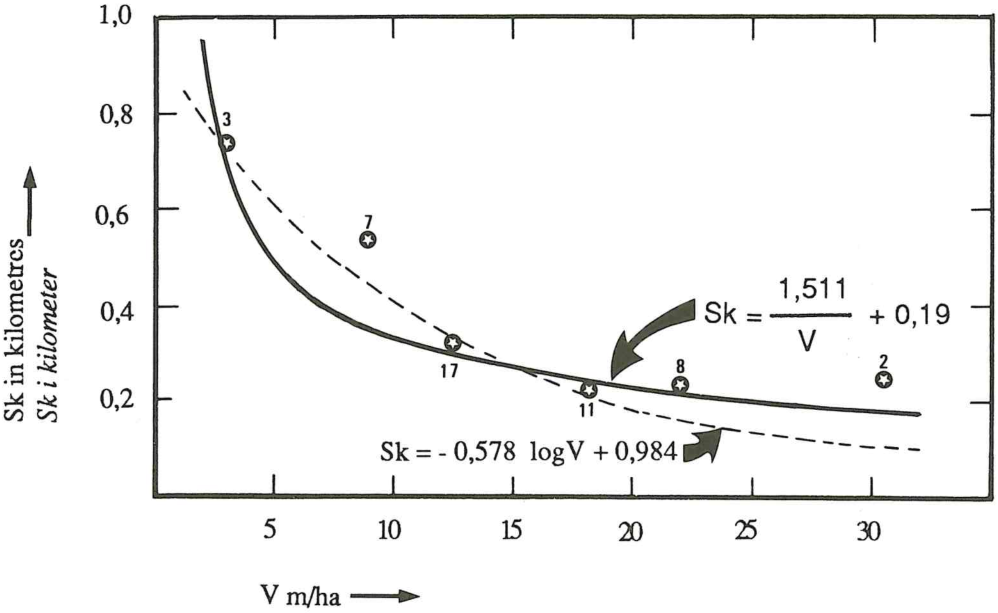


Fig. 5. The selection of a logical type of function (FLAA 1990)
Valg av logisk funksjonstype.

When Flaa smoothed this function within the observed values, he received the following functions which explained how the skidding distance varied with the terrain conditions and the road density:

Easy terrain:

$$\mathrm{sk} = \frac{0.19 \cdot V + 1.511}{V} \tag{9}$$

Steep terrain:

$$\mathrm{sk} = \frac{0.5 \cdot V + 0.944}{V} \tag{10}$$

This is a logical function, by means of which it also is possible to find how the road network factor (f) varies with terrain and road density in the Cappelen estate in Landsmarka:

Easy terrain:

$$2.5 \cdot f = 0.19 \cdot V + 1{,}511$$

$$f = 0.076 \cdot V + 0.60 \tag{11}$$

Steep terrain:

$$2.5 \cdot f = 0.5 \cdot V + 0.944$$

$$f = 0.2 \cdot V + 0.38 \tag{12}$$

The results are given in Table 3.

Table 3. The road network factor (FLAA 1990).
Vegnettsfaktoren.

Road density	*Road network factor f*	
m/ha	*Easy terrain*	*Steep terrain*
10	*1.36*	*2.38*
15	*1.74*	*3.38*
20	*2.12*	*4.38*
25	*2.50*	*5.38*

Similar relationships between skidding distance, road density and terrain conditions have been found by other authors. Research work in this field should be encouraged because it will help to better the planning of road networks in different terrain types on productive forest lands.

* * * * * *

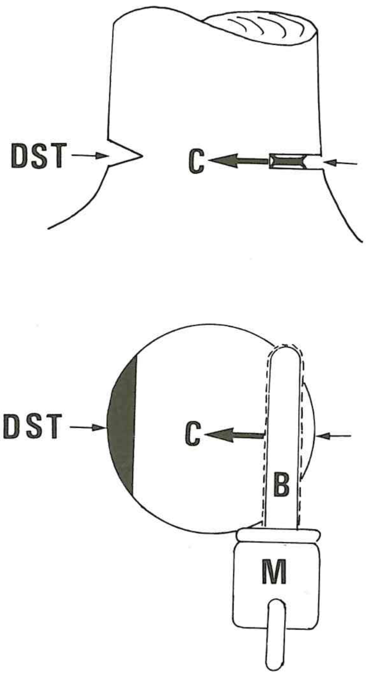
When the research officer searches after a function which describes the relationship between the dependent and the independent variables he should study the method, the physical conditions etc. and seek a type of formula or mathematical function which in principle could describe and explain the relationships. This may be called a model. This is his hypothesis of the type of function. He may do this before he starts the statistical treatment of the collected data.

The type of function or functions are then tested with regression analysis. This may give the dimensions of the regression coefficients in the hypothetically suggested function and the correlation between the estimated function and the collected data.

In the following examples from Norwegian forest operations research we tried to find suitable types of functions based on the knowledge about operational methods, the physical and forestry factors etc. The hypothesis lead to model functions which were numerically smoothed in relation to the observed data from the field work. These examples may give the reader some ideas on the development from field observations through logical model functions to the final findings of the forumlaes which shows the relation between influencing factors and time consumption.

Example 7. Sawing time and breast height diameter.

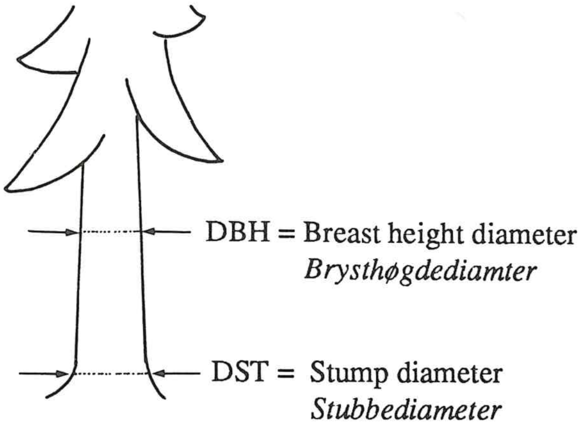
The conversion of trees to logs is a treatment on the surface area of each log, while the output is the cubic volume of the log. The branching and barking take place along the log surface, and the bucking and felling on the circular surfaces at the two log ends.



M = Motorsaw
Motorsag
B = Sawblade
Sagblad

C = The saw chain cut off the fibers on the upper and lover part of the circular surface.
Sagkjeden kutter av fibrene på den øvre og nedre delen av den sirkulære overflate.

Fig. 6. The circular stump surface.
Stubbeavskjæret har en sirkulær flate.



$$K = \text{Stump quotient} = \frac{DST}{DBH}$$

Stubbekvotient

Fig. 7. Stump quotient.
Stubbe-kvotient.

During felling the chain saw cuts the tree at the stump and has to work on the circular stump area (G cm^2). The saw chain cuts off the fibres on the upper and lower side, and transports the saw dust out of the kerf (Fig. 6).

This knowledge leads to the the hypothesis that the main sawing time is proportional to the circular stump area:

$$y = b \cdot G + a \qquad (13)$$

According to the felling instructions the feller should cut the tree off the stump at the highest rootbranch. It is, therefore, a relation between the stump diameter (DST) and the breast height diameter (DBH). We call this relation (k):

$$k = \frac{DST}{DBH} \qquad (14)$$

The formula (13) may be converted as follows:

$$y = b \cdot \frac{\pi}{4} DST^2 + a$$

$$DST = k \cdot DBH$$

$$y = b \cdot \frac{\pi}{4} \cdot (k \cdot DBH)^2 + a$$

$$y = b \cdot \frac{\pi}{4} \cdot k^2 \cdot DBH^2 + a$$

We may include the fixed factor $\frac{\pi}{4} \cdot k^2$ in the regression coefficient:

$$b_2 = b \cdot \frac{\pi}{4} \cdot k^2 \tag{15}$$

This hypothesis, therefore, leads us to the following function which describe how the main time consumption during felling in 1/10 min varies with the breast height diameter (DBH) in cm:

$$y = b_2 \cdot DBH^2 + a \tag{16}$$

In the cutting studies in Norwegian spruce and pine forests we found the following function for the main cutting time (1/10 min) in Norway spruce based on time studies of 25 363 trees (Samset et al. 1969):

$$y = 0.0096 \cdot DBH^2 + 0{,}7 \tag{17}$$

In this investigation, the stump quotient was k = 1,274 for Norway spruce. We may convert the equation (17) by means of equation (15) as follows:

$$b = b_2 \cdot \frac{4}{\pi \cdot k^2}$$

$$b = 0.0096 \cdot \frac{4}{\pi \cdot 1.274^2}$$

$$b = 0.0096 \cdot 0.7845 = 0.00753$$

$$y = 0.00753 \cdot G + 0{,}7 \tag{18}$$

Conclusion: The hypothesis that the main time consumption during felling varied in direct proportion to the cut stump area led to the model that the time should vary with the square of the breast height diameter. This function was selected and smoothed in the scatter plot of observed times from the time study by means of regression analysis according to the least square fit method. In reality it was knowledge about cutting with motorsaw which made us select the model function.

Example 8. Travelling time and gear shift.

During an investigation of tractor transport we found the optimal speed where the tractor operator should change from one gear to another. The tractor operators where tested during a winter season. The travelling time per 100 meter as well as the gear which was used were recorded during the time study (Samset 1956).

Fig. 8 shows the per cent frequency with which the operators changed from one gear to another at various speeds. The average travelling time per 100 meters at the moment when he changed from one gear to another hap-

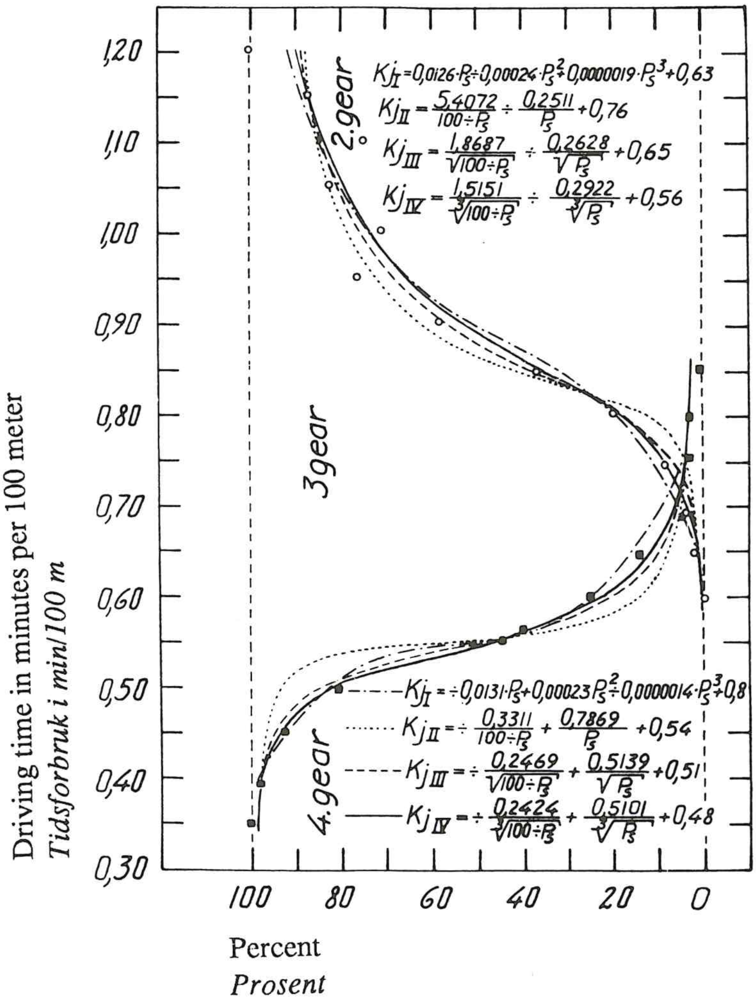


Fig. 8. Smoothed function of travelling time (in minutes per 100 meters) for varying frequency of instances in second and fourth gear, in relation to frequency of instances travelled in third gear. Ferguson 80 mm bore with half tracks on compact snow road. (Samset 1956).
Utjevnede funksjoner for kjøretiden i minutter pr. 100 meter ved varierende prosentisk antall tilfeller traktoren kan kjøre i 2. eller 4. gear i forhold til 3. gear. Ferguson 80 mm boring med halvbelter på fast snøpakket veg.

pened on average at 50% of the cases in each of the two gears.

Fig. 8 shows that the speeds where he still used, for example the 4th gear, followed an S-shaped function.

By studying the scatter plot we found that the relative number of times that the operator changed from 4th gear to 3rd gear could be smoothed by means of a S-shaped equation. The general cubic equation might be used since the function has two turning points. This has been done and we found the following function:

$$kj_I = -0{,}0131 \cdot Ps + 0{,}00023 \cdot Ps^2 - 0{,}0000014\ Ps^3 + 0{,}8 \qquad (19)$$

Curve No. kj_I in Fig. 8 shows that this function fits well in with the observed values, and as such it gives a good description of the relationship between the independent and the dependent variables.

Equation 19 however, is not logical because it gives no information about the problem.

During the field work we experienced that the operator used partly 3rd and partly 4th gear at middle speeds between the two gear positions. At increased speeds the operator used the 4th gear increasingly. The 4th gear percentage approached asymptotically the 100% axis in the diagram. This phenomenon might be described by a hyperbolic function:

$$y_1 = -\frac{b_2}{100 - Ps} + a$$

By decreasing speed, the operator used the 4th gear position decreasingly. The curve approached the 0% axis asymptotically which also may be described by a hyperbolic function:

$$y_2 = \frac{b_3}{Ps} + a$$

A combination of the two hyperbolic parts gives the following function:

$$kj_{II} = -\frac{b_2}{100\text{-}Ps} + \frac{b_3}{Ps} + a \qquad (20)$$

The hypothesis led to equation (20) which was fitted into the scatterplot by means of a regression analysis:

$$kj_{II} = -\frac{0.3311}{100\text{-}Ps} + \frac{0.7869}{Ps} + 0{,}54 \qquad (21)$$

The function is shown as no. kj_{II} in Fig. 8. This function is not as good as the general cubicfunction (19). The influence of the two hyperbolic variables (Ps and 100-Ps) are too strong, and had to be softened. This may be done by successive trial forms, using square–root and 3rd root of the hyperbolic variables (curve kj_{III} and curve kj_{IV} in Fig. 6). By using the 3rd root of these factors in the hyperbolic function we came up with the following result which led to a good description of the phenomena (see Fig. 8):

$$kj_{IV} = -\frac{0.2424}{\sqrt[3]{100\text{-}Ps}} + \frac{0.5101}{\sqrt[3]{Ps}} + 0.48 \qquad (21)$$

By comparing these speeds with the optimal speeds for gearchange we found that the tractor operators usually changed gears at too low a speed.

Example 9. Speed of a falling load from helicopter.

During helicopter transportation of timber, from a high felling site located above a lake for floating, we tried dropping the load from a high altitude in order to reduce the cycling time between each helicopter load. (Samset 1964.)

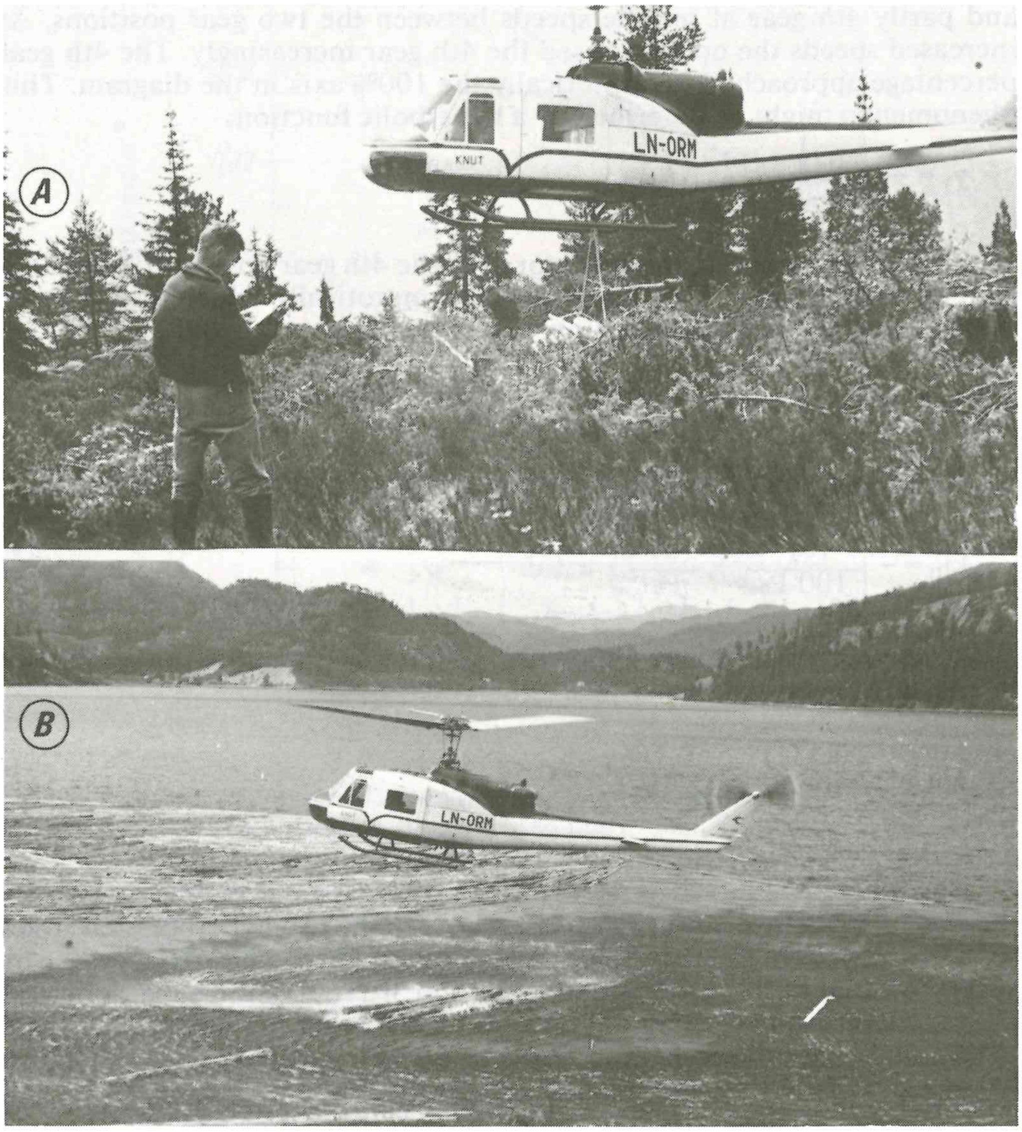


Fig. 9. Timber transport with Bell 204 B. Kviteseid 1962.
A: Time keeper Oluf Aalde studies the loading.
B: Unloading at the lake from low altitude. (Samset 1964)
Tømmertransport med Bell 204 B. Kviteseid 1962.
A: Tidsstudiemann Oluf Aalde studerer pålessing.
B: Avlessing i fløtningsvassdrag fra lav høyde.

We investigated the problem by dropping the load from various heights (Figs. 10 and 11). With a camera we could reconstruct the falling curve and thus the speed of the load when it accelerated from the helicopter until the load dropped against the water surface on the lake.

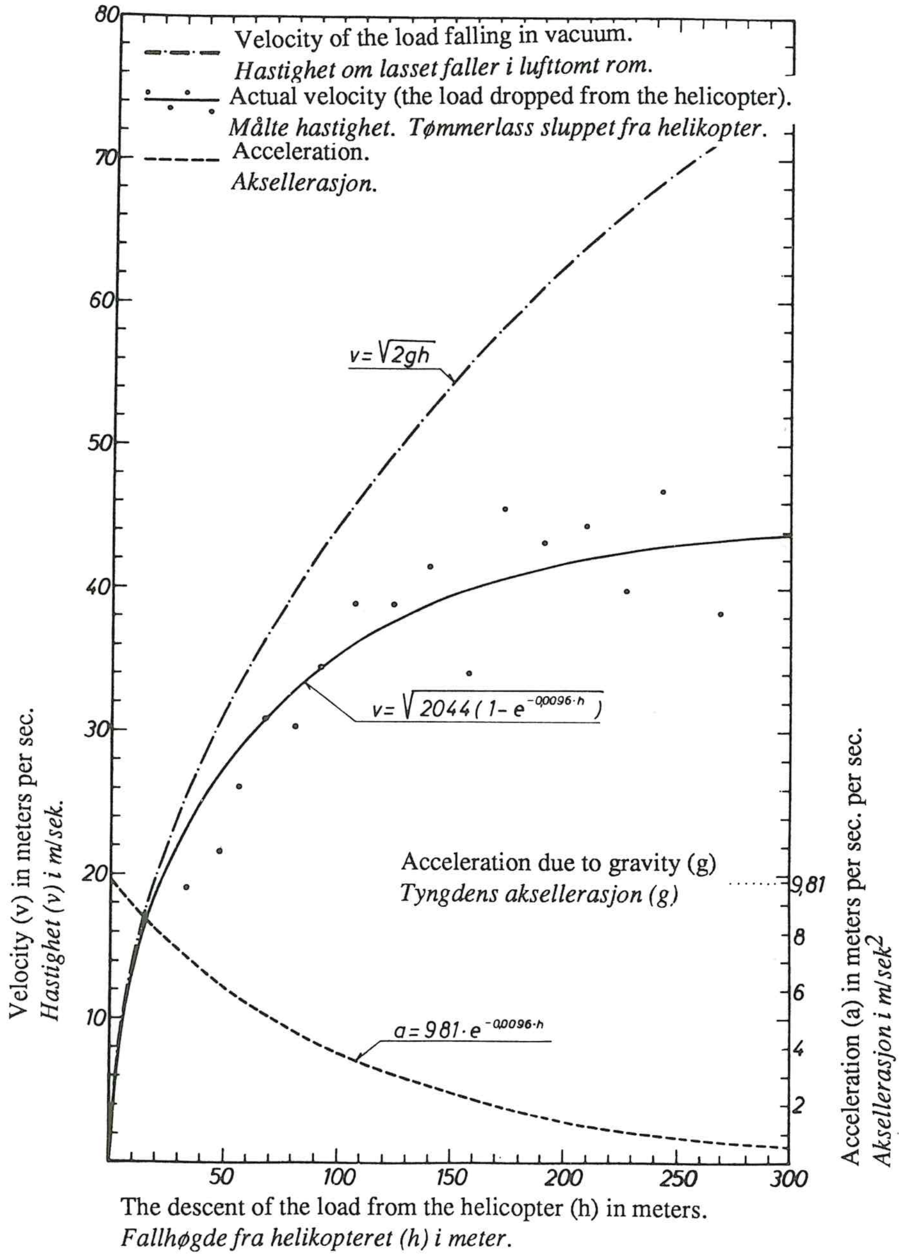


Fig. 10. The correlation between speed, acceleration and length of descent when a 2.27 f/m³ load (solid volume) is dropped from 300 m height. (SAMSET 1964). *Hastighetens og aksellerasjonens variasjoner med fallhøyden for et 2.27 f/m³ lass, sluppet fra 300 meters høyde.*

If the load falls in a vacuum, the relationship between the speed (v m/sec), height difference (h m) and the gravitational acceleration (g, 9.81 m/sec^2), can be described by the formula:

$$v = \sqrt{2g \cdot h} \tag{23}$$

When the load falls from the helicopter it meets air with varying density which reduces the speed. This reduction is also dependent on the form and shape of the load. The mathematical deduction is shown in the research report (Samset 1964, p. 274–281) and the conclusive speed formula is the following:

$$v = \sqrt{\frac{g}{b_2} \cdot (1 - e^{-2b_2 h})} \tag{24}$$

Symbols:

g: gravity acceleration, (9,81 m/sec^2)
h: height difference, (m)
e: the cardinal number in the natural logarithm.

b_2 (=0,0048) in the formula is the regression coefficient. The influence of the air density, the load shape etc. is included in the regression coefficient. When smoothing this formula by regression analysis the following function gave the speed in meters per second:

$$v = \sqrt{2044\,(1 - e^{-0.0096 \cdot h})} \tag{25}$$

$$(R=0.905 \quad S=10.04\%)$$

The function and the speeds of the dropping load is illustrated in Fig. 10. When the height of fall is 300 meters the rate of speed as determined by the formula is 43.9 m/sec or 158 km/h.

The highest obtainable speed, calculated by means of function (25) (h=∞) is 163 km per hour. In reality there will be equilibrium between the force of gravity and the air resistance. However, for the sake of simplicity the factors influencing the air resistance were kept constant. (Samset 1964 p. 276-277). As these factors vary slightly during the descent of the load, function (25) is valid only between h = 0 m and h = 300 m.

Conclusion: In this example we could use knowledge about a falling load and the resistance it meets during its descent from helicopter to the water surface in forming a hypotesis about the model function to be selected.

The next step was to simplify these formulaes for applied use, which led to the construction to equation (24). This function was smoothed in the scatter plot according to the least square fit method by means of regression analysis (equation 25).

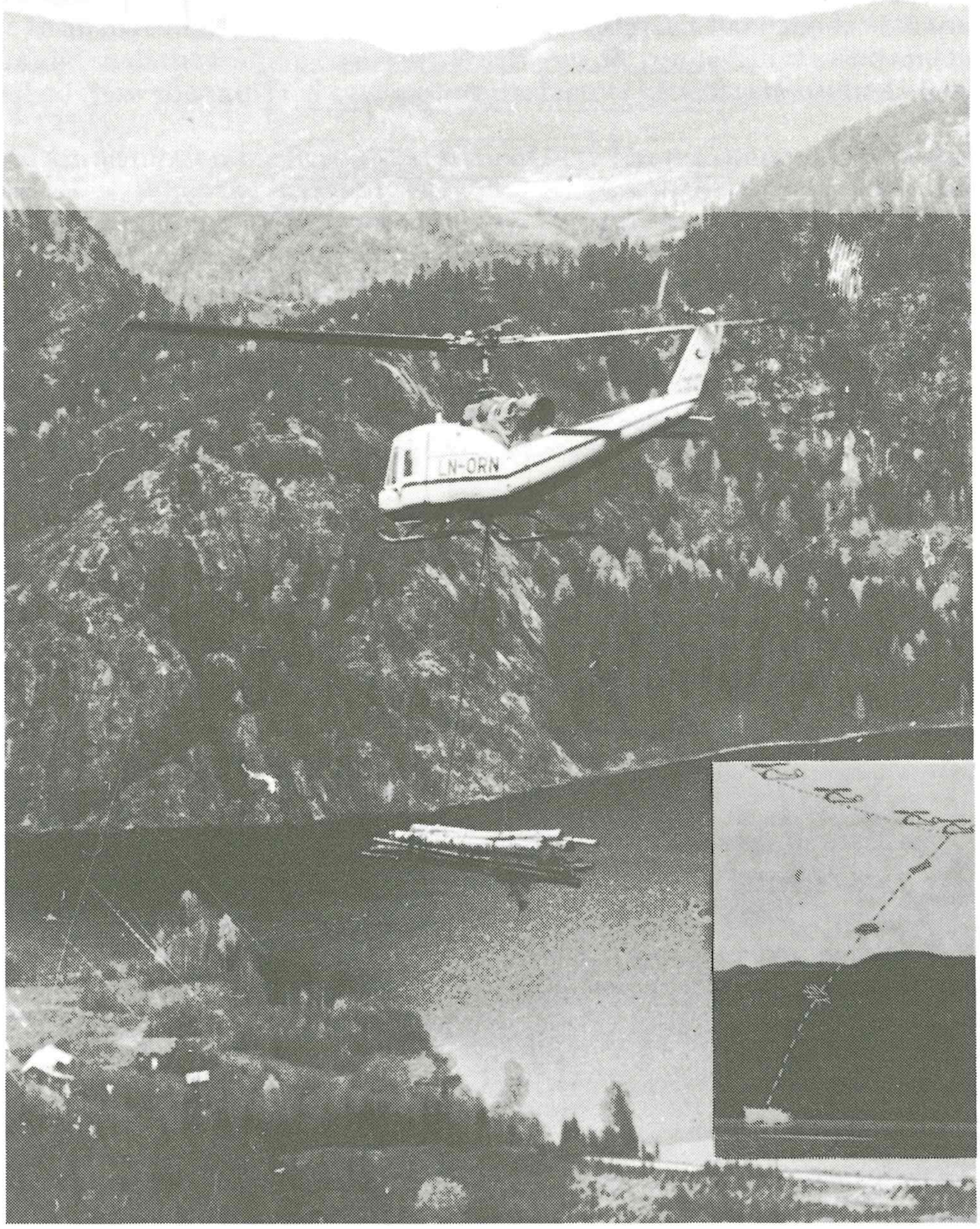
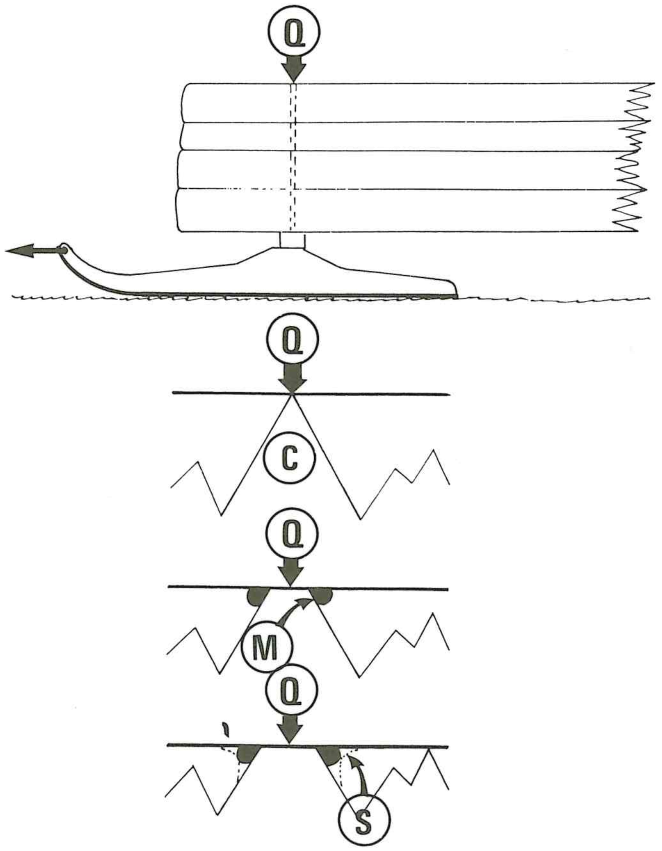


Fig. 11. The helicopter at 300 m height above the level of the lake immediately before dropping the load. The small inserted picture shows the curve of the drop from the 100 meter height reconstructed on the basis of a series of photographs. (Samset 1964).
Helikopteret i 300 m over Kviteseidvann, umiddelbart før lasset slippes. Det innfelte bilde viser lassets fallbane under slippet fra 100 meters høyde, rekonstruert etter en seriefotografering.



Ⓒ = Snow crystal on the compact snowsurface.
Snøkrystall på det faste snødekke.

Ⓠ = Load from runner on snow crystal.
Belastning fra meier mot snøkrystall.

Ⓜ = Melting metamorphosis. The melted snow freezes the runners fix to the snow crystal.
Smelte-metamorfose. Den smeltede snø fryser meien fast til snøkrystallet.

Ⓢ = Sublimation metamophosis. Water-molecules migrates from the void and increase slowly to fastern the runner to the snow crystal.
Sublimasjons metamorfose. Vannmolekyler vandrer fra poreluften og fester meien langsomt til snøkrystallet.

Fig. 12. The load rests on a few ice crystals which melts due to the high specific pressure. (SAMSET 1956).
Meien hviler på noen få iskrystaller som smelter på grunn av det høye spesifikke trykk.

Example 10. Friction coefficient during start.

In an investigation of timber transport on compact snow roads with tractors and sleds the friction coefficients between the runners of the sled and the packed snow road surface were among the factors which were studied. (Samset 1956).

During motion the friction coefficient between the runner and the snow road is low. When the sled stops, the runners freeze to the compact snow road and the friction coefficient which resists the start increases, dependent on the duration of the stop as well as the load on the runners.

The friction coefficient during start were tested on a test track road covered with compacted snow. After movement, the sled was brought to complete stop. After a specific time the sled was started again and the pulling force measured. The duration of the stop was measured in 1/100 minutes (cmin) and varied from a few cmin to a few hours. This was done with varying spesific pressure of runners on the compact snow (b bar), and varying snow temperature (- °C).

When the sled stops the runners are resting on the top of the snow crystals along the road-surface, fig. 12. The specific pressure may increase and is sometimes as high as 3.000 bar (kp/cm^2). At this pressure the melting point is −21 °C. With the melting the surface area increases and the melting stops. The water from the melting snow freezes the runners fixed to the snow surface. This *melting metamorphosis* is the first part of the process.

Fig. 13. Timber loaded on a sleigh with four runners. (Samset 1956)
Tømmerlass transporteres på doning med fire meier.

After the melting has stopped the *sublimation metamorphosis* moves water-molecules from the voids to the snow crystals and runners and these are gradually fixing the runners to the snow. In reality the metamorphosis goes continuously from melting to sublimation. There are some sublimation metamorphosis during the melting period and some melting and freezing during the first part of the sublimation metamorphosis. After a while there is sublimation metamorphosis only, and the increase of the starting friction coefficient is very slow. The runners therefore, continue to be freeze fixed to the snow surface, but rather slowly.

After the sled and runners stop, the runners freeze fix to the snow very fast during the melting metamorphosis and later on slowly. This is a typical logarithmic phenomenon and our hypothesis was to select a logarithmic function as model function. In order to test the hypothesis the observations were plotted on a diagram with logarithmic abscissa (Fig. 14). The other variables were kept constant at their average value in order to study the influence of the time for stop only (Mi in 1/100 min.). As illustrated in Fig. 14 the shape of the function was a straight line over the logarithmic abscissa which prove that the logarithmic function was a good choice:

$$FST = 61.5 \cdot \log MI + 132 \qquad (26)$$

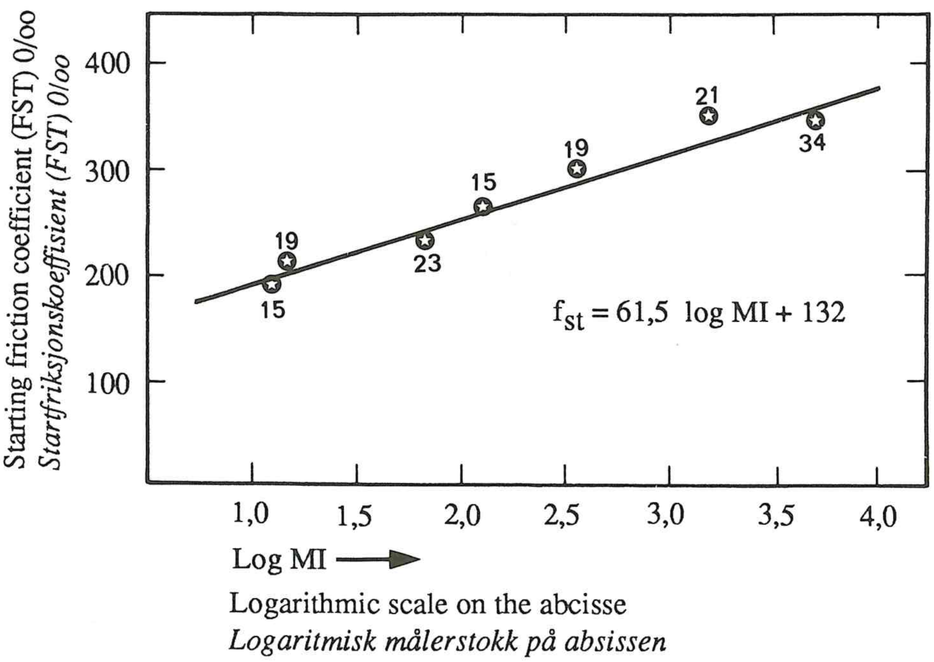


Fig. 14. With logarithmic abscissa a logarithmic function gives a straight line. (SAMSET 1956).
Med logaritmisk skala på absissen blir den logaritimiske funksjonen en rett linje.

We also found that there was some relationship between the temperature, the load on the runners and the duration of the stop. A few functions showing these phenomena were smoothed within the collected data and tested. This led to the following general function for the start friction coefficient where FST is the start friction coefficient in kp per ton, MI is the duration of the stop in 1/100 minutes, t is the snow temperature in °C, and b is the specific pressure of the runners against the road in kp/cm^2:

$$FST = +37.4 \log Mi - 8.3\, t \cdot \log Mi - 151.4\, b + 215$$

$$(R = 0.77, S = 23.3\%) \qquad (27)$$

Conclusion: The knowledge about melting and sublimation metamorphosis between runners and compact snow road together with the information the research officer received during his field work are the necessary background in order to form a hypothesis concerning selection of a logarithmic function (Fig. 12). This function was tested by using a diagram with a logarithmic abscissa (Fig. 14). The model function was then smoothed within the selected and observed influencing factors by means of regression analysis.

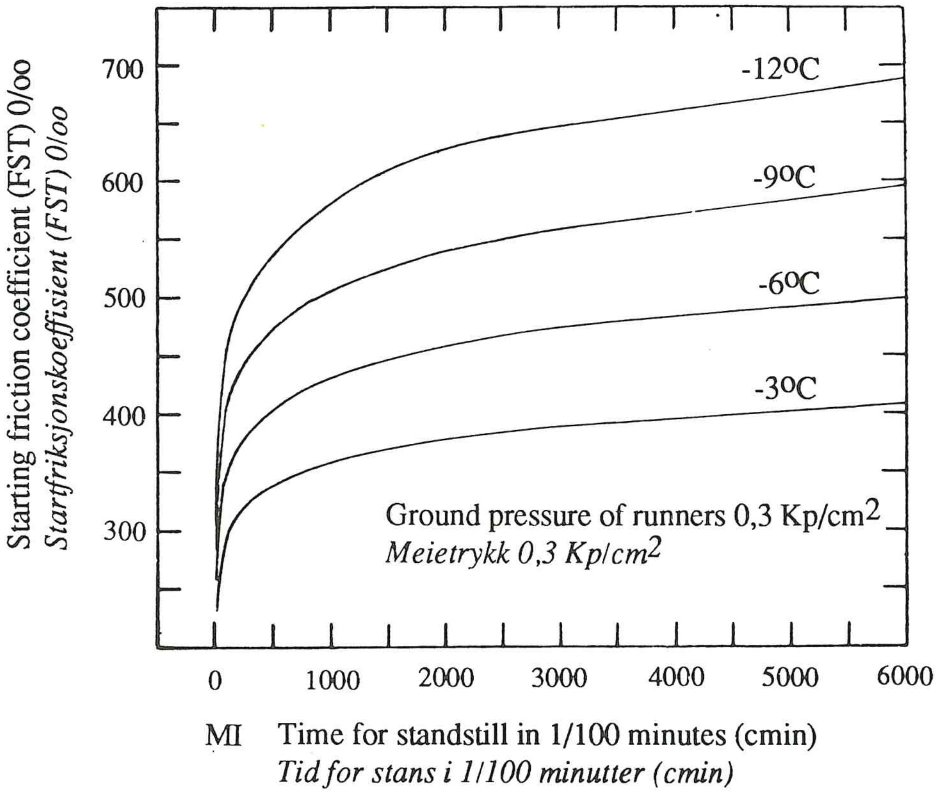


Fig. 15. Friction coefficient during start of runners on compact snow road (Samset 1956).
Startfriksjonskoeffisient mellom meier og fast snøpakket vegdekke.

In example 10 we showed how to use an abscissa with a logarithmic interval in order to find out if the model function is logarithmic. If the scatter plot forms a straight line, the model function is logarithmic.

Likewise the research officer may try out other possibilities or mathematical functions, for example quadratic, hyperbolic, eliptic, sin function etc. The scale on the abscissa is marked according to the mathematical function he wishes to test. When the scatter plot forms a straight line over the abscissa with one of these mathematical intervals the research officer receives a good hint about a useful model function such as illustrated in Fig. 14. The same prosedure may of course also be carried out on the axis of ordinate.

An illustration of the form and shape of various types of functions are shown in Fig. 16, after Ezekiel 1959. It may help the research officer in his selection of a model function.

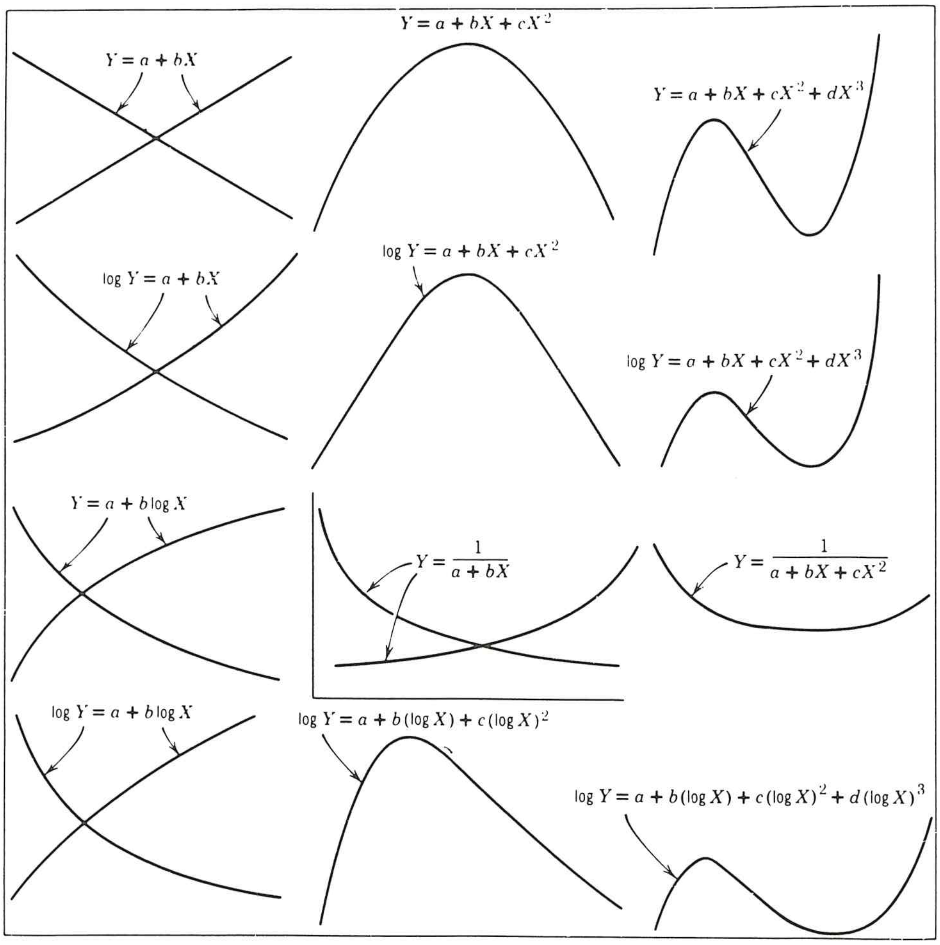


Fig. 16. Curves illustrating a number of different types of mathematical functions (Ezekiel 1959).
Kurvene illustrerer en del typer av matematiske funksjoner.

It happens that only a part of a mathematical function gives a logical and good description of the relationship between the dependent and independent variables. As an example we may choose an elliptic function.

$$(y = b\sqrt{1 - \frac{x^2}{a^2}})$$

This function may give a good description of how the dependent variable (y) for example time consumption, varies with the influencing factors (x) within the range of the observed factors (from x_1 to x_2 in Fig. 17).

Outside the range of validity the function is useless and may give a wrong result as illustrated in Fig. 17. The time function is not complete before the upper and lower limits of its range of validity are given. These limits (x_1 and x_2) should usually be within the range of observations which have been measured during the field study.

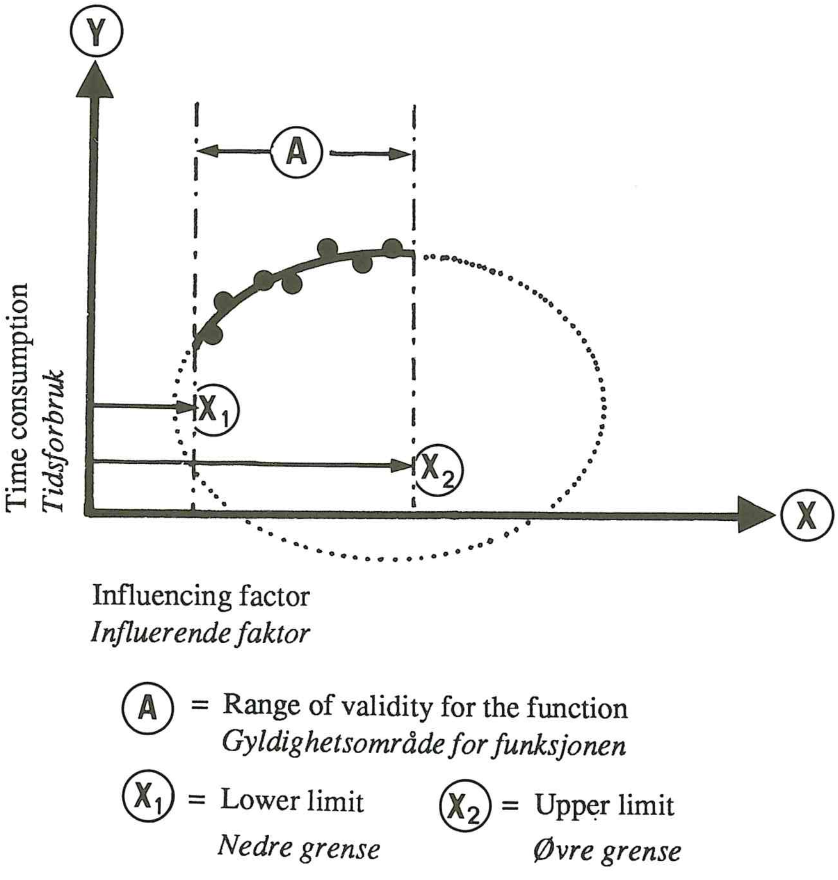


Fig. 17. The range of validity should be given for each function.
Man bør alltid oppgi gyldighetsområdet for en funksjon.

2.3. Conclusion

It is important to try to eliminate subjective estimated factors from a study. If this cannot be avoided, and the spacing between them are metric, the factors may sometimes be used as class–variables.

Knowledge about forestry methods, operations, physical and other environmental factors should be used to transfer subjective estimated variables into objective measurable variables (influencing factors).

The first step in the treatment of the collected observations is to find a type of function which describes the relationship between influencing factors and time consumption. Knowledge about all parts of the soil the water content, the geology, the terrain conditions, the climate, the forest operations etc. is the main source and basis for the selection of a mathematical formula which hypothetically may describe the relationship.

The hypothetical function or formula (the model) can then be smoothed within the collected data of time consumptions by means of regression analysis.

The resulting average function may be tested by means of correlation or variance analysis according to standard statistical methods.

3. Dependent variables (time per unit)

The aim of a time study is usually to investigate the productivity which is the ratio of output to a particular input. A performance study measures the output in relation to the input actually applied. For operational methods in forestry the productivity or performance is usually given as quantity per time unit such as m^3/h, m^3/kWh, km/h etc.

When calculating how the time consumption varies with the influencing factors the *time per unit* should always be used such as hour/m^3, kwh/m^3, hour/km, or min/m^3, min/tree, min/log, min/bundle, min/kWh, min/km etc. The performance or rate (unit per time) is a hyperbolic function in relation to the task measured in time per unit. By using time per unit it is usually easier to find simple functions which describe the correlation.

This also simplify the use of time study findings in cost calculations. The time per unit may be converted to monetary values by multiplying the time consumption with the time cost.

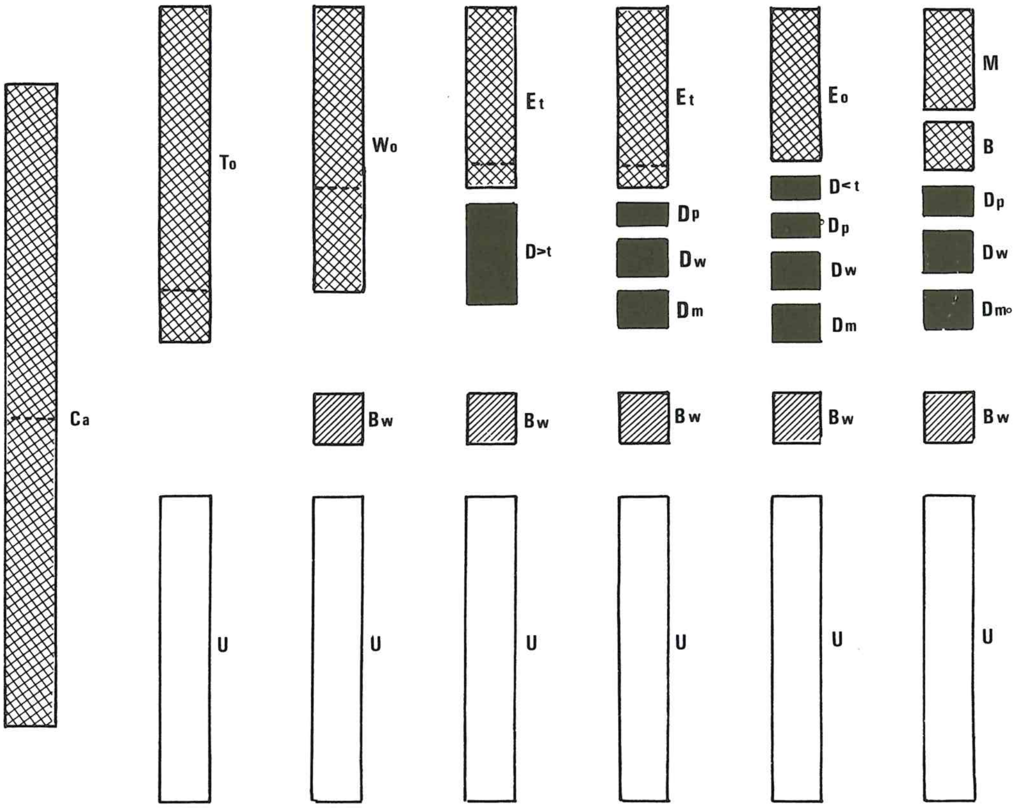
We recommend to use the time consumption per unit during the treatment of time study observations and in the presentation of how time consumption varies with the influencing factors.

The function for the time consumption may afterwards be transferred to productivity or performance by calculation.

3.1. Time elements

The Forestry Work Study Nomenclature (NSR 1978) describes the time studies and performance studies which are used in the nordic countries. This is an agreement between Denmark, Finland, Sweden and Norway worked out by the Nordic Work Study Council (NSR). It was first published in 1963 and revised in 1978. It is published in Danish, Finnish, Norwegian, Swedish, English and German.

An element time is the time for carrying out a certain work element. The smallest units are recorded by stop watch or other recording equipment, for



Ca = Calendar time *Kalendertid*

To = Total working time *Tjenestetid*

Wo = Working place time *Arbeidsplasstid*

Et = Gross effective time *Grunntid*

Eo = Effective time *Virketid*

M = Main times *Hovedtider*

B = By times *Hjelpetider*

D>t = Delay time >t *Tapstid >t*

D<t = Delay time <t *Tapstid <t*

Bw = Moving times, repair etc. *Forflyttinger, reperasjoner m.v.*

U = Unutilized time *Ikke utnyttet tid*

Dp = Personal delay time *Persontapstid*

Dw = Work delay time *Arb.tapstid*

Dm = Machine delay time *Maskintapstid*

Fig. 18. Division of the calendar time, total working time and work place time into time elements.
Oppdelingen av kalendertid, tjenestetid og arbeidsplasstid i deltider.

example portable computers. These may be divided into direct element times (main time), which directly changes a work object, and indirect element times (bytime) which indirectly changes the work object.

Depending on the influencing factors these may be divided into quantity dependent times which vary with the produced volume, or period dependent times which vary with the length of the period of the operation.

Some of the times are variable element times. All direct element times vary with the volume or the length of the period. Some of the indirect ele ment times vary also with the produced volume or the length of the period. Other indirect element times are fixed in relation to the produced volume or the length of a period of the operation.

The smallest time elements which are observed during the time study are the main times and the by-times as well as the delay times. The total working time is the sum of all these time elements during the work at the object, the working day on the working place and during the season. This time concept may be systematized as follows (Fig. 18):

Calendar time Ca. All available time in a period (e.g. one week: h = 7x24 = 168 hours.

Total working time T_o. Total working time required indirectly or directly to carry out a certain task.

Unutilized time U. The remaining part of the calendar time which can not be referred to the total working time.

Work place time W_o. The time spent in performing a task at a working place.

Moving time B_w(mov). The time of moving machines, equipment and workers from one working place to another. It is usually a periodfix by time (see Fig. 19).

Change over time B_w(start). The time used for preparation of machines, equipment and the conditions of the working place when beginning and after finishing a certain task. It is usually a period-fixed by time.

Repair time B_w(rep). Repair and maintenance time which is not a normal procedure on the working place, but has to be carried out other times than during the normal work place time (it is often repair and maintenance carried out on the machines in the evenings). In some studies it is necessary to separate the time of repair and maintenance from the other times due to the repair reason, such as transport to work shop, waiting time etc. This time is a period-variable by time (see Fig. 19).

Interruption time B_w(stop). Time when no work is being carried out due to external conditions, such as social problems, climate etc., usually defined as a period variable by time.

Travelling time B_w(tr). Daily travel with persons and machines to and from the working place is a period variable by time.

Meal B_w(meal). The total time required for meals during the working day. If this time is being measured, it is a period variable by time.

Effective time E_o. The time required to perform a specified work element which directly or indirectly changes the work object in regard to its form, position or state. Effective time may be divided into:

Main time M. The part of the effective time which *directly* changes the working object with regard to its form, position and state. The main time is always variable in relation to the produced quantity. It is a direct quantitative variable main time.

By-time B. The part of the effective time which *indirectly* changes the work object. The by-times are sometimes fixed and sometimes variable in relation to the produced quantity, and should be defined as quantity-fixed or quantity variable by time (see Fig. 19).

Gross effective time E_t. With practical time studies a rougher method is used for the timing and some of the delay times are shorter than the registration accuracy ($<$t). Such delay times are added to the effective time under the concept «gross effective time» ($E_t = E_o + t$).

The registration accuracy may be for example t = 5 mins., 10 mins. or 15 mins. If, e.g. the time elements are recorded with 15 minutes accuracy, the gross effective time includes the effective time with the addition of delay times shorter than 15 minutes (E_{15}). See chapter 3.1.3.

Delay time D. An interruption that interferes with the continuity of a performance. Many of the delay time elements happens at irregular intervals and in most cases it is difficult to find a functional relationship between influencing factors and delay time consumption. In forestry work studies we accept that the delay time usually increases with the length of the effective time and normally in proportion to the length of the effective time. It is therefore, generally accepted to figure out the length of delay times as a percentage of the effective time, and when calculating the work place time we add the delay time and the effective time by multiplying the effective time with the delay time rate: 1+D(n). The delay time can be divided into:

Unavoidable delay time D(n). An inevitable interruption due to the nature of work and its continuity on rational lines.

Personal delay time D(p). Delay times caused by the worker which are necessary for him when carrying out the work in a rational manner.

Operational delay time D(o). Unavoidable delay time caused by the organization of work or machines and equipment which is used during the work. It can be divided into:

Work delay time D(w). Delay times caused by the organization of the work.

Machine delay time D(m). Time lost due to faults with the machines, and repair and maintenance which take place on the work place.

Tool delay time D(tool). Time lost due to faults with the equipment and repair and maintenance which take place on the work place.

Avoidable delay time D(un). Delay times which are unnecessary for a rational work or working method, and which can be avoided.

3.1.1. *The effective time function E_o*

The effective time is the sum of all element times during the work elements with an object.

When for example the cutter is converting a tree to logs, he undertakes several work elements such as walking to the tree, snow showelling, felling, limbing, bucking etc. The element times may vary with different influencing factors. Walking to the tree varies for example with the distance between the trees, while the felling is independent on this distance but is dependent on the tree dimension.

The same is the case with most work tasks, for example for the element times of multi-functioning harvesting machines.

It is a possibility to investigate how the total effective time at the tree (the sum of all time elements) varies with all the factors which influences the various time elements. It is a danger that the influence on some of the minor work elements are smaller than the variation in the total effective time. In that case the influence of the factor of these small element times may not be visible when smoothing a model function based on the total effective time.

A detailed time study gives the time for each time element. A model function should be constructed for each of the time elements and these functions should be smoothed within the recorded element times. There may be many trials before the research officer finds the best element time functions with suitable influencing factors with statistically acceptable regression coefficients.

When the time functions for all work elements have been reached the total effective time function can be found afterwards by summing up all element time functions.

The research officer must try out whether this total effective time function gives a good description of the time variation with the influencing factors. The effective time consumption should be calculated by means of the sum function and compared with the observed effective times. He can then investigate the correlation and the standard error between the calculated and recorded effective times.

Example 11

In the Norwegian countrywide cutting study (SAMSET et al. 1969) the sawing time varied with DBH^2 (breast height diameter), the bucking time with $DBH^2 \cdot h$ (breast height diameter and relative height) etc. The other influencing variables were: snow depth (e) and distance between the trees (g). The numerical smoothing of each time element functions gave the following regression coefficients and intercept for motormanual cutting and conversion of Norway spruce into unbarked logs as illustrated in Table 4.

The element time functions (y in 1/10 min) was the following:

Walking time between trees increases with the distance (g) and the snowdepth (e):

$$y = 0.2 \cdot g + 0.02 \cdot e \cdot g + 0.1 \qquad (28)$$

The snow shovelling time increases with the snow depth (e):

$$y = 0.7 \cdot e + 1.0 \tag{29}$$

The felling main time increases with the square of the breast height diameter:

$$y = 0.096 \cdot DBH^2 + 0.7 \tag{30}$$

The felling by-time is dependent on the breast height diameter:

$$y = 0.44 \cdot DBH - 2.7 \tag{31}$$

The limbing main time (power saw) decrease with increased relative height (h_r) because there are less branches the higher the relative height is. The time consumption increases, however, with the factor $DBH^2 \cdot h_r$, because this indicates larger branches and branch wound areas. The limbing

Table 4. The summation of the regression coefficients of the subfunctions for the function of effective time (y in 1/10 mins. per tree). Unbarked Norway spruce. (SAMSET et. al. 1969)
Summering av regresjonskoeffisientene i delfunksjonene til virketidsfunksjon (y = virketid i 1/10 minutt). Ubarket norsk gran.

$$y = b_2\ DBH + b_3\ hr + b_4\ DBH\ h_r + b_5\ DBH^2 + b_6\ DBH^2\ h_r + b_7\ e + b_8\ g + b_9\ e\ g + a$$

	Influencing factors *Influerende faktorer*										
Sub-operations *Deloperasjoner*	a	DBH	h_r	$DBHh_r$	DBH^2	DBH^2h_r	e	g	eg	R	S %
	Regression coefficents *Regresjonskoeffisient*										
Walking between trees ...... *Gange mellom trærne*	0,1							0,2	0,02	0,8476	62,0
Snow shovelling .... *Snømåking*	1,0						0,7			0,5915	54,3
Felling main time .... *Felling hovedtid*	0,7				0,0096					0,7873	53,2
Felling by-time .... *Felling hjelpetid*	—2,7	0,44								0,3005	172,4
Limbing by power saw *Kvisting med motorsag*	—21,5	3,20	—5,1			0,0183	1,2			0,8430	39,2
Marking for cross-cutting ... *Aptering*	—4,0	0,23	1,8	0,24			0,2			0,6645	59,0
Bucking .... *Kapping*	—0,9		1,9		—0,0012	0,0079				0,7494	74,9
Branding .... *Merking*	7,9	—0,34	—6,5	0,43						0,5330	76,5
Collecting tools .... *Samling redskap*	0,6	0,04					0,1			0,2219	116,9
Total effective time .... *Sum virketid*	—18.8	3,57	—7.9	0,67	0,0084	0,0262	2,2	0,2	0,02	0,8261	38,0

time also increases with the snow depth because it is more difficult to use the motorsaw for limbing the deeper the snow is:

$$y = 3.20 \cdot \text{DBH-}5.1 \cdot h_r + 0.0183 \cdot \text{DBH}^2 \cdot h_r + 1.2 \cdot e\text{-}21.5 \qquad (32)$$

The other time element functions in Table 4 can be explained similarly. Some of the time element functions are dependent upon the same influencing factors. Others are dependent on different influencing factors.

The resultant function of the effective time is the sum of all the element time functions. This can be done by summing up the regression coefficients and intercepts as illustrated in table 4. (See equation (40) page 47).

It is of importance to examine whether the sum function denotes the effective cutting time in a satisfactory manner. The cutting time can be calculated according to the effective time function for each of the 25.363 trees which were time-studied during the field work. The actual time which was used for the cutting of each of the trees, was found as the difference between the time readings at the beginning and at the end of the cutting of each tree.

There may be a small deviation for each tree between the time actually used (y) and the time calculated according to the effective time function (y'') which can be expressed as z=y-y''.

In the study reported in example 11 the coefficient of correlation (R) between the recorded times and the times calculated by means of the effective time function was R=0.8261 and the standard error S=38.0 %. By this method we succeeded in finding a function for the effective time consumption and how the time consumption varies with the influencing factors. We also found to what extent the effective time can be sub-divided into time element functions and how the independent variables influenced the time consumption, for each of the work elements.

If the study is a part of a method improvement involving for example machine deveopment, some element times may be short and difficult to measure. Automatic registration may even be needed.

The sub-division of an operation into work elements depends upon the purpose of the study (method development, training, economic and wage calculations etc.).

3.1.2. Work sequences

All work tasks in forestry are accomplished by means of a production. The secondary part of the forestry production is an activity carried out by persons *(action)* and machines, tools or other capital production factors in the form of a *process.*

The process consists usually of more than one operation. Each of the operations is composed of several *work elements.* Each operation may be carried out by a machine operated by one worker or a team of workers. It is a *man/machine system.* One may analyse the choice of machine type and the number of the crew. Sometimes several operations based on different machines and crews may follow after each other in a sequence of operations. Such man/machine systems can be analysed by means of a *system analysis.* If such an analysis is based on theoretical figures the result is mainly a *motivated hypothesis.* It may give some ideas in connection with work planning.

A reliable result, however, can only be achieved by putting such a man/machine system in action. A *working system in operation* is a *working method* which is a dynamic activity where the working system takes part. A *working method* can be measured by time-studies and performance analysis.

Timber transport is an example on a transport production, which consists of several operations such as terminal operations (loading, unloading etc.) and underway operations (transport with load, return with empty transport mean etc.).

Each of these operations consist of several work elements. Since all the work elements are carried out by the same man/machine system (the same persons and machines) within one operation, the effective time for the operation may be calculated by summing up the regression and intercept coefficients of the time element functions as shown in example 11 and Table 4.

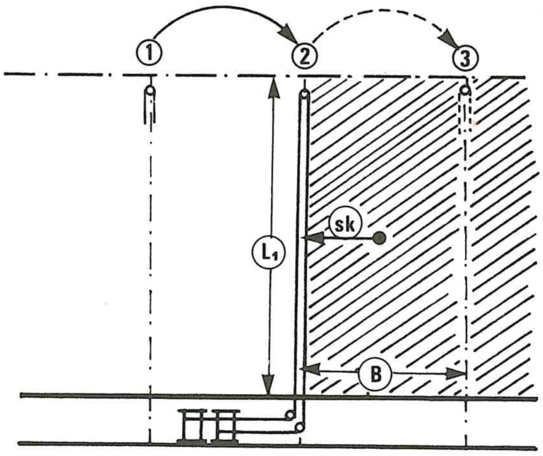
Sometime, however, it happens that some of the operations in a process are carried out by one man/machine crew while other operations are carried out by another crew (for example loading crew and transport crew, or harvesting team and forwarder team etc.).

In such cases it is needed to adjust the observed time consumptions for differences in the workers performance level before the summation of the element time functions within each of the operations as well as for all the operations within the process. Methods for adjustment for the workers or the operators performance differences are discussed in chapter 3.5.

When this has been done, one may find the effective time function of the entire process in a similar way as shown in Table 4. One may use such a time function in order to find optimal solutions by taking partial derivatives with respect to the various influencing factors in the function.

Example 12.

A 4-men crew operated a radio-controlled cable crane with a delimbing/bucking machine at the landing. The crew rigged the crane and moved it sideways in parallel strips or corridors perpendicular to the steep hillside (Samset 1981, page 268). The crew was felling, setting the chokers, trans-



porting the whole trees and converting the trees into logs at the landing in one work sequence. As soon as one strip was cut the skyline was moved parallel and close to the edge of the forest in order to continue the felling skidding transport and conversion. The skidding distance (sk) was the half of the width of the strip (B).

Which is the optimum width (B) of the corridor taking the rigging as well as the cable crane operation into account?

The operation was carried out under the following conditions:

L_1 = Length of the cable crane. 400 m.
L_T = Transport distance. 200 m. ($2 \cdot L_T = L_1$)
sk = Skidding distance, perpendicular to the skyline, m.
B = Width of the strip or corridor = $2 \cdot$ sk
v = Average load = 1,15 m^3 per load
n = Number of trees per load = 3.
V = Volume per decare = 20 m^3 per daa.
I = Rigging time in hours per m^3

Cable crane operation:

Work place time in minutes per load according to time studies (Samset 1981):

$$W_o' = 0.0162 \cdot L_T + 0.0748 \cdot sk + 0.4473 \cdot n + 3.32 \qquad (33)$$

By inserting the above mentioned conditions in the formula (33) we get the work place time in hours per /m^3:

$$W_o'' = 0.000117 \cdot L_1 + 0.00054 \cdot B + 0.068 \qquad (34)$$

Rigging the cable crane:

Work place time in hours per setup according to time studies (Samset 1981):

$$I_1 = 0.0104 \cdot L_1 + 0.2$$

Volume per setup:

$$V_1 = \frac{L_1 \cdot B}{1{,}000} \cdot V$$

Work place time per m^3:

$$I = \frac{I_1}{V_1} = \frac{10.4 \cdot L_1 + 200}{B \cdot L_1 \cdot V} \qquad (35)$$

Work place time for rigging and operation:

$$W_o = W_o'' + I$$

$$W_o = \frac{10.4 \cdot L_1 + 200}{B \cdot L_1 \cdot V} + 0.000117 \cdot L_1 + 0.00054 \cdot B + 0.068 \qquad (36)$$

The four man crew carries out the rigging as well as the operation. The optimum width which gives lowest possible costs is therefore the same as for the lowest possible work place time (W_o). This minimum work place time may be found by taking the derivatives. In our example we wish to find which width of the corridor (B) gives minimum costs and take the partial derivative of the work place time (W_o) with respect to the corridor width (B). We get minimum work place time when the first partial derivative is 0, and the second is positive:

$$\frac{\delta W_o}{\delta B} = -\frac{10.4 \cdot L_1 + 200}{B^2 \cdot L_1 \cdot V} + 0.0054 \qquad (37)$$

$$\frac{\delta^2 W_o}{\delta B^2} = +2 \cdot \frac{10.4\, L_1 + 200}{B^3\, L_1 \cdot V} \text{ (positive)}$$

$$\frac{\delta W_o}{\delta B} = 0 \text{ when:}$$

$$\frac{10.4 \cdot L_1 + 200}{B^2 \cdot L_1 \cdot V} = 0.00054$$

$$B = \sqrt{19259 \cdot \frac{1}{V} + 370370 \cdot \frac{1}{L_1 \cdot V}} \qquad (38)$$

This shows that the width of the corridor decreases with the volume per decare. The lenght of the cable crane has litle influence on B.

Table 5

V m^3/daa	B meter
10	45
20	32
30	26

In the example we kept a few variables constant (for example v=1.15 m^3/load). One may put these factors into the function (36) and find how the minimum costs vary with their variation.

3.1.3. The workplace time (W_o) and the effective time (E_o)

The effective time (E_0) is the sum of the *main times* and the *by times.* It is the time required to perform a specific work element which directly or indirectly changes the work object.

The effective time is usually the basis for studying the time consumption during a time study and the aim is to find out how the effective time varies with the influencing factors. One must bear in mind that this is just a part of the total time and the entire callendar time for a machine or a method used

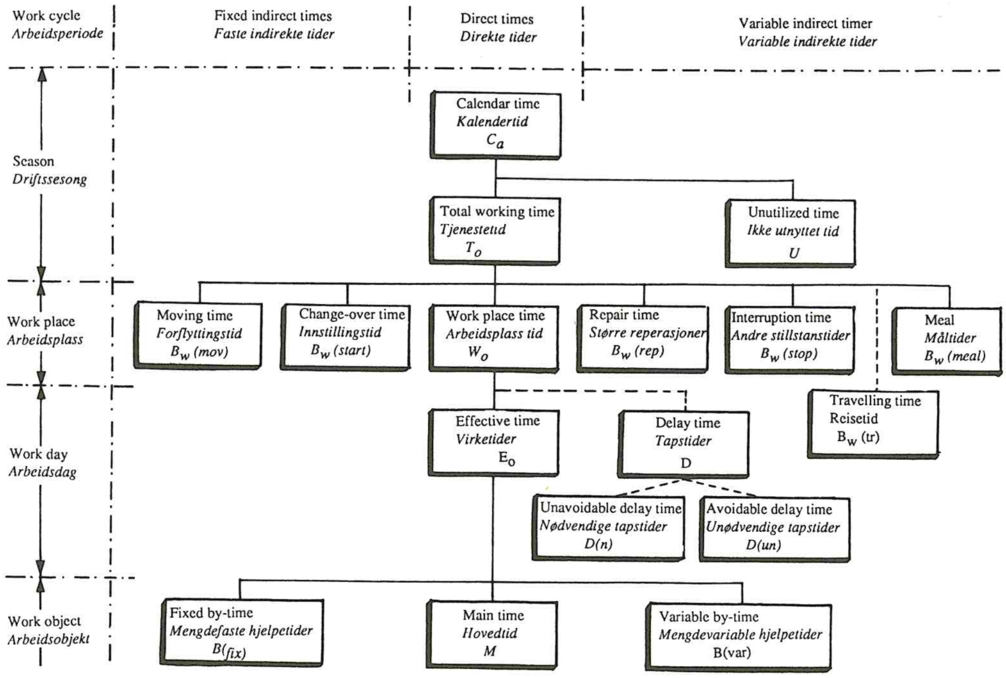


Fig. 19. The time concepts.
Tidsbegrepene.

in the forest operation. When adding the *delay times (D)* to the *effective time* (E_o) we receive the *work place time* (W_o). This is the time consumption which is used for calculating the performance of the operation during the working day (Fig. 19).

Many of the delay times happen at irregular intervals and the length of the time varies discontinuously. It is therefore difficult to find a time function for most of the delay times. They are, however, period-dependent and it is generally accepted that the length of the delay time consumptions varies in proportion to the length of the effective time. Usually the delay time is given as a percentage of the effective time. During a study of cutting by motorsaws we found that the delay times represented $p_w = 27,7$ %. The corresponding *rate* was $p_w = 0,277$.

The work place time can be obtained as follows:

$$W_o = E_o \cdot (1 + p_w) \qquad (39)$$
$$W_o = E_o \cdot 1.277$$

It takes usually a longer period to find a good average for the delay times than to find the function describing the variation of the effective time with the influencing factors. It is often necessary to carry out one study for the effective time and a longer statistical study to find a good average for the delay times.

Table 6. Time concept for sawing time by motor chain saw.
Tidsbegreper for sagetiden med motorsag.

	Lab.test *Lab.test*		Cutting study (Samset 1969) *Hogstundersøkelsen (Samset 1969)*					
	Sawing in testing stand (Robotic time) *Saging i prøvebenk*		Main time *Hovedtid*		Effective time time *Virketid tid*		Workplace time *Arbeidsplass-tid*	
	cm^2/min	%	cm^2/min	%	cm^2/min	%	cm^2/min	%
Spruce (8 motorsaws) *Gran* *(8 motorsager)*	4,000	100	1,742	43.5	1,330	33.2	1,068	26.7
Pine (3 motorsaws) *Furu* *(3 motorsager)*	4,200	100	1,801	42.8	1,451	34.5	1,164	27.7

Since the study of delay times sometimes causes problems, practical *comparative studies* of two or more different methods are limited to the effective times (E_o).

It happens that the effective times are recorded more roughly. Delay times shorter than for example 15 minutes are included and is called the gross effective time (E_{15} see chapter 3.1). The gross effective time is sometimes called PMH = Productive time measured. (Richardson, R., 1989).

One may believe that the average delay times included in the E_{15}-time would give an average of 7.5 minutes. This is not justified. The average delay time during the E_{15}-study is usually higher than 7.5 minutes. In spite of the fact that this type of recording is easier to carry out during the field work this method should not be used in scientific correlation or comparative studies.

In mechanized forest operations, especially in highly mechanized operations, some of the time elements may be *machine steered* and other time elements are influenced by the ability of the operator (*manually steered* time elements). Professor Tom Bjerkelund (Bjerkelund 1979), University of New Brunswick suggests analysing the *robotic times.* These are the time consumption which the machine is able to perform under completly optimal conditions.

In a motor-saw study (Samset et.al. 1969) the various sawing times during felling were tested, based on detailed time studies of 25.363 trees with 8 different types of 1-man chain-saws (Table 6). The main times, effective times and work place times were compared with the robotic time. The robotic time was measured with the saw in a test stand. The main time was approximately 43% of the robotic time and the work place time 27% of the robotic time. The difference depended on the working technique of the 24 experienced workers, which took part in the investigation.

The difference between the work place time and the robotic time will vary with the type of machine used in the operational method. Felling by chain-saw is a motor-manual operation. When the machine is steered by an operator in a highly mechanized operation, the machine-steered part of the time consumption is higher the more mechanized the operation is. Completely automized machines (i.e. robots) are not influenced by the input of the operator.

In some detailed studies it may be of interest to investigate and compare the influence of the machine steered part and the manually steered part of the element times. These are usually difficult to measure by ordinary time studies. More advanced instruments with automatic recording may be needed. There exist for example fast running video cameras which may be useful for this purpose.

The time elements (main times, by times, and delay times) are usually within the limits which the time keeper can master. *These effective times should be the smallest time units for time studies in forestry. Comparison and correlation studies should usually be based on the effective times and delay times. The results should be given as a sum of effective times and delay times in the form of work place time.*

3.1.4. Adjustment of the level

By means of the subjective performance rating (chapter 3.4.) one seeks to find the «normal time consumption». This is doubtful, because a research operation usually depends upon a limited number of research workers and machines for economic reasons. There is a danger that a «standard time» based on such limited material will not agree with the level in practical forestry operations throughout the country. As mentioned in chapter 3.4. it is also doubtful because of an estimation of the performance rate is subjective. An error may occur due to the complexity of forest work, its great number of varying work elements and the great variation of working conditions.

An alternative is to *measure the difference* between the individual worker's performance and the average performance of all workers in the study when they are carrying out their work under standardized working conditions. (Chapter 3.5.)

In this case the aim of the research operation is to find the mean time or the mean time-functions which describe how the time consumption varies with the working conditions. The individual worker's time consumption is adjusted by means of their performance differences from the average performance in the study. In this way the time functions are based on equal performance capacities for all the methods which are being studied in the research operation. The adjusted observations of the element time consumptions are then smoothed by means of a regression analysis in order to achieve the *average time function* for the effective time consumption E_0).

During the time study the delay times are recorded when actually working at the work place. It is assumed that the delay times increase with the length of the operation and are given as a percentage increase (p_w) of the effective time (E_0), in order to find the time consumption during the work place time (W_0).

$$W_0 = (1 + p_w)\, E_0$$

The average work place time function is found by multiplying each of the regression coefficients in the function with this rate of percentage increase due to the delay times.

Example 13.

During the countrywide cutting study in Norway (SAMSET et al. 1969) the delay time during the work place time was 27.7%. The time function during the work place time can be found by multiplying each of the regression coefficients and the fix coefficient by this rate of increase due to delay times:

$$W_0 = 1.277\, E_0$$

The effective time mentioned in Table 4 is described by the following function (1/10 mins/tree):

$$\begin{aligned} E_0 = {} & 3.57 \cdot DBH - 7.9 \cdot h_r + 0.67 \cdot DBH \cdot h_r + 0.0084 \cdot DBH^2 \\ & + 0.0262 \cdot DBH^2 \cdot h_r + 2.2 \cdot e + 0.2 \cdot g + 0.02 \cdot e \cdot g - 18.8 \end{aligned} \qquad (40)$$

The work place time in 1/10 mins per tree may be described by a new function where each of the regression coefficients and the fix coefficient are multiplied by 1.277:

$$\begin{aligned} W_0 = {} & 4.56 \cdot DBH - 10.1 \cdot h_r + 0.86 \cdot DBH \cdot h_r + 0.0107 \cdot DBH^2 \\ & + 0.0335 \cdot DBH^2 \cdot h_r + 2.8 \cdot e + 0.26 \cdot g + 0.026 \cdot e \cdot g - 24.0 \end{aligned} \qquad (41)$$

* * * * * *

In practical operations it is easier to measure the total length of the work place time during the day than the total length of the effective time.

The result from a time study should always be given as the time consumption and its variation with the influencing factors during the work place time.

The level of the average time function in a research operation has to be adjusted according to the general level in practical forest operations.

The adjustment of the level may be done by collecting production figures from a number of practical operations. At each work place the daily production and the length of the work place time should be recorded in order to figure out the work place time per unit of the volume produced, for example W_0 per m^3. At the same time the average working conditions should be described. These are the averages of the same variables – i.e. influencing factors – as have been used in the effective time function which were found during the time study in the research operation.

When the work place time per m^3 from practical operations has been collected, these average times may then be plotted in relation to the work place times according to the time function from the research operation. The ratio between the average time function in the study and the time consumption in practical forest operations can be given as a multiplication factor. The average function which describes the work place time in practice may be achieved by multiplying each of the coefficients in the function by this factor.

There is also a difference between the work place time and the total working time (Fig. 19). In additon to the work place time on the working place there are some additional times such as delays caused by weather conditions, illness, transport times between working places etc.

If the time function shall be used as a basis for fixing the payment for piecework it should describe the time consumption during the *total working time* (T_0). The work place time (W_0) is the time the workers are actually working on the work place. The total working time (T_0) is the time the workers are paid for.

In Norway for example, there exist (1990) an agreement between the employers and the employees organizations that the official total working time should be 37.5 hours per week. This corresponds to 7.5 hours per day in a 5 days week.

During piece work the workers often use longer working days. This has to be recorded in order to achieve a fair comparison between workers, machines or methods.

Statistics showing work place time and total working time in practical forestry operations are difficult to produce.

The simplest way of collecting performance figures from practical operations would be to circulate a questionnaire to the supervisor or the operators in practical operations. This method is not recommended. The people who are involved in daily production are too occupied to place the necessary enthusiasm in this kind of extra work. Our Institute has tried this method on several occasions. Sometime we even placed recording instruments on the forest machines. This did not help except that many instruments got lost. The data collected in this manner were not reliable, had many mistakes and was delivered irregularly.

The data collection from practical operations has to be supervised by a research officer who frequently visit the operations for inspection and control. His contact man and the operator should receive an agreed payment for each accepted questionnaire. In addition it is an advantage to control measure the statements about the production at regular intervals.

Production statistics in practical forest work has to be organized and controlled by the research officer.

Example 14.

During the countrywide study, mentioned in example 13, the timekeeper visited each research area, in order to time-study the research-cutters. In addition he also contacted the other cutters, working in the area.

In agreement with the lokal forest administration he received information from the research workers and from the other workers about the length of the work place time as well as the length of the total time each day. The daily production was also reported. This information was sent to the local time keeper for control. He sent it to the research institute every week.

The workers were paid for each accepted form and the time keeper could discuss possible mistakes next time he visited the area.

The research officers had measured some of the average influencing factors on sample plots on each cutting area before the time study operation started. Other factors such as climatic factors were given in the form filled out by the worker and controlled by the time keeper.

The difference between the effective time and the work place time was found to be $p_w = 27.7\%$ (example 13) and the difference between work place time (Wo) and total working time (T_0) was $p_d = 18.9\%$.

The function of the time consumption during the total working time in practical forest operations may be based on the effective time function as follows:

$$T_0 = (1+p_d)(1+p_w)E_0 \tag{36}$$
$$T_0 = 1.277 \cdot 1.189 \cdot E_0$$
$$T_0 = 1.518 \cdot E_0$$

This shows that one has to add 51.8% to the average effective time function in order to achieve the time function for the total time consumption in practice. This may be done by multiplying each of the regression coefficients and fixed coefficient in the function for the effective time with the factor 1.518.

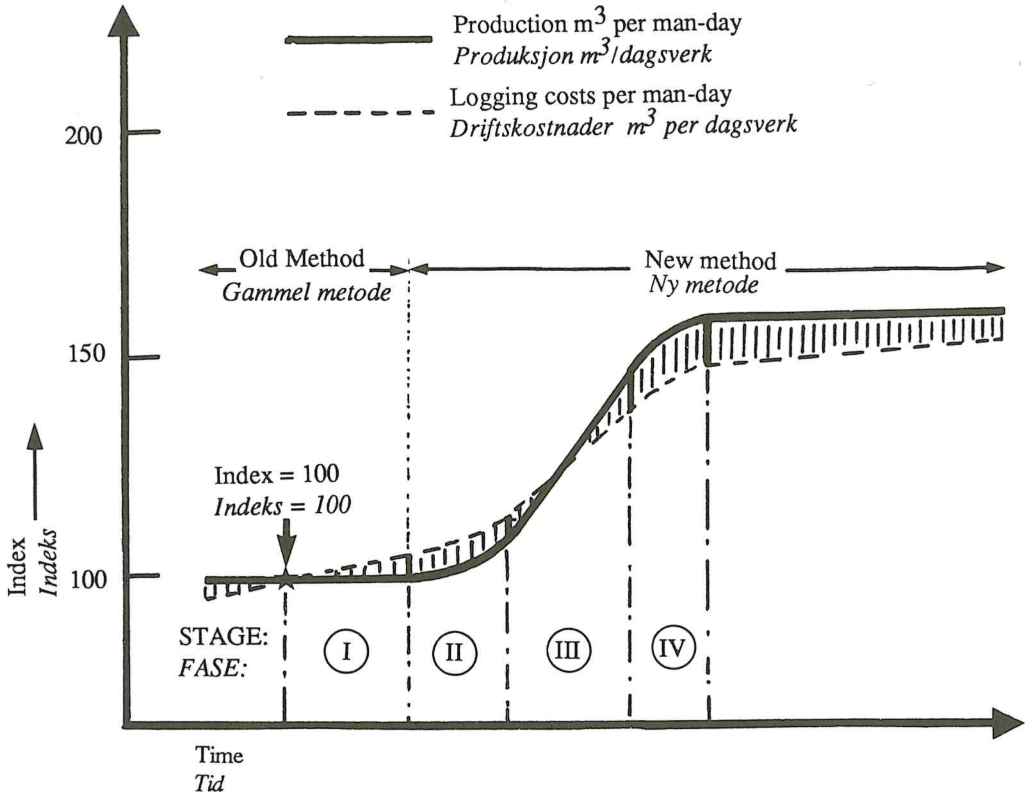
A similar statistical investigation of work place time, total working time and daily production was carried out in connection with a country-wide time– and performance analysis of tractor transport in Norway 1987/88 (GJEDTJERNET 1989) The time study included tractor operations distributed on research areas all over the country. Many timekeepers and various types of tractors participated in the study.

On each research area the local timekeeper received forms from each tractor operator which he controlled locally before the forms were sent to the research institute once a week. The information on the form included average influencing factors, daily production, as well as work place time and effective time for each day. The combination of detailed time studies as samples within each research area and the statistics from the entire practical operation gave a successful result.

3.2. Comparative and correlation studies

When the operational costs of a method become too high new methods must be developed and introduced. This evolution has been analyzed and described by SAMSET (1961), who suggests that this development follows a law of conformity: THE LAW OF DISCONTINEOUS EVOLUTION (Fig. 20).

The development from one method to the next takes place in four stages where stage II is the development stage. New machines and methods are developed and introduced in practical forestry. Sometimes more than one machine and one method are being suggested and it is necessary for the



STAGE I.	Economic pressure stage. Costs per man-day increase more than productivity for the traditional methods.
FASE I.	*Prispress-fasen.*
STAGE II.	Development stage. The costs per man-day have become too heigh in relation to the productivity of the method. Economic pressure leads to intensive experimental activity to find a new method.
FASE II.	*Utviklings-fasen.*
STAGE III.	Introduction stage. The new method is introduced on the marked.
FASE III.	*Introduksjonsfasen.*
STAGE IV.	Stabilizing stage. The new operational methods is put into action but is still in the process of development, for example in the case of organizing the work and applying it to forestry.
FASE IV.	*Stabiliseringsfasen.*

Fig. 20. The law of discontinuous evolution (Samset 1966)
Loven om den sprangvise utvikling.

research station to compare these methods and give advice to practical forestry.

After the machine and method have been accepted and put into the general use it is necessary to investigate the productivity of the machine and how this productivity varies with the influencing factors. BERGSTRAND (1987) divide these two types of studies in *comparative studies and correlation studies.*

The comparative studies may take place during the development stage II and/or the introduction stage III. The aim of this study is to compare the productivity of two or more different methods and machines. It is necessary to try out the machines on comparable test grounds where the forestry conditions, tree dimensions and terrain conditions are practically equal. The research officer should also ensure that the operators have the same experience and qualifications for operating the machines. Some times comparable figures are found only when the same operator is used for the operation of the various machines in the methods to be compared. The aim of the comparison is to give advice concerning which method should be followed up and introduced to practical forestry under different conditions.

The correlation studies should only be carried out on machines and methods which are generally used in practical forest operations. The correlation studies should be carried out after the stabilizing stage IV has been passed (Fig. 20).

Fig. 21. Comparative study of small harvesting machines, 1989. (Stage II, in Fig. 20).
Sammenlignende tidsstudier av små kvistemaskiner 1989. (Fase II, i Fig. 20).

The amount of observations are different for comparative and correlation studies. The number of observations to be studied may be examined by making a trial before the investigation starts. This is a short study in order to find out the distribution of the observations. The statistical litterature describe methods which may give the research officer some advice concerning the amount of observations he may need.

Fundamentally the need for numbers of observations increases with the number of influencing factors. In addition the distribution of the observations is of importance.

A practical rule of application. The independent variables are factors influencing the time consumption. These measurable factors describes working conditions and difficulties, such as trees, logs, terrain, forest floor, climate etc. Such factors vary a great deal around an average.

> *Comparative studies* concentrate on comparing one or several methods or machines and one tries to reduce the number of observations. The methods are tested under as equal conditions as possible where the influencing factors are the same.
>
> If the research units (for example stands) are selected in such a manner that tree shape, dimension, stand density and terrain are approximately equal and the measurements show that the averages are equal the research officer must still ensure that the distribution around the averages allows comparable conditions. Such limited comparative studies do not allow comparison of the methods productivity with changing dimensions of the influencing factors.
>
> *Correlation studies* emphasise how time consumption varies with the variation of influencing factors. Usually more than one research unit is needed in order to secure variation of a factor (Fig. 22). This may be taken care of by selecting two units – one with small dimensions – and one with large dimensions (or with easy and difficult conditions). In spite of the variation of the influencing factor within each unit, only two research units are usually too few to give good information about the functional relationship between the factor and time consumption (Fig. 22 A). We have experienced good results by selecting three units, where the average factors are small or easy in one unit, medium in another and large or difficult in the third unit (Fig. 22 B).

The number of observations required within each unit depends on the variation of the influencing factor. Our experience is that at least 10 observations should be collected for each of the influencing factors when there is large variation in the influencing factors, such as tree dimensions within a stand. If the variation is smaller such as bundles or logs, five observations may be sufficient.

This three-unit selection for each of the influencing factors together with the variation of five to ten observations within each research unit gives usually a good background for the choice of a reliable mathematical function during the treatment of the collected data.

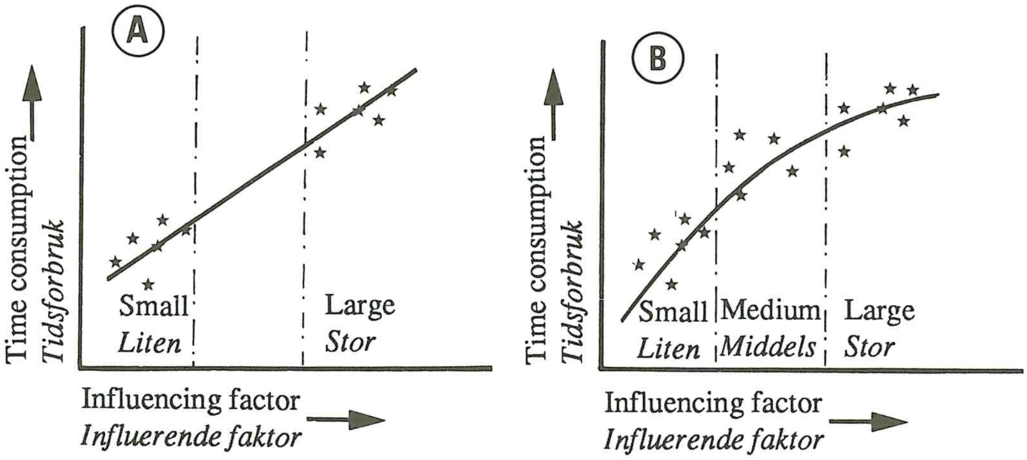


Fig. 22. Three-dimentional grouping of influencing facctors.
Tredimensjonal gruppering av influerende faktorer.

If the number of influencing factors are high the number of observations will often be too high and the research operation too costly and time consuming. In such cases it is necessary to limit the study to the most important influencing factors, while the other factors are kept constant under easy conditions. The influence of these factors (difficulty classes) are studied on a few research areas only, in order to find the addition to the time consumption which these factors (or difficulty classes) cause.

Example 15.

The following example may illustrate how to plan the need of observations in a correlation cutting study distributed over five research areas. One tree represents one set of observations, and the number of work elements to be observed per tree have been discussed before in chapter 3.1.1. In a correlation study we want to investigate the variation of the effective time consumption caused by the following influencing factors:

Tree dimension	3 units (small, medium, large)
Relative height	3 units
Steepness of ground	3 units
Roughness of ground	3 units
Snow depth	3 units
Temperature	3 units
Tree-species	2 units (spruce – pine)
Conversion	3 units (barked, unbarked, unbranched)
Number of research areas	5 units (North, Central and South in the country)
Observations per unit	10 trees

The total number of trees to be studied may be calculated as follows:

3x3x3x3x3x3x2x3x5x10 = 218,700 trees

The enormous material would lead to a time consuming and costly research operation. It is necessary to reduce the number of observations. This can be done by deviding the study into a main study and an additional study branching out from the main study. In the above list the main study consists of the italicized influencing factors only. This investigation will be carried out on flat, easy ground and unbarked timber only, with the following amount of observations:

3x3x3x3x2x5x10 = 8,100 trees

The other influencing factors may be studied within one of the research areas only:

Steepness of ground	3 units
Roughness of ground	3 units
Summer/winter	2 units
Tree species	2 units
Conversion	3 units
Relative height	1 unit (medium)
Tree dimensions	3 units
Observations per unit	10 (trees)

3x3x2x2x3x1x3x10 = 3,240

The total need of observations is 8,100 + 3,240 = 11,340 trees.

In a norwegian cutting study (Samset et al. 1969) it took the research officer several months to plan the investigation. Research areas were selected all over the country. The time study was carried out by 14 time keepers from January to November 1965.

When we started the planning all possible influencing factors were taken into account. The need of observations was calculated to over 300,000 trees. In order to reduce the need of observations, we planned a main study under easy forestry and terrain conditions with additional studies as branches to the main study. The need of observations were reduced to 30,000 trees.

Each time keeper followed a time table showing which cutter he should visit every day and which research unit should be cut that day.

The plan specified the number of trees which should be studied. The plan was worked out for 4 weekdays. On fridays the time keeper could supplement with additional studies covering part of the plan where too few observations had been collected (due to illness, weather conditions or other unexpected delay times). The total number of trees which was studied was somewhat less than the plan: 25,363 trees.

3.3. Performance rating

The aim of a scientific time study is to find out how the effective time consumption varies with the influencing factors. If the research operations take place at different work places and with different workers at each place, errors may arise due to the variation of the workers performance capacity. If the influencing factors differ from one work place to another, the variation of the worker's performance capacity may lead to incorrectly estimated functions between the dependent and independent variables. Since the function partly shows how the time consumption varies with the independent (influencing) factors and this is partly influenced by the workers varying performance capacity it is necessary to adjust for this variation in the workers performance capacity.

One possibility is to use the same group of workers at all work places. This may be costly and impractical, especially if the work places are located a long distance from each other.

With mechanized forest operations, it often takes a long time to train the workers to be experienced operators with good operating techniques. It is difficult and impractical to use the same operators on all machines which are used in the research operations.

The operational methods to be analyzed may be divided into the following systems:

1. Manual work
2. Motor-manual work
3. Mechanized operation
4. Automation of the sequences of the work elements
5. Remote control of the machines.

Some of these types of methods are completely *man-steered,* some are completely *machine-steered.* In most mechanized forest operations there exist a combination of man-steered and machine-steered work elements.

Manual or motormanual work is usually completely influenced by the worker's performance capacity. A completely automized or remote controlled machine is usually completely machine-steered. A robot which is frequently used in the industry is completely machine-steered.

Most forest operations depends upon a mixture of man-steered and machine-steered work elements. The worker's strength and manual working abilities is not so influential in highly mechanized operations as in motormanual work. The machine operator's performance capacity depends more on psychological factors: his ability for rapid observations under many varying conditions and his driving or operating techniques. There seems to be a larger variation in the operators performance rates in mechanized operations than between the workers in manual work. This is illustrated in Tables 7, 8 and 9.

In a countrywide study on hauling timber with various sizes of tractors from stump to roadside GJEDTJERNET (1989) calculated a performance rate for the machine operators studied. During the underway operations the performance rate of the machine and operator was mainly dependent on the operator's performance rate. During loading and unloading (the terminal operations) the performance rate was partly dependent on the operator and partly on the size of the loader, described by means of the factor «weight of loader» (Q) multiplied by «the power of the loader» (kW): see chapter 3.5.4.

3.4. Subjective performance rating

In industrial time studies subjective performance rating is widely used. This may lead to an acceptable result since the working conditions are easy and mostly standardized. One attempts to eliminate differences which are caused by the individual performance level of different workers by subjective performance rating of each individual worker. The time-study man gives a subjective rating or performance capacity which is supposed to indicate to what degree a worker's output differs from a supposed normal production. Each individual's recorded times are adjusted by this factor. The aim is to establish normal production levels, for example in connection with the construction of standard time-tables (the M.T.M. method etc.). The worker should carry out his task according to a standardized working method which is developed through systematic method studies. WITTERING (1973) has described this as follows:

«During the method study one attempts to achieve the best method for each of the work elements and the best sequence of work elements within the work operation.
The standardized working method is then described in details.
The worker is trained to carry out the standardized working method.
The worker's ability to carry out his work according to the standard method is controlled by film or video studies and by time studies. The training curve is analysed and the training period continues until the worker's ability has been stabilized».

The time study can start and the experienced time-keeper gives a subjective performance rate for each individual worker. This performance capacity rating has been tried in forest work studies. In his dr.thesis APPELROTH (1982) carried out subjective performance rating in manual planting of containerized nursery stock after mechanical site preparation. The subjective performance rating in this report was controlled by film studies. Under such easy conditions with rather simple work elements a subjective performance rating may be used with an acceptable result.

In other operations the work is more complex and consists of a more complicated sequence of work elements. The working conditions vary with terrain, climate, types of trees and stands etc. This makes the subjective performance rating doubtful.

STEINLIN (1955) conducted an interesting research on time-study methods in manual felling and cutting. He concluded with the following statements:

1. For each of the work elements a worker's performance capacity varies during the day, from day to day and throughout the season. These variations are not systematic and they are influenced by a man's health, his temperament and by the environment.
2. The worker's performance capacity is different from one work element to another. This variation is different for the different workers. One worker may have a high performance capacity on one work element, and low for another while the opposite may be the case for the next worker.
3. For one and the same work element the work capacity is different for different workers. The psycholgical impact on the performance capacity is different for different workers. Some workers have a rather stable work capacity, while others have more erratic capacity.
4. If there are more workers with great differences in the performance capacity in a crew, a tension may develop between the workers. The erratic worker easily adjusts his working capacity to the capacity of the more stable workers in the crew.

The working conditions are not homogeneous throughout the forest. They vary from place to place and season to season depending on climatic conditions. There are hardly two trees with identical conditions as regards working environment. In this connection the forest is vastly different as working place compared with the more even working conditions found in industry.

STEINLIN (1955) suggested that subjective performance rating should not be used in connection with time-studies on forest operations. This was based on experiences with manual forest work which is completely man-steered. In mechanized forest operations where the time consumption for each of the work elements depend on a varying mixture of man-steering and machine-steering, a subjective performance rating is even more complicated.

In forest operations an unbiased opinion by the time study man may be very difficult to attain. The numerous reasons for variation, both on the individual level and due to working conditions, could result in large errors in estimating these factors. To avoid this problem, it has become common practice in time studies, as in other studies of a biological nature, to conduct experiments according to sound statistical methods without any form of subjective adjustment of the times (SAMSET 1950, MATTSON MÅRN 1953, MAKKONEN 1954, HÄBERLE 1967). This principle has been generally adopted among forest research officers dealing with forest operation. During the meetings of the IUFRO Section 32 in Paris, 1955, it was agreed that «a subjective estimate of performance capacity is a highly unsatisfactory method for use in conjunction with scientific time-studies as long as the work capacity cannot be measured» (IUFRO 1957). Similar conclusions have been arrived at among forest research institutions in forest operation in the Fenno-Scandinavian countries (NSR 1978).

The main purpose of a time or a performance study in forestry is to find out *how the time consumption varies with the influencing factors.* Also in this case it is necessary to eliminate the influence of the operator's or worker's performance capacity especially when the different methods are carried out in different places by different workers.

Time studies should not necessarily give the «normal or standard» time consumption, but should show how the time consumption varies with the influencing factors. It also may give comparable time functions for each of the methods which have taken part in the investigation.

The average time consumption in practical operations for these methods should be based on the average level of the productivity in practice. This may be obtained by means of simple statistics from a great number of operations where the influencing factors also have been recorded. The level of the time functions found in the research operation can then be adjusted by levelling the function according to these statistics in order to find the business or practice level of the time function). (Chapter 3.1.4 and example 14).

3.5. Objective measurement of the workers performance differences

Simplifying the experimental plan and reduction of experimental size are major advantages which could be achieved *if* the establishment of a proper rating could be accurately and simply achieved (HILF 1957, PLATZER 1967, LANDSCHÜTZ 1967, APPELROTH 1982).

It is obvious that if most of the variation in the performance capacity of the workers could be eliminated, the necessity of a large sample would be greately reduced, in the research operation. Some kind of adjustment for the worker's or operator's individual performance level is needed in order to eliminate the influence of the worker's or the operator's performance capacity on the time consumption. This is necessary in order to find out in which way the time consumption varies with the working conditions described by means of the influencing factors.

The Norwegian Forest Research Institute has tried out some methods of *measuring the differences in the workers or operators performance capacity.* In principal, it is carried out *a comparative study, where the influencing factors are kept as equal as possible in order to compare the workers performance levels.*

The average performance capacity of all the time studied workers in the investigation are calculated. Each worker's performancing rate emerges by figuring out his performance capacity relative to the average performance capacity in the study.

These measured performance rate differences were recorded on a part of the research areas where the conditions (and the influencing factors) were comparable and practically equal. They were then used to adjust all the recorded time consumptions before the treatment of the observations started.

3.5.1. Measurement by means of standard stands

The use of standard stands as a basis of research on performance capacity was carried out in connection with felling and transport of small sized wood by Norwegian Forest Research Institute 1954–1958. The *standard stand method* proved to be suitable for comparing the cutting production in Tynset (Central Norway), and in Kjose (South Norway) (SAMSET 1961). The research operation was conducted by local workers at each location. At each location a standard stand was selected. The standard stands had practically equal working conditions (dimensions, height, terrain etc.). The difference

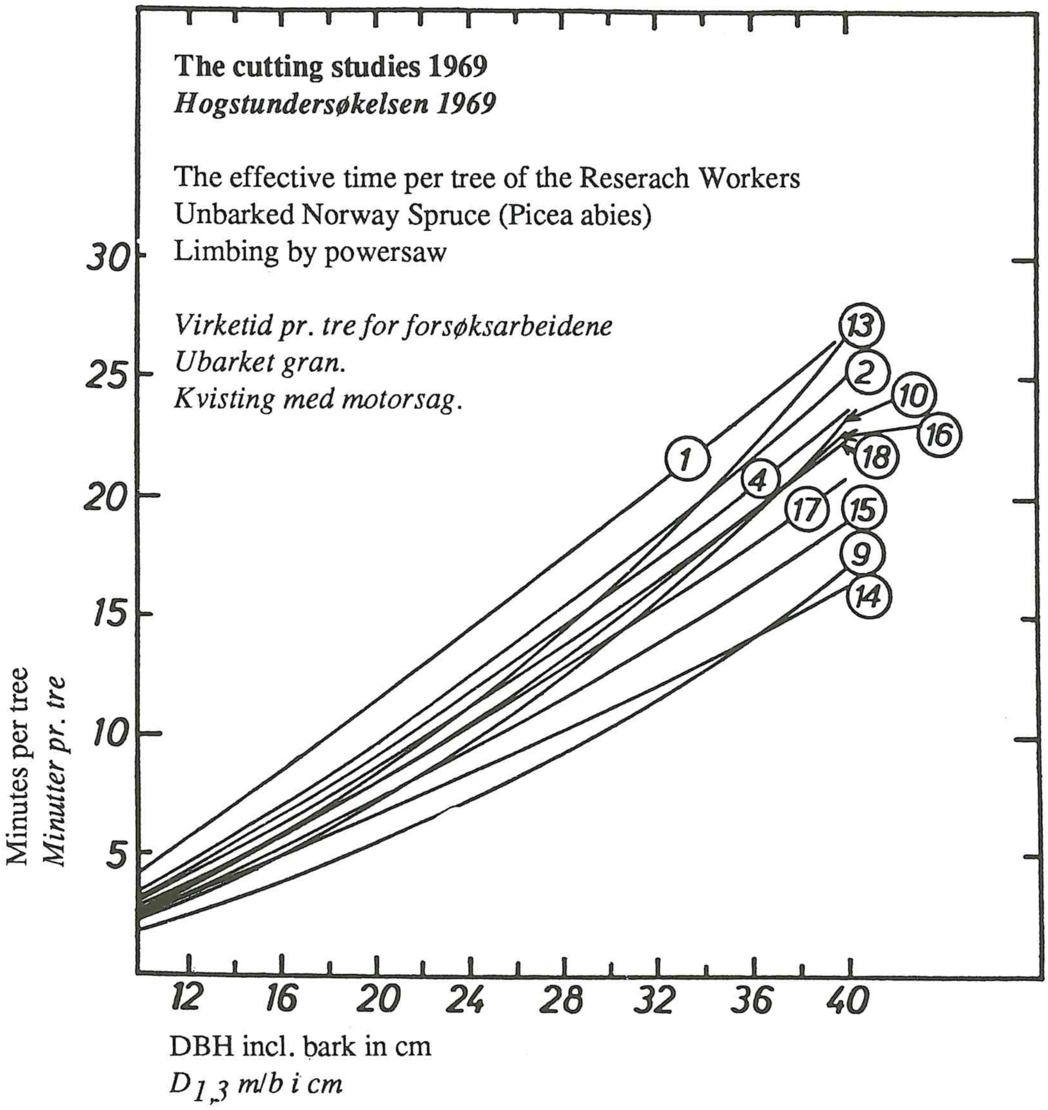


Fig. 23. Variation in the cutters performance capacity. (SAMSET et.al. 1969).
Forskjell i hoggernes ydelsesgrad.

in the workers' performances, therefore, was due to the cutter's performance capacity. By repeating work in the standard stands at regular intervals during the experimental period, one could find the average performance capacity for each of the cutters, and their performance rate in relation to the average performance of all cutters.

The individual cutters time consumption could then be adjusted by the average performance capacity. The systematic errors due to differences in the worker's performance capacity were practically eliminated.

3.5.2. Measurement by means of standard workers

While planning the country wide cutting study in Norway (SAMSET et. al. 1969), several uncertainties were encountered in the choice of standard stands. It was therefore decided to evaluate the cutters individual and average performance capacity by reference to *standard cutters.* («Control» cutters).

The standard cutters were specially selected. They travelled to all cutting areas and worked together with each of the local research cutters in the study one day each time. By repeating the cycle several times during the research period (one year), we could determine the differences in production levels between the research cutters in the study and the standard cutters. The research cutters time consumption was then adjusted according to this difference in output.

During each visit the standard cutters and the research cutters in the study completed one day's work using the cutting method which was scheduled according to the experimental plan.

As the visiting standard cutters and the local research cutters worked side by side in the same research plot, the working conditions as regards terrain, stand type and climate, were very similar. Each day's performance capacity for the research cutters in relation to the average production of the standard cutters was then:

$$PR = \frac{EST}{ER}$$

PR = The measured performance rate of the regular cutter.
EST = Ave. effective time for the standard cutters.
ER = Ave. effective time for the research cutters.

The performance capacity of each research worker was adjusted by means of this factor. After adjustment, the data for the time consumption were smoothed by regression analysis.

The use of standard cutters gave a simple method for eliminating the difference in the performance capacity of the research cutters.Two dependable forest workers were selected as standard cutters (cutters no. 17 og 18).

The average of the standard cutters was very close to the average performance capacity of all the cutters who took part in the investigation (Fig. 23).

Table 7. The average performance degree of the research cutters in per cent (Samset et. al. 1969)
Forsøkshoggernes gjennomsnittlige ydelsesgrad i prosent.

Cutter number *Hogger nr.*	Resarch region *Forsøks-område*	Limbing by axe *Øksekvisting*		Limbing by power saw *Motorsagkvisting*	
		DBH = 15 cm	*DBH* = 35 cm	*DBH* = 15 cm	*DBH* = 35 cm
1	Kjose	97	87	74	81
2	»	109	109	88	88
3	Akerholt	118	108	—	—
4	»	130	130	94	94
5	Valebø	103	137	105	130
6	»	125	125	109	109
7	Jeppedalen	118	108	—	—
8	»	102	132	—	—
9	Brandval	—	—	157	133
10	»	133	121	119	98
11	Rendalen	109	109	99	108
12	»	136	107	120	91
13	Meråker	—	—	104	85
14	»	155	137	162	147
15	Bangdalen	136	102	114	114
16	»	109	98	—	—
17	Typehugger	102	102	107	107
18	»	103	103	97	97
19	Steinsjøen	77	62	72	62
20	»	91	90	85	65
21	»	111	103	103	103
23	Jeppedalen	95	95	—	—
24	Meråker	86	86	—	—

The average of the performance capacity of all cutters compared with the average performance capacity of the two standard cutters was 1.07–1.12 when delimbing with axe and 1.01–1.06 when delimbing with power saw. For the individual cutters the spread in performance capacity was between 0.62 and 1.62 (Table 7).

In a cutting study in greek fir and pine forests 1968/69 (Störmnes et al 1972) a similar set of curves as illustrated in Fig. 23, was worked out. The increase of the effective time consumption per tree with increasing tree dimensions was drawn for each of the research workers who participated in the study. The average curve for all research workers was found and each individual worker's time consumption was measured in relation to the average time consumption. This is the same as the measured performance rate in relation to the average time consumption in the study.

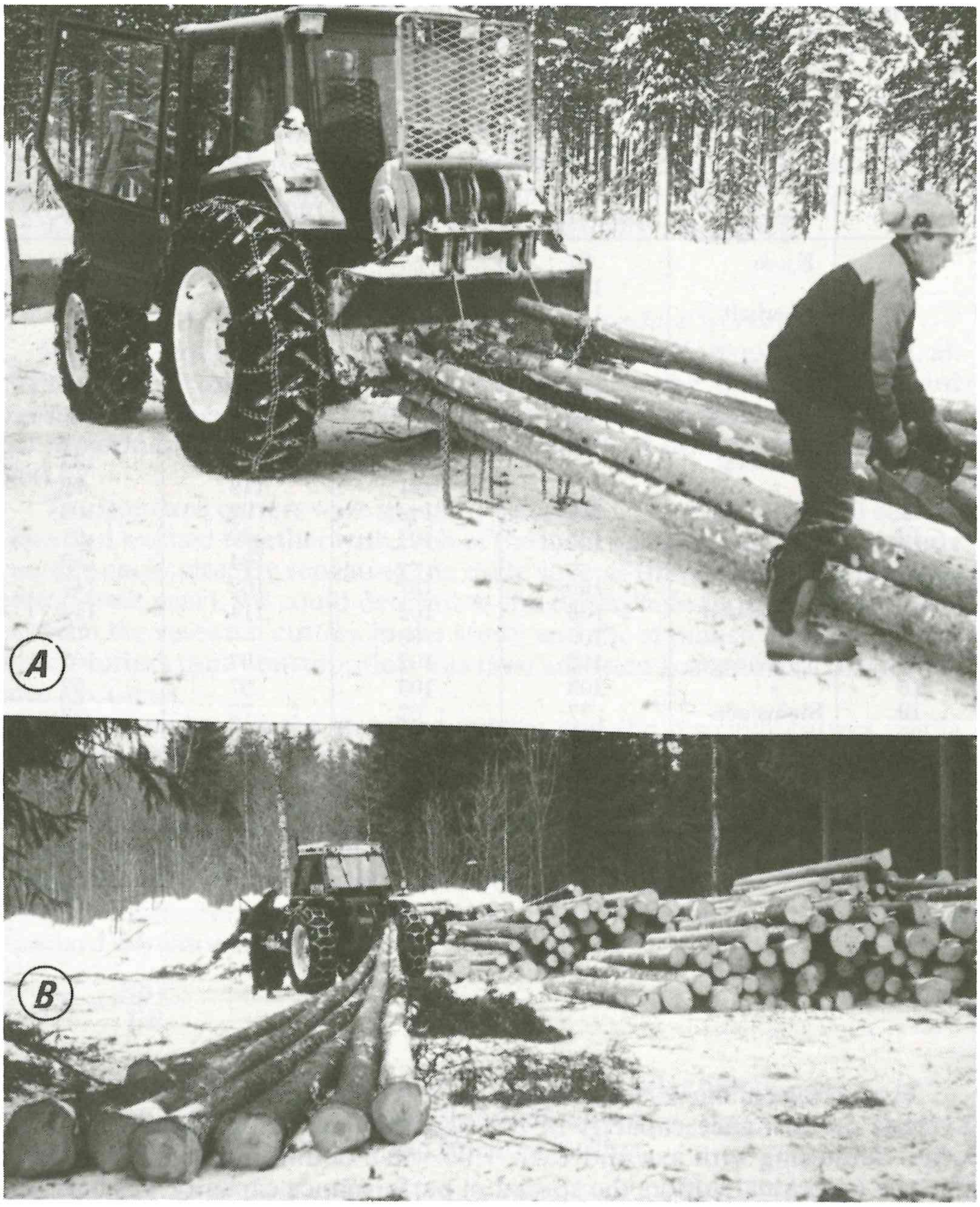


Fig. 24. «Ground» skidding of stems by agricultural tractor. Time studies of tractor tranport. A: Terminal operation. B: Underways operation (Gjedtjernet 1989)
Stammelunning med landbrukstraktor. Fra traktorundersøkelsen A: Terminaloperasjon. B: Undervegsoperasjon.

3.5.3. Measurement by means of standard roads

In the countrywide investigation of the tractor transport, 1986-87 the research operations took place on various research areas from the polar circle to the south of the country. Most tractor types used in practical logging took part in the investigation from the smallest agricultural tractors to the biggest forwarders and skidders. The tractor transport was carried out in the terrain, along skid roads, or along tractor roads between the felling site and the truck road (GJEDTJERNET 1989).

The variation in the operators performance capacity was measured successfully by means of *standard roads.* The standard roads were selected in each of the research areas. The operators had to transport a standard load along the standard road several times during the season (one year), and the underway time with load and without load was recorded as well as the variation in the slope, curvature, road surface etc.

Table 8. Performance degree during the under-way operation for the skidder operators (GJEDTJERNET 1989).
Ydelsesgraden under underveis-operasjonene for førere av lunnetraktor.

Tractor no. *Traktor nr.*	Performance rate (skidding) *Ytelsesgrad (lunning)*			
	Bare ground with load *Barmark med lass*	Bare ground without load *Barmark uten lass*	Compact snow-road with load *Snøpakket veg med lass*	Compact snow-road without load *Snøpakket veg uten lass*
1	1,00	1,02	1,30	1,47
2			1,99	1,71
3			0,90	0,95
4	1,49	1,07	2,11	1,69
5			1,80	1,77
6			1,46	1,62
7	1,23	1,10	0,94	0,78
8			1,55	1,30
9	0,87	0,94	0,76	0,80
10			1,22	1,47
11	1,55	0,92	1,41	1,02
12	1,30	1,87	0,81	1,04
13			0,83	0,71
14	0,83	0,99	0,92	0,95

The transport speeds were little influenced by the size of the tractor. The reason was that the operator tends to use a load size which corresponds to the size of the tractor. It seems that the operator adjust the speed of the tractor mainly according to the road conditions. The resulting variation in the operator's performance capacity is given in Table 8 for ground skidding of stems and in Table 9 for transport with trailer or forwarder.

All the recorded element times were adjusted according to these measured performance rates which are each individual operator's performance capacity in relation to the average of all operators performance capacity in the study. The adjusted element times were used when smoothing the functions of the effective transport times by means of regression analysis.

Table 9. Performance degree during under-way operation for the forwarder operators (GJEDTJERNET 1989).
Ydelsesgraden under underveis-operasjonene for førere av lastetraktorer.

Tractor no. *Traktor nr.*	Performance rate (caaried load) *Ytelsesgrad (båret lass)*			
	Bare ground with load *Barmark med lass*	Bare ground without load *Barmark uten lass*	Compact snow-road with load *Snøpakket veg med lass*	Compact snow-road without load *Snøpakket veg uten lass*
1	2,40	2,33	1,32	1,35
2	0,84	0,71	1,12	1,07
3			0,86	0,92
4	0,89	0,79	1,08	1,16
5			1,01	0,82
6	1,33	1,00	1,35	1,22
7	1,19	1,52	1,03	1,59
8	0,89	1,28	0,87	0,96
9	0,96	0,85	0,82	0,92
10	0,96	0,96	0,82	0,70
11	0,95	0,97	1,00	0,86
12			1,63	1,73
13	0,81	0,79	0,87	0,80
14	0,77	0,90	1,00	1,03
15	0,76	0,86	0,64	0,67
16	1,19	1,33	1,36	1,33
17	0,93	0,89	1,43	1,25
18	1,30	1,32	1,03	1,05
19	0,95	0,83	1,04	1,07
20			0,96	1,19
21	2,17	2,36	0,72	0,76

3.5.4. Measurement by means of standard landings

In the investigation described in chapter 3.3. and 3.5.3. the variation of the operator's performance capacity during loading and unloading was measured by means of standard landings. As an example may be mentioned the results from loading and unloading by means of hydraulic knuckleboom loaders.

On each of the research areas standardized piles and standardized landings were laid out at each end of the standard road. The working conditions were practically equal and the logs had the same size in all of the standard piles and landings. Since the tractors and hydraulic loaders varied in size we found that the variation on the performance capacity varied with the size of the hydraulic loader and the operator. (GJEDTJERNET 1989).

The operation of these loaders was partly machine-steered and partly man-steered. Since the problem was to find an acceptable average for loaders used in practical forestry various measures were measured which could be used for the adjustment of performance differences due to the machine steered part of the terminal operation. Factors, such as crane length, lifting torque, power of the oil delivery etc. were tried out. The factor which gave best result was Q · kW which is the crane weight (Q) multiplied with its power (kW). After the adjustment of the machine-steered part of the loading operation by means of this factor, the remaining man–steered part was used for the adjustment of performance differences due to the operators, as illustrated in Table 10. The recorded element times during loading and unloading were adjusted by means of these measured performance rates before smoothening the loading and unloading times with regression analysis.

3.5.5. Measurement by means of standard testing machine

New developments have brought about forestry machines for complex multi-element operations. These are machines which carries out several work elements within one operation simultainously, and are sometimes called «Multi-function machines» (MELLGREN 1989), (limbing-, bucking– and harvesting machines, chipping machines etc.) These have often advanced cabins with ergonomically well–designed work places for the operators.

Each operator must be trained to maintain a high productivity, qualitatively as well as quantitatively. The productivity depends much on the operators experience, working techniques and efficiency. It is difficult to measure the differences in various operators performance capacity because it partly depend on the machine-steering and partly on the man-steering. The machine's high production potential increase the operators performance variations in a postive as well as in negative direction.

The time-keeper, therefore, meets enormeous difficulties in trying to estimate the performance rate subjectively, even more than in simple manual work. The measurement of differences in the operators performance capacity is also difficult because the working conditions varies from one machine to another.

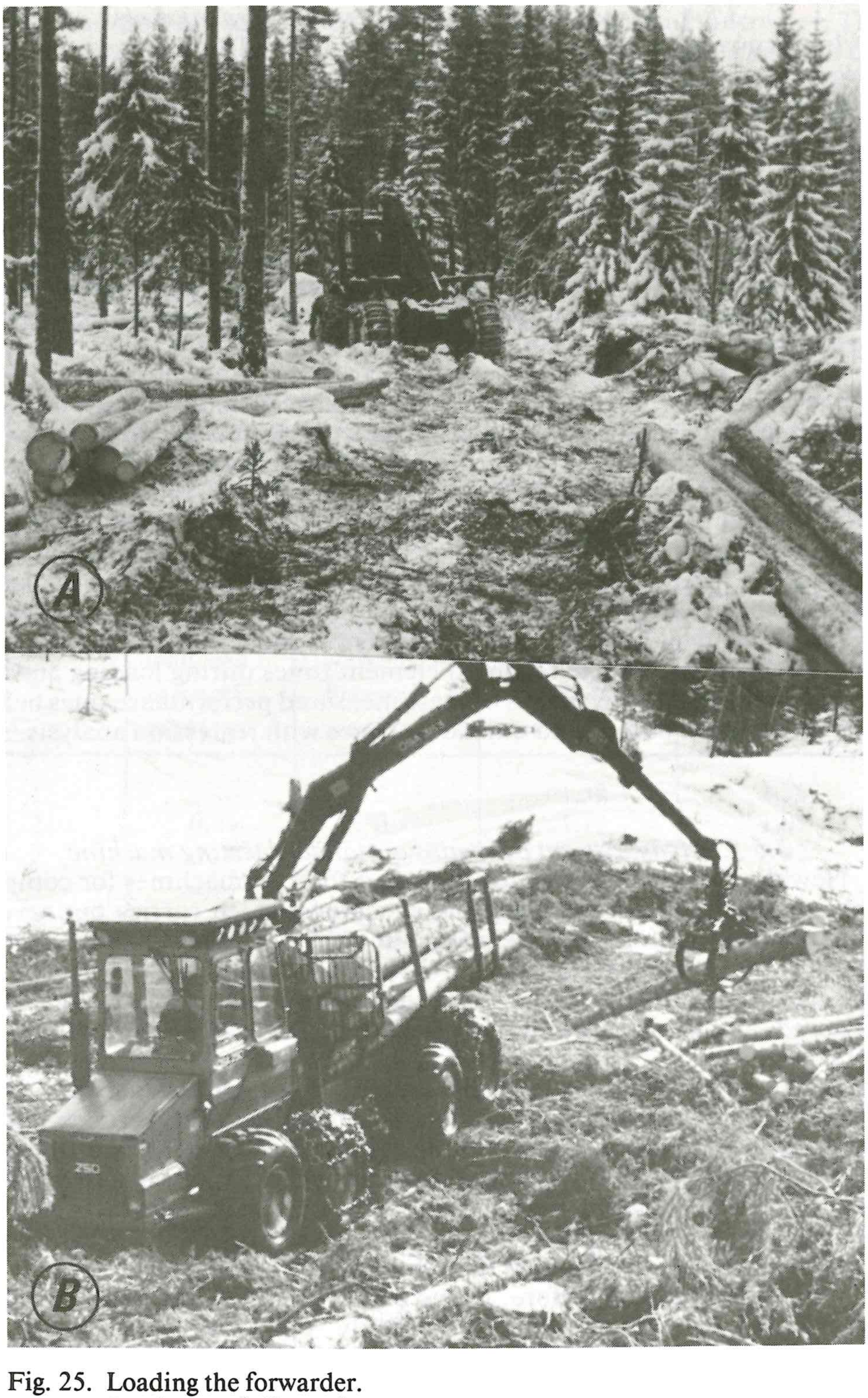


Fig. 25. Loading the forwarder.
Lasting med vikarm kran.

The experiences we have received during 40 years with forestry work and time studies have led us to the following hypothesis:

1. Instead of measuring the performance differences of operators on various machines the operator can work on a test machine under standardized working conditions. The operator's cabin in the standard task test machine is constructed in such a way that the working conditions are similar but not identical to the multi-element or the multi–function machines in the research programme.

Table 10. Performance degree during the terminal operation for the forwarder operators (GJEDTJERNET 1989).
Ydelsesgraden under terminaloperasjonene for førere av lastetraktorer.

Tractor no. *Traktor nr.*	Performance rate (carried load) *Ytelsesgrad (båret last)*	
	Loading *Lasting*	Unloading *Lossing*
1	1,10	1,19
2	1,09	1,07
3	1,26	1,14
4	1,03	1,08
5	1,11	1,03
6	0,86	0,80
7	0,76	0,90
8	1,44	1,03
9	1,25	0,95
10	1,01	0,93
11	0,97	0,90
12	1,28	1,08
13	1,01	1,04
14	0,92	0,90
15	0,93	1,16
16	0,83	0,93
17	1,27	1,39
18	1,87	1,06
19	0,68	0,73
20	1,43	1,37
21	0,73	0,69

In spite of the fact that the work is not identical with the operation of the various multi-element machines the various operators meet the same working condition in the test machine. The various operators performance capacity in the testing machine give an *indication* about his performance capacity when he operates the multi-element machine.

2. The operator should execute a standard working programme (standard task) with the test machine. This will give an indication of his performance capacity in relation to the average of all the operators in the research programme.

This hypothesis is based on our experiences with measurement of performance capacities. In order to test the hypothesis we have build a testing machine at The Norwegian Forest Research institute.

A hydraulic knuckleboom loader is mounted on a trailer. A separate diesel engine on the trailer powers the loader. The worker operates the crane in a cabin with well designed operator's seat and control system.

As soon as the test programme has been worked out the testing trailer can be transported from one research operation to another. The local operator can carry out the test programme which will give a pointer about his performance rate in relation to the average rate of all operators in the research programme.

Fig. 26. The trailer-mounted test machine for measuring performance differences, may be transported after a tractor or a truck to the research area.
Den tilhengermonterte testmaskin for måling av ydelsesgradsforskjeller kan bli transportert etter traktor eller bil til forssøksområdet.

4. Erfaringer angående tids– og prestasjonsstudier i skogbruket

Undersøkelser av driftsmetodenes produktivitet eller prestasjoner omfatter vanligvis tidsstudier eller andre former for registrering av tidsforbruket og måling av forhold og vanskelighetsgrader som påvirker tidsforbruket. Det gjelder å finne frem til lovmessigheter angående hvorledes tidsforbruket varierer med påvirkende faktorer, ofte i form av tidsfunksjoner.

Statistiske metoder for bearbeiding av materialet og regressjonsanalyser er beskrevet i statistiske lærebøker og blir ikke nærmere diskutert i dette arbeidet. Isteden vil vi konsentrere oss om overføring av subjektive kvalitative påvirkende faktorer til kvantitative målbare kjennetegn og hvorledes man kan komme frem til hensiktsmessige logiske funksjonstyper som forteller noe om hvorfor og hvorledes tidsforbruket varierer med arbeidsforholdene der driftsmetodene har vært undersøkt.

Det finnes dataprogrammer for et stort antall funksjoner som kan gi en bra utjevning innen punktsvermen av de tidene som er observert. En slik bearbeiding gir vanligvis ikke forklaring på hvorfor tidene varierer med de påvirkende faktorene. Isteden bør forskeren komme frem til logiske funksjoner der han bygger på sin kunnskap om skog, terreng, klima og driftsmetoden samt sine iakttakelser under markarbeidet. I virkeligheten er en god planlegging og bearbeiding av et forsøk først og fremst avhengig av forskerens kunnskaper, fantasi, intelligens og arbeidsevne.

I den driftstekniske forskning har vi siden 1947 publisert over 100 større vitenskapelige analyser av korrelasjonsstudier og over 290 vitenskapelige arbeider angående sammenlignende studier. I nærværende arbeide har jeg forsøkt å samle noen erfaringer fra denne 40-årige virksomhet som kanskje kan være til nytte for kommende generasjoner av forskere på området.

4.1. Kvalitative og kvantitative påvirkende faktorer

Noen av de influerende faktorene er objektivt målbare. Det er de kvantitative faktorene (diameter, høyde, bratthet m.v.). Andre er kvalitative faktorer som må bedømmes subjektivt. Forskeren bør søke å omarbeide dem til kvantitative eller målbare faktorer.

En fremgangsmåte som er beskrevet av BERGSTRAND (1987) er å bruke dummyvariabler. Man kan anvende en faktor der furu = 0, gran = 1 eller stor traktor = 0, liten traktor = 1 m.v. Fremgangsmåten kan også brukes for tre dummyvariable. Fremgangsmåten er vist i kapitel 2.1. (Formel 1, 2, 3 og 4).

En annen fremgangsmåte er å fremstille et kvalitativt kjennetegn med klassevariabler der det er lik avstand mellom klassene. Fremgangsmåten er vist i eksemplene 1, 2 og 3 for terrengklassenes vedkommende. På grunnlag av studier der man hadde talt opp antall ujevnheter pr. hektar kom man frem til ujevnhetsklassene (Tabell 1) som gav uttrykk for vanskelighetsgradene ved terrengkjøring.

Eksempel 4 gjelder markens bæreevne. Man kan måle egenskaper ved jordens kornsammensetning og fuktighetsforhold for indirekte å finne frem til et klassifiseringsgrunnlag. Eksemplet viser hvorledes LÖFFLER i Syd-Tyskland kom frem til 5 bæreevneklasser på denne måten. (Tabell 2).

Kvistmengdens betydning for hogstarbeide med gran– og furutrær ble opprinnelig bedømt gjennom kvalitative kjennetegn i form av subjektivt bedømte skogklasser. KLEM (1934) fant at det var en sammenheng mellom trærnes avsmalning og kvistmengden på trærne (Eksempel 5, Fig. 3). SAMSET (1950) utnyttet denne erkjennelsen til å beskrive trærne ved hjelp av *relativ høyde* som er det enkelte tres høyde i forhold til en valgt gjennomsnittlig høgdekurve (Fig. 4). Det viste seg at det var en god sammenheng mellom den relative høyde og tidsforbruket under kvisting, kapping m.v.

Det er viktig at forskeren bruker tid på å analysere de kvalitative påvirkende faktorene, som bare kan bedømmes skjønnsmessig. Hvis ingen annen mulighet foreligger kan de kvantifiseres ved hjelp av dummyfaktorer eller klassevariabler. Fremgangsmåten er imidlertid ikke god før man får erstattet de kvalitative kjennetegnene med målbare faktorer som direkte eller indirekte gir uttrykk for størrelsen av de kvalitative kjennetegnene.

4.2. Valg av logiske funksjonstyper

De kvantitativt målbare faktorene er enklere å ha med å gjøre. Også her er det viktig at forskeren søker å finne logiske sammenhenger mellom faktorene og tidsforbruket (eksempel 6 og Fig. 5).

Under fellingen av et tre skjærer sagtennene av trefibrene på undersiden og oversiden av sagskåret og transporterer flisen ut. Derfor varierer sagetiden med arealet av stubbe-avskjæret. Dette er direkte proporsjonalt med kvadratet av brysthøydediameteren som vist i eksempel 7, (Figur 6 og 7).

Når man kjører med meiedoning på fast snøveg vil trykksmeltingen føre til at det er en halvt flytende og halvt tørr friksjon. Meien glir godt på underlaget. Stanser meien vil den fryse fast til underlaget. Det skyldes at det blir stort spesifikt trykk på de enkelte snøkorn. Ved et spesifikt trykk på 3000 kp/cm^2 smelter snøen ved -21°. Smeltevannet fryser meiene fast til snøkornene med en gang. Etter fastfrysingen fortsetter sublimasjonsmetamorfosen ved at vannmolekyler vandrer fra porevolumet i snøen og fester seg dels til meien og dels til snøkornene. Denne delen av sammenfrysningen går langsomt. Kunnskaper om smeltemetamorfose og sublimasjonnmetamorfose førte til at forskeren i dette tilfellet kunne velge en logaritmisk funksjon for å finne hvorledes startfriksjonskoeffisienten varierte med tiden for stans slik det er beskrevet i eksempel 10 og Figur 12, 14 og 15.

I et anet tilfelle (eksempel 9) var problemet å finn ut hvor lang tid et lass brukte for å falle ned til vannflaten etter at det var løst ut fra helikopteret i stor høyde (Fig. 9, 10 og 11). Ved å ta utgangspunkt i den vanlige formelen for hastigheter under fritt fall og den motstand tømmerlasset møtte under sin ferd gjennom luftlagene kom vi frem til en generell funksjon for hastigheten (Formel 24). Denne ble utjevnet etter miste kvadraters metode ved regressjonsanalyse for å finne en god plassering i forhold til de observerte hastighetene (Formel 25 og Fig. 10).

* * * * * *

Disse eksempler viser hvorledes forskeren på grunnlag av sin kunnskap om skog, terreng, klima og metode kommer frem til en hensiktsmessig funksjonstype før utjevningen begynner. Deretter utjevnes denne funksjonstypen innen de registrerte observasjonene for å komme frem til en god kvantifisering av den valgte funksjonstypen. I mange tilfeller kan mer enn en funksjonstype komme på tale og valget mellom dem skjer i så fall etter vanlig statistiske regler. Det hender at en funksjonstype bare beskriver forholdet mellom tidsforbruket og den påvirkende faktoren innenfor et visst område, mens den er ubrukelig utenfor. Derfor må man oppgi hvilket område funksjonene gjelder for. (fra X_1, til X_2 i Fig. 17).

4.3. Deltidsfunksjoner og virketid (E_0)

Ved tidsstudier observerer man tidsforbruket for de enkelte deloperasjonene og finner frem til den funksjonelle sammenheng mellom de påvirkende faktorene og tidsforbruket ved hver enkelt deloperasjon. Årsaken til dette er at de enkelte deloperasjonene påvirkes av forskjellige faktorer. Gang mellom trærne påvirkes av avstanden mellom trærne, mens fellingen påvirkes av tre-dimensjone. Hvis man bare slår sammen samtlige deltider og utjevner hele virketiden under ett vil man kunne miste innflytelsen av enkelte påvirkende faktorer. Disse øver stor innflytelse på den enkelte deltid, men innflytelsen er liten i forhold til spredningen av hele virketiden.

Det er viktig å studere virkningen på deltidene av de enkelte påvirkende faktorer fordi dette kan ha betydning såvel for videre utvikling av arbeidsmetodene som for rasjonalisering av hele arbeidsprosessen.

Den samlede virketiden fremkommer som en summering av deltidene. Det kan skje med en oppsummering av regressjonskoeffisientene for de forskjellige deltider innenfor hver av de påvirkende faktorene. (Tabell 4).

Det er viktig å undersøke om den endelige funksjonen passer godt i hele materialet. (Eksempel 11) Dette ble gjort under hogstundersøkelsen (SAMSET et al. 1969). Virketiden for hvert av de 25.363 trær ble beregnet ved hjelp av sumasjonsformelen for virketiden. De beregnede virketidene ble sammenlignet med observasjonene fra tidsstudiematerialet. Det viste seg at virketidsfunksjonen ga en god beskrivelse av tidsforbruket under hogst.

4.4. Arbeidsrekkefølge

Alle arbeidsoppgaver blir realisert gjennom en produksjon, og i skogbruket omfatter den sekundære skoproduksjonen innsatsen av mennesker og maskiner i skogbrukets tjeneste. Hver skoglig arbeidsoppgave omfatter en *prosess* som dels er *menneskestyrt* og dels er *maskinstyrt.* Man taler om forskjellige *mann–maskinsystemer* som kan analyseres ved hjelp av en *systemanalyse.* Som regel fører dette bare frem til en *begrunnet hypotese* om hvilke resultater man bør kunne forvente ved forskjellige fremgangsmåter.

Hvis et statisk mann-maskinsystem settes i virksomhet får man en dynamisk *driftmetode* som kan analyseres gjennom *tidsstudier* og *produktivitetsmålinger*.

Oftest blir en *prosess* delt opp i *arbeidsoperasjoner* f.eks. terminaloperasjoner (lessing og lossing) og underveiseoperasjoner (tur og returkjøring) under en transport. Hver arbeidsoperasjon består av en rekke *deloperasjoner* og summen av deltidene er virketiden for hver av arbeidsoperasjonene.

Under forutsetning av at man har justert virketidene innen hver arbeidsoperasjon for yteselsesgradsforskjeller hos arbeidskraften kan man summere virketidsfunksjonene for samtlige arbeidsoperasjoner innen en *arbeidsrekkefølge*. Da tapstidene kan variere fra en arbeidsoperasjon til en annen, er det en fordel å legge tapstidene til virketidene, slik at man summerer tidsfunksjonene for arbeidsplasstiden. (Fig. 19)

Slike tidsfunksjoner for hele arbeidsrekkefølgen kan brukes til optimalanalyser. *Eksempel 12* viser et eksempel på en slik analyse, der vi har undersøkt hvilken stripebredde som gir lavest mulige kostnader når man tar hensyn både til monteringen og driften av taubanene (funksjonene 33, 35, 36 og 38).

4.5. Materialets størrelse

Materialets størrelse kan beregnes ved å gjennomføre et prøveforsøk foran den egentlige forskningsoppgaven for å finne en foreløpig størrelsesorden av observasjonenes spredning. Det finnes regler i statistiske lærebøker for hvorledes man på det grunnlaget kan beregne hvor stort materialet bør være.

Etter 40 års arbeide med prestasjonsanalyser har vi funnet frem til erfaringstall som kan være til hjelp under planleggingen av hvor omfattende forsøket bør være. Behovet for observasjoner beror på antallet av påvirkende faktorer (uavhengig variable). Som regel vil man velge tre grupper observasjoner innenfor hver påvirkende faktor. (Liten, middels og stor dimensjonsklasse, høy, middels og lav relativ høyde. Flatt, middels bratt og meget bratt terreng o.s.v.) En slik tredimensjonal gruppering gjør det mulig å analysere om det foreligger en rettlinjet eller krumlinjet sammenheng mellom påvirkende faktorer og tidsforbruket. (se Fig. 22) Innenfor hver gruppering vil det foreligge en viss spredning av observasjonene. Det er f.eks. mange tredimensjoner innenfor en gruppering av stort sett små trær.

Vi er kommet frem til at det trenges ca. 10 arbeidsobjekter innenfor hver gruppering for hver av de påvirkende faktorene. Er det liten variasjon kan man gå ned til 5 arbeidsobjekter.

Om man under planleggingen ønsker å ta med mange påvirkende faktorer kan denne regel føre til behov for et meget stort antall observasjoner. I så fall må planen revideres, i det man bare tar med de viktigste faktorene i hele prestasjonsanalysen. Da velger man ut forsøksfeltene slik at det er liten variasjon i de mindre betydningsfulle faktorene. Deretter planlegger man en tilleggsanalyse på et utvalg av felter der man undersøker økningen av tidsforbruket på grunn av vanskeligshetsklassene for de mindre betydningsfulle påvirkende faktorene. Eksempel 15 gir et eksempel på fremgangsmåten.

Under planleggingen av hogstundersøkelsen (SAMSET et. al. 1969) kom vi først frem til et behov av arbeidsobjekter på ca. 300.000 trær. Ved å revidere planene, slik at hovedanalysen ble begrenset til hogst av ubarkede trær på pent terreng og ta hensyn til andre bearbeidingsmetoder, hogst i bratt terreng o.s.v. som tilleggsstudier, ble materialbehovet redusert til ca. 30.000 trær. Tidsstudiemennene fulgte en timeplan som var satt opp på forhånd og resultatet ble 25.363 trær.

Korrelasjonsstudiene er de mest omfattende fordi man analyserer hvorledes virketidene varierer med mulige påvirkende faktorer. Slike studier bør bare gjennomføres for metoder som er innarbeidet i praksis. (etter fase IV i Fig. 20).

I andre tilfeller er analysen en sammenligning av nye driftsmetoder. Da anvendes et *sammenligningsstudium,* idet formålet er å sammenligne to eller flere nye maskiner eller driftsmetoder (BERGSTRAND 1987). Man velger forholdsvis sammenlignbare skog– og terrengforhold. I virkeligheten betyr det at man kan redusere antall påvirkende faktorer. Derved kan studiet gjennomføres med forholdsvis få observasjoner. Sammenligningsstudiet blir ofte tatt i bruk for å undersøke hvilke av nye driftsmetoder man bør arbeide videre med. (Fig. 21). De settes ofte inn i fase II, Fig. 20.

4.6. Arbeidsplasstid og tjenestetid

Det man kommer frem til gjennom deltids-studiet er virketiden. Det er imidlertid arbeidsplasstiden som gjelder i praksis. Dette er hele den tiden arbeideren med sine maskiner er i arbeide på arbeidsplassen. Man må legge de nødvendige tapstider til virketidene.

$$W_0 = (1 + p_w) E_o$$

I løpet av sesongen må arbeidskraften utføre en del andre nødvendige operasjoner i tillegg til arbeidsplasstiden: Igangsetting og istandgjøring før arbeidet kan ta til på et felt, transport mellom arbeidsplassene, transport til feltet fra garasjen hver enkelt dag, arbeidsstans på grunn av klima m.v. Summen av arbeidsplasstiden og de periodefaste eller periodevariable hjelpetidene er tjenestetiden, som er grunnlag for betaling for arbeidet. (Fig.19)

$$T_0 = (1 + p_d)W_0$$
$$T_0 = (1 + p_w)(1 + p_d)E_0$$

I hogstundersøkelsen var tapstidsprosentene 27,7 %, mens tjenestetidsprosenten var 18,9 %. (Eksempel 14) Dette ble undersøkt innenfor tidssudiesesongen. Tidsstudiemennene samlet inn dagstatistikk fra samtlige arbeidere. De utvalgte forsøksarbeiderne ble tidsstudert i form av stikkprøver gjennom hele driftssesongen. Tillegget til virketiden for å få tjenestetiden var altså 51,8 % av virketiden:

$T_0 = 1.2771 \cdot 1.189 \cdot E_0$
$T_0 = 1.518 \cdot E_0$

Såvel tapstidene som tjenestetidstillegget beror tildels på tilfeldige årsaker, slik at de varierer sterkt. Det trengs et stort materiale for å få gode verdier.

Ved *korrelasjonsstudier* er studieperioden lang fordi man trenger et stort materiale for å få virkningen av alle påvirkende faktorer. Vanligvis er den tilstrekkelig lang til at man får brukbare verdier også for tapstidsprosentene (p_w) og tjenestetidstillegget (p_d).

Ved *sammenligningsstudier* blir det få påvirkende faktorer fordi man prøver å sammenligne metodene under forholdsvis like betingelser. Da kan materialet bli for lite til en god analyse av tapstider og tjenestetidstillegg. Ved publisering av slikt materiale, blir man begrenset til virketider. Hvis noen forsøker å regne ut prestasjoner på grunnlag av virketidsforbruket kan de få forhåpning om at metodene gir mulighet for høyere prestasjoner enn man kan regne med i praksis. Dette forhold har ført til et behov for å samle erfaringer for tapstidenes og tjenestetidstilleggets størrelse. Slike erfaringstall kan samles inn fra forskjellige undersøkelser som omfatter forskjellige forhold, maskintyper og metoder. Forskningsinstitusjonene kan samle erfaringstallene for tapstider og tjenestetidstillegg i et bibliotek, f.eks. en databank som støtter forskere i deres arbeide. Derved vil forskeren kunne gi det utøvende skogbruk en antydning om de undersøkte metodenes prestasjoner under arbeidsplasstiden og under hele tjenestetiden.

Ofte vil tjenestetidstillegget være av størrelsesorden 50-55 % av virketiden for manuelle og motormanuelle metoder, mens mekaniserte driftsmetoder vil ligge noe høyere, gjerne 55-60 % av virketiden. De høyeste tilleggene til virketiden får man ved nye driftsmetoder og maskiner fordi reparasjoner og vedlikehold blir fremherskende og fordi mannskapet mangler den nødvendige teknikk og rutine, sammenlignet med metoder som har bred anvendelse i skogbruket.

4.7. Ytelsesgraden

Skogsarbeiderens eller maskinførerens arbeidsevne varierer for de forskjellige arbeidsmetodene, særlig fordi noen av arbeidsmetodene er *menneskestyrte* (manuelt eller motormanuelt arbeide), mens andre arbeidsmåter er mer eller mindre *maskinstyrte.* Ved en fjernstyrt eller selvstendig arbeidende robot er arbeidet i det vesentlige maskinstyrt. (Tabell 6)

I større korrelasjonsundersøkelser er det en fare for at noen arbeidere deltar under enkelte vanskelighetsforhold (influerende faktorer), mens andre av arbeiderne deltar under andre arbeidsforhold der andre influerende faktorer forekommer. Om arbeidskraften har forskjellig ytelsesgrad vil ytelsesgradsforskjellene øve innflytelse på tidsfunksjonene. Da får man ikke et korrekt bilde av hvorledes tidsforbruket varierer med de influerende faktorene.

4.8. Subjektiv ytelsesvurdering

Man kan justere for arbeidernes ytelsesgrad ved en skjønnsmessig ytelsesvurdering. Det går ut på at tidsstudiemannen foretar en skjønnsmessig vurdering av arbeiderens ytelsesgrad samtidig som han tidsstuderer. Han gir en karakter som ofte varierer fra ca. 1,3 for de dyktigste arbeiderne til 0,8 for den svakere arbeidskraften. Karakteren 1,0 skulle gjelde for en gjennomsnitts arbeider. Metoden har vært anvendt under tidsstudier i industriell serieproduksjon der arbeidsforholdene er forholdsvis oversiktlige, f.eks. MTM-metoden.

Skjønnsmessig ytelsesvurdering brukes lite i skoglig arbeidsforskning, men har vært anvendt bl.a. i Storbritania og Tyskland (WITTERING 1973). Man forsøker å støtte tidsstudiemannens skjønn ved standardisering av arbeidsmetoder og ved film– eller videoopptak. APPELROTH (1982) har forsøkt metoden ved forholdsvis oversiktlige arbeidsmetoder innen skogplantingen.

STEINLIN (1955) gjennomførte en undersøkelse for å studere brukbarheten av skjønnsmessig ytelsesvurdering. Han kom frem til følgende konklusjoner:

1. For hver enkelt deloperasjon varierer arbeiderens ytelsesgrad i løpet av arbeidsdagen, fra dag til dag og gjennom sesongen. Variasjonene er ikke systematiske og blir påvirket av menneskets helse, temperament og av arbeidsmiljøet.
2. En arbeiders ytelsesgrad varierer fra en deloperasjon til en annen. Variasjonen er forskjellig for de forskjellige arbeidere. En arbeider kan ha høy ytelsesgrad under et arbeidsmoment, men lav ytelsesgrad under et annet. Det motsatte kan være tilfelle for en annen arbeider.
3. For en og samme deloperasjon er ytelsesgraden forskjellig for de forskjellige arbeidere. Den psykologiske virkning på ytelsesgraden er også forskjellig for forskjellige arbeidere. Noen har noenlunde stabil arbeidskapasitet mens andre er labile.
4. Hvis arbeiderne i en gruppe har forskjellig ytelsesgrad, kan det bli spenningsforhold mellom dem. Enkelte arbeidere lar seg påvirke i sin ytelsesgrad av de mer stabile arbeidere.

Disse forhold viser at det er vanskelig for en studiemann å gjennomføre en tilfredsstillende skjønnsmessig vurdering av ytelsesgraden. Dertil kommer at arbeidsbetingelsene varierer sterkt med skog, klima og terrengforhold og med de forskjellige arbeids metodene. Ytelsesvurderingen blir uoversiktlig. Dette er understreket av en rekke forfattere (SAMSET 1950, MATTSON MÅRN 1953, MAKKONEN 1954, HÄBERLE 1967). Under et møte i den driftstekniske seksjonen av IUFRO i Paris i 1955 ble det understreket at skjønnsmessig ytelsesvurdering er subjektiv og bør ikke anvendes i skoglig arbeidsforskning (IUFRO 1957). Det samme prinsipp er stadfestet av medlemsorganisasjonene innen Nordiska Skogsarbetsstudiernas Råd (NSR 1978).

4.9. Objektiv måling av ytelsesgradsforskjeller

Ettersom skogsarbeiderne eller maskinførerne har forskjellig ytelsesgrad har mange forfattere understreket betydningen av å justere for ytelsesgradsforskjellene (HILF 1957, PLATSER 1967, LANTSCHÜTS 1967, APPELROTH 1982). Da en skjønnsmessig ansettelse av ytelsesgrad og ytelsesgradsforskjeller byr på store vanskeligheter og dessuten er subjektiv bør den ikke anvendes i vitenskapelig arbeidsforskning. Det er nødvendig å finne et alternativ.

Formålet med tidsstudiet er å finne den funksjonelle sammenhengen mellom arbeidsbetingelsene eller de influerende faktorene på den en side og tidsforbruket for deloperasjonene på den annen side. Prestasjonsnivået vil i alle tilfelle gjelde for det gjennomsnittlige nivået blant forsøksarbeiderne.

Det endelige nivå som bl.a. kan brukes til analyse av arbeidskraftbehov, maskinkraftbehov eller som grunnlag for økonomiske kalkyler og prissetting, må være et gjennomsnittstall for samtlige arbeidere i skogbruket. Arbeidsgiver og arbeidstaker vil ha forskjellig oppfatning av hvilken arbeidskraft som skal brukes til en slik vurdering av gjennomsnittsnivået. Det kommer man frem til gjennom forhandlinger og eventuell landsomfattende statistikk. Forskerens oppgave blir derfor å finne hvorledes tidsforbruket varierer med arbeidsbetingelsene, mens det er en forhandlingssak senere å justere nivået for prestasjonene. Dette prinsipp ble allerede lansert av MATTSON MÅRN i 1953.

For å komme frem til brukbare funksjoner for sammenhengen mellom de avhengig og uavhengige variabler kan man gjennomføre en målemessig justering av ytelsesgradsforskjellene ved tidsstudier av arbeidskraften under forhold der de influerende faktorene er like. Dette kan skje ved kortvarige studier som stikkprøver på prøveflater gjennom hele forsøksperioden. De ytelsesgradsforskjellene man da kommer frem til brukes til justering av de observerte deltidene. Tidsfunksjonen for sammenhengen mellom de influerende faktorene og tidsforbruket blir derfor gjennomsnittsfunksjonen for samtlige arbeidere som deltar i forsøket. I det følgende gis det en del eksempler på målinger av ytelsesgradsforskjeller.

4.9.1 Måling av ytelsesgradsforskjeller ved hjelp av typebestand

Anvendelse av typebestand til måling av ytelsesgradsforskjeller ble brukt i forbindelse med de småvirkeforsøk som Det norske Skogforsøksvesen gjennomførte i 1954/58. En gruppe skogsarbeidere arbeidet i Tynset (Midt-Norge) og en annen gruppe i Kjose (Syd-Norge). Det viste seg at typebestandsmetoden var en god måte til en analyse av skogsarbeidernes ytelsesgradsforskjeller (SAMSET 1961). På hvert sted var det valgt ut noen type-bestand som hadde omtrent de samme arbeidsbetingelser hva skogsmarkens jevnhet, bratthet, tredimensjon og relativ høyde angår. I løpet av forsøkene som varte et år, arbeidet de lokale skogsarbeiderne i typebestandene med jevne mellomrom. Derved hadde man grunnlag for en analyse av forskjeller i prestasjonene under ellers like arbeidsbetingelser. Det gav grunnlag for å beregne de enkelte skogsarbeideres ytelsesgrad i forhold til gjennomsnittsprestasjonen for samtlige skogsarbeidere som deltok i forsøket. De ytelsesgradsforskjellene man på den måten kom frem til ble brukt til å justere hele tidsstudiematerialet i Tynset og i Kjose.

4.9.2 Måling av ytelsesgradsforskjeller ved hjelp av typearbeidere

Under den landsomfattende hogstundersøkelsen i Norge var det valgt ut hogstfelter over hele Øst-Norge, fra polarsirkelen til Syd-Norge (Samset et.al. 1969). På hvert sted arbeidet lokale hoggere, men det var vanskelig å finne sammenlignbare typebestand.

Isteden ble det valgt ut to typehoggere. En ble pekt ut av Skogbrukets Arbeidsgiverforening og den andre av Norsk Skog og Landarbeiderforbund. Typehoggerne besøkte samtlige hoggere som var med i undersøkelsen. På hvert sted arbeidet de sammen med de lokale hoggerne. Slik fortsatte analysen ved at typehoggerne besøkte samtlige forsøksbestand og forsøkshoggere over hele landet flere ganger i løpet av den ett-årige forsøksperioden.

Etter som de besøkende typehoggerne og den lokale hogger arbeidet side om side på samme hogstfelt i samme slags terreng og under samme klimatiske og skoglige forhold var altså arbeidsbetingelsene sammenlignbare. Hver dags ytelsesgrads– forskjell kunne derved regnes ut:

$$PR = \frac{EST}{ER}$$

Her er:

PR = De lokale hoggernes ytelsesgrad.
EST = Virketid/m^3 for typehoggeren.
ER = Virketid/m^3 for den lokale hogger.

Tidsforbruket pr. tre og m^3 ble justert med denne faktor for samtlige hoggere. Tidsfunksjonene ble beregnet på grunnlag av de justerte observasjoner av tidsforbruket med vanlig regressjonsanalyse.

Typearbeidermetoden var en enkel fremgangsmåte til eliminering av ytelsesgradsforskjellene mellom hoggerne. Det viste seg at typehoggernes prestasjoner lå nær opp til gjennomsnitten i materialet (Figur 23 hogger nr. 17 og 18). Ytelsesgraden for samtlige hoggere som deltok i undersøkelsen varierte mellom 0,62 og 1,62. (Tabell 7).

En lignende fremgansmåte ble brukt under en hogstundersøkelse i gresk edelgran og gresk furuskog 1968/69 (Strömnes et.al. 1972). Her ble hver enkelt forsøkshoggers prestasjonsnivå regnet ut i forhold til gjennomsnittsprestasjonene for samtlige hoggere som deltok i undersøkelsen. De enkelte hoggernes ytelsesgradsforskjeller var med andre ord deres prestasjoners forskjell fra gjennomsnittsprestasjonene i materialet.

4.9.3 Måling av ytelsesgradsforskjeller ved hjelp av typeveg

Norsk institutt for skogforskning gjennomførte en landsomfattende analyse av tømmertransport fra stubbe til bilveg i driftssesongen 1986/87 (Gjedtjernet 1989). Det var tatt ut forsøksfelter på forskjellige steder i landet fra polarsirkelen til Syd-Norge. De fleste traktortyper var med i undersøkelsen, fra de minste landbrukstraktorer til de største lunnetraktorer og lastetraktorer. Det var forskjellige traktorer og forskjellige kjørere på de forskjellige steder, og det var fare for at kjørernes ytelsesgradsforskjeller kunne påvirke tidsfunksjonene under regresjonsanalysene.

For å måle ytelsesgradsforskjeller i undervegstidene (lasskjøring og returkjøring) ble det lagt ut en typeveg i hvert forsøksområde. Typevegene var valgt ut slik at kjøreforholdene var sammenlignbare fra et sted til et annet. Med jevne mellomrom ble de lokale traktorer og kjørere tatt ut for kjøring på typevegen. Derved fikk man grunnlag for å måle de lokale kjørernes prestasjoner under sammenlignbare kjøre- og vanskelighetsforhold ved hjelp av gjennomsnittlige kjøreprestasjoner på typevegene. Dette gav grunnlag for beregning av de lokale kjøreres ytelsesgradsforskjeller i forhold til den gjennomsnittlige ytelsesgraden i materialet. Deretter ble hele tidsstudiematerialet justert ved hjelp av ytelsesgradsforskjellene før de endelige tidsfunksjonene ble regnet ut ved hjelp av vanlig regresjonsanalyse. Tabell 8 og 9 er eksempler på de enkelte kjørernes ytelsesgrader.

4.9.4 Måling av ytelsesgradsforskjeller ved hjelp av typeterminaler

For å kunne måle ytelsesgradsforskjeller i forbindelse med på- og avlessingsarbeidene under tømmertransport med traktor ble det lagt ut standardiserte lunner ved pålessingsstedet og velteplasser ved avlessingsstedet (GJEDTJERNET 1989). Terminalene ble lagt ut slik at de var forholdsvis like hva påvirkende faktorer angår (terreng, avstand fra lunne/velte til traktor, stokkdimensjoner m.v.) Ved stammetransport var innvinsjingsstedet standardisert (terreng, avstand til stammene, stammedimensjon m.v.)

Som eksempel tas med resultatet fra lastetraktorene med hydrauliske vikarmkraner. Ettersom det deltok traktorer med forskjellige typer og størrelser av virkarmkranene og ettersom man i denne undersøkelsen ønsket å analysere gjennomsnittsproduksjonen og produksjonens variasjon med arbeidsbetingelsene i landet kom man frem til at vikarmkranene kunne beskrives med en faktor der både kranvekten (Q) og kranens effekt (kW) inngikk: Q x kW. Dette gir uttrykk for den maskinstyrte delen av ytelsesgraden.

Tabell 10 viser de gjennomsnittlige ytelsesgradene som skyldes maskinførerens del av ytelsesgraden under lasting og lossing med vikarmkraner. De lokale traktorene og traktorførerne ble testet på typevegenes terminaler med jevne mellomrom over hele driftssesongen. De lokale traktorførernes tidsforbruk på typeterminalene ble sammenlignet med de gjennomsnittlige tidsforbruk for samtlige kjørere i forsøket. Deretter ble hele tidsstudiematerialet justert med de enkelte kjørernes ytelsesgrader før tidsfunksjonene ble utjevnet ved hjelp av regresjonsanalyser.

4.9.5 Måling av ytelsesgradsforskjeller med testmaskin

I moderne skogsmaskiner (flishoggere, barkemaskiner, kvistemaskiner, hogstmaskiner m.v.) fungerer skogsarbeideren som maskinoperatør. Operatøren betjener maskinen i en bekvem kabin på maskinen. I dette tilfellet er ytelsesgrad-analysen komplisert. En måling av forskjellige operatørers ytelsesgradsforskjeller er imidlertid viktig, fordi det viser seg at produksjonen varierer mye med operatørens arbeidsevne, kjøreteknikk m.v.

På grunnlag av erfaringene med typebestand, typehoggere, typeveier og typeterminaler har vi kommet frem til en *hypotese* at om operatøren gjennomfører et arbeide av lignende karakter som den han må utføre i kabinen på en skogsmaskin, vil ytelsesgradsforskjellene målt i testmaskinen være *likedannet* med operatørenes ytelsesgradsforskjeller under kjøring av skogsmaskinen.

Norsk institutt for skogforskning bygget en slik testmaskin i 1988. (Fig. 26) På en tilhenger er det montert driftsmotor, hydraulisk vikarmkran og en bekvem førerkabin til betjening av kranen.

Testmaskinen kan fraktes fra et forsøksfelt til et annet, idet den kan fraktes etter en bil eller traktor. Den lokale maskinoperatør får til oppgave å utføre et standard arbeidsprogram under kjente arbeidsbetingelser med testmaskinen.

De forskjellige operatørers ytelsesgrad i testmakinen vil deretter bli sammenlignet med samtlige arbeideres gjennomsnittlige ytelse i testmaskinen. Ytelsesgradsforskjellene som derved fremkommer bør kunne brukes til å justere prestasjonene med de aktuelle skogsmaskiner i løpet av forsøksperioden. De justerte tidsobservasjonene kan deretter brukes til å finne de endelige tidsfunksjonene ved hjelp av regresjonsanalyse.

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